

THE ASEAN JOURNAL OF RADIOLOGY

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From The Editor

Green radiology, greener AOOCR2026, and the greenest Singapore

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Charles Goh, M.B.B.S.
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During AOOCR 2026, Green Radiology was in the spotlight. The conference theme was "Imaging Beyond Borders, Shaping a Sustainable Future", and sustainability was woven into the subspecialty tracks and scientific competition, with topics ranging from resource-efficient breast cancer screening, to sustainable practices in IR, US, CT and MRI. Dr Danny Cho, President-Elect of the Asian Oceanian



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Similar to other organizations around the world, from the United Nations to a small shop on the street, environmental consciousness is reflected in policies, and is advertised, or practiced through various activities, I myself have observed that the concepts of "Green Radiology" or "Sustainable Radiology" have been incorporated into the scientific program in almost all congresses in recent years. However,

Society of Radiology, delivered the plenary lecture on "Reducing the Carbon Footprint of Imaging – Actionable Strategies for Green Radiology", and we continued the conversation during the leadership dialogue panel discussion on "Leading Change in a Resource-Constrained Future". The panelists, Rajiv Rattan, from Australia, Andrea Rockall, from the UK and Reed Omary, from the USA, shared perspectives from different continents. While there are certainly many common problems with common solutions, the effects of climate change on our countries and practices vary considerably, and our solutions for these thorny issues need to factor in our unique social, cultural, political and economic situations. Through conversations both on and off the podium, participants shared best practices, successes and challenges, and the seeds were sown for future collaborations and exchanges.

As the impact of climate change continues to be felt around the world, our radiology community needs to take the lead in stewarding our imaging resources well. By reducing low-value imaging, switching scanners off or to low-power modes when idle, optimizing scanning protocols, reducing active contrast and waste, and collaborating closely with industry, we can reduce our carbon footprint significantly, while maintaining high standards of diagnosis and intervention. Together, we can make a difference today, for a brighter tomorrow!

there is no better venue than Singapore, which hosted the 24th Asian Oceanian Congress of Radiology (AOCR) from 20-23 August 2026, where green initiatives were projected on the screen, throughout the congress, and everywhere in the country. Drinking water was provided in paper cartons or could be drunk from purifiers that were available in the congress and all hotel rooms, and even in re-used wine bottles placed on the tables of restaurants. It is therefore not surprising to learn that Singapore is on its way to achieving net zero emissions by 2050, as stated in its national commitment. Last year, Singapore's Ministry of Health (MOH), MOH Holdings Pte Ltd (MOHH), and the Centre for Sustainable Medicine (CoSM) at the Yong Loo Lin School of Medicine, National University of Singapore (NUS Medicine), released their first-ever comprehensive national emissions report for Singapore's healthcare sector, and the first comprehensive study across Asia, demonstrating that Singapore's healthcare system is 18% more sustainable than previously estimated, with the country delivering world-class healthcare at 20% lower carbon intensity than other advanced economies [1]. A whole-of-system approach to decarbonization is believed to be the key to successfully balancing the rising health demands, climate risks, and resource pressures and deliver both better health outcomes and a healthier planet [2].



During AOCR 2026, Dr. leong Chon Man, the President of Macao Radiology Association, and Dr. Wiwatana Tanomkiat, the Editor-in-Chief, hosted a private lunch to personally congratulate Emeritus Professor Dr. Ng Kwan Hoong and Madam Sia Leng Suan on the occasion of Professor Ng receiving the Asian Oceanian Society of Radiology (AOSR) Gold Medal. Distilled drinking water was served in a re-used wine bottle.

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Original Article

Diagnosis of anterior cruciate ligament tear: Value of oblique axial MR image

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Abstract

Background: Accurate magnetic resonance (MR) evaluation of anterior cruciate ligament (ACL) injuries can be challenging due to the oblique orientation of its bundles. Oblique axial MR imaging has been proposed to improve visualization of the ACL bundles and may facilitate the detection of ACL bundle tears.

Objective: To investigate the diagnostic value of adding oblique axial ACL imaging to the routine knee MRI protocol for detecting ACL tears and differentiating partial ACL tears from complete tears.

Materials and Methods: This retrospective study included 144 patients at Siriraj hospital who underwent knee MRI between August 2018 and April 2022 followed by arthroscopy. Protocols A (routine protocol) and B (with additional oblique-axial imaging) were compared for their performance in the detection of ACL tears, differentiation of partial from complete ACL tears and detection of isolated ACL bundle tears. The performances of an inexperienced (reader 1) and an experienced (reader 2) reader were also compared.

Results: The specificity and accuracy for the diagnosis of partial ACL tears were significantly higher for protocol B for reader 2, while for reader 1 these values did not reach statistical significance. With protocol B, the specificity and accuracy of reader 2 were significantly superior to those of reader 1. For the detection of isolated ACL bundle tears, the sample cohort of partial tear cases was too small for statistical evaluation.

Conclusion: The addition of oblique-axial imaging to routine knee MR imaging improves diagnostic accuracy for detecting partial tears of the ACL. However, the extent of its usefulness may also rely on the reader's experience.

Keywords: ACL, ACL tear, Oblique axial MR imaging of the ACL.

Introduction

The anterior cruciate ligament (ACL) plays a crucial role as a primary passive restraint to anterior tibial translation and supports knee rotational stability [1]. The ACL anatomically consists of the anteromedial (AM) and the posterolateral (PL) bundles which are named according to their relative insertion sites on the tibia [2]. ACL tears are common knee injuries, accounting for up to 64% of knee injuries in athletes [2]. Although not as common as complete ACL tears, partial tears account for about 10%-27% of ACL injuries [1,3-5].

Recognizing partial ACL tears has been a challenge using both by clinical and imaging approaches. It requires a combination of examinations such as clinical findings, imaging findings, and sometimes arthroscopic assessment when indicated [3]. Unlike a complete ACL tear, which no longer has the capacity to heal, a partial ACL tear retains a limited blood supply by way of the medial geniculate artery, which may allow healing to occur [6-8]. The treatment approach for ACL partial tears is thus highly individualized for each patient [3]. The conservative method is preferred for patients who are at low risk of progression based on clinical stability and lifestyle activity level. On the contrary, those with high-risk lifestyle activities and clinical instability may be better suited for surgical treatment [3]. Moreover, for management purposes, the associated injuries, the percentage of remaining fibers, and the functionality of those remaining remnants need to be taken into account.

Undoubtedly, MRI plays an important role in aiding the diagnosis and guiding treatment of ACL tears. Additionally, if an isolated bundle tear is present, isolated single-bundle reconstruction instead of full ACL graft reconstruction may be considered [6,11-14].

However, there remains some difficulty in using MRI to diagnose partial ACL tears, to distinguish partial from complete tears [3,13,15-18], and to differentiate between the AM and PL bundles [13]. For instance, previous studies found that the accuracy of MR imaging for the diagnosis of partial ACL tears is much lower than that for complete tears with a sensitivity of about 40-77% and a specificity of about 62-79% [15,18-20, 21-25]. As one strategy to improve the diagnostic accuracy of MRI for ACL injuries, Ng et al. and HL et al. [6,24] reported that the addition of an oblique-axial view of the ACL improved the sensitivity and overall accuracy for detecting partial ACL tears. However, this imaging plane is not routinely included in the standard knee MRI protocol in most hospitals in Thailand. Therefore, this study aims to investigate the value of adding this oblique axial image to the routine sports knee MRI protocol. We hypothesized that the addition of an oblique axial MR image to a standard knee MRI protocol would improve the detection of ACL bundle tears.

Materials and methods

This retrospective study reviewed a total of 144 patient records from Siriraj Hospital of patients who underwent knee MRI between August 2018, and April 2022 followed by arthroscopic examination. The study population consisted of 113 males and 31 females ranging in age from 8 to 75 years (mean age of 34 years). Patients with prior knee surgery or those presenting with suspected knee tumours were excluded from this study. The average time interval between the MRI and arthroscopy was 4.5 months (ranging from 9 days to 16 months).

MR examinations were performed on two 3-T scanners available at our institution, including the Ingenia (3.0-T; Philips Healthcare, Best, The Netherlands) and the Magnetom Vida (3.0-T; Siemens Healthineers, Erlangen, Germany). Dedicated phased-array knee coils were used for all examinations. The routine knee MRI protocol used in this study was based on widely accepted musculoskeletal imaging protocols dedicated to sports-related knee injuries at our institution, which typically include multiplanar imaging in the sagittal oblique sequences (T2-weighted, proton density-weighted, and proton density fat-suppressed) and the coronal oblique sequences (T2-weighted with fat suppression and T2-weighted) planes for optimal evaluation of the ACL and other intra-articular structures [9,10] as summarized in Table 1. An additional oblique axial sequence of the ACL was also obtained, with images acquired in a plane perpendicular to the course of the ACL, using sagittal and coronal images as localizers (Figure 1). The MRI acquisition parameters are listed in Table 2.

The routine knee MRI protocol was designated Protocol A while the routine knee MRI protocol in combination with oblique axial imaging was designated Protocol B (Table 1). The images were independently reviewed by two readers who were not aware of the arthroscopic findings. The first reader was a third-year radiology resident while the second reader was a musculoskeletal radiologist with 5 years of experience. Protocols A (routine knee MRI) and B (routine knee MRI plus oblique axial ACL imaging) were acquired during the same examination for each patient. The image sets for each protocol were then evaluated independently by the readers at separate sessions, with a minimum washout period of 3 months between assessments to reduce recall bias.

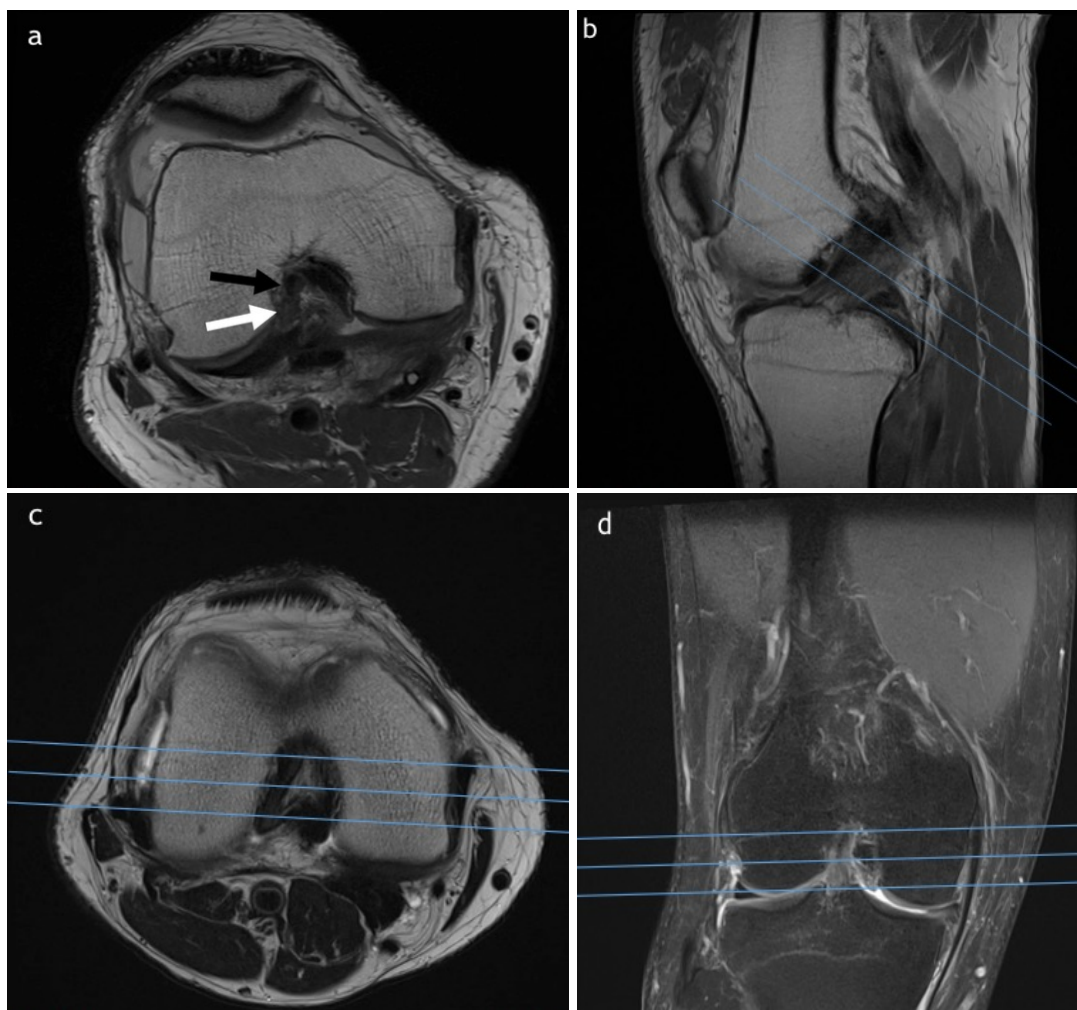


Figure 1. An oblique axial intermediate-weighted MR image of the ACL (a) and its localizations on sagittal T2W (b), true axial T2W (c), and coronal T2W (d) images are shown. The anteromedial (black arrow) and posterolateral (white arrow) bundles are labeled in picture a.

From the MR images of each protocol, ACL bundles were interpreted as intact, partially torn, or completely torn. Figure 2 shows the normal appearance of the anteromedial and posterolateral bundles on oblique axial imaging. A complete tear was defined as the complete disruption of both ACL's anteromedial (AM) and posterolateral (PL) bundles. On the other hand, a partial ACL tear was defined as an injury involving at least one of the AM or PL bundles without complete tear of both bundles. The injury parameters that were evaluated were included the presence of high signal intensity (SI), focal swelling, thinning, wavy course or discontinuity of each ACL bundle. An intact ACL was defined as having a normal appearance and complete integrity along the course of both ACL bundles running from the proximal femur to the distal tibial attachment.

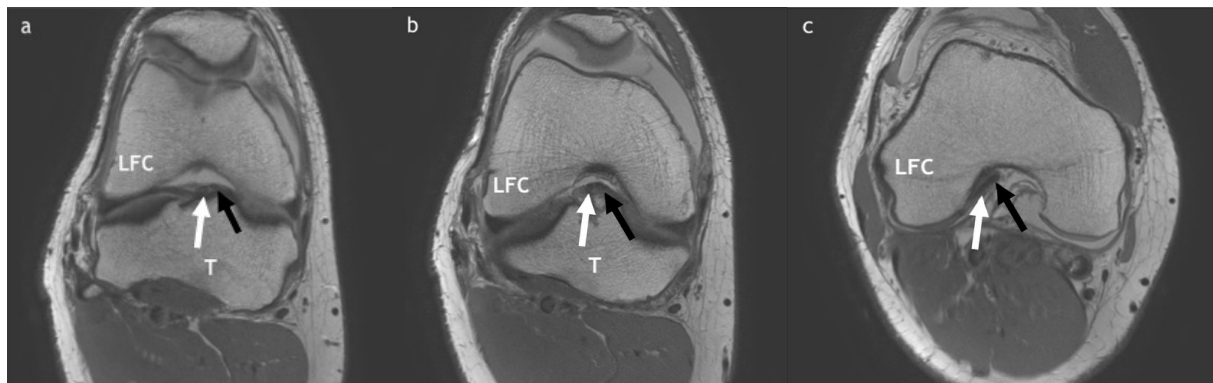


Figure 2. Oblique axial intermediate-weighted MR images of the ACL in a 43-year-old man. Normal appearance of the individual ACL bundles at the distal insertion on the tibia (a), the middle portion (b) and the proximal insertion on the femur (c). The intact anteromedial bundle (black arrow) is located in the more anteromedial position while the intact posterolateral bundle (white arrow) is located in the more posterolateral position. Both ACL bundles show a normal course and signal intensity. LFC, lateral femoral condyle; T, tibia.

MR results were compared with arthroscopic findings. The statistical data were collected as frequencies (number of cases) and percentages. MR imaging Protocols A and B were analyzed for their diagnostic accuracy in detecting ACL lesions, represented by sensitivity, specificity, positive predictive value, negative predictive value and overall accuracy. All statistical calculations were performed using SPSS (Statistical Package for the Social Sciences; SPSS Inc., Chicago, IL, USA) released for Microsoft Windows (2006). The ordinal data in terms of sensitivity, specificity and overall accuracy of Protocols A and B were compared using McNemar's test. A P-value of less than 0.05 indicated a statistically significant difference. Inter-observer agreement between the resident (reader 1) and the musculoskeletal radiologist (reader 2) was then calculated using Cohen's weighted K statistics. A value of less than 0 implied no agreement; values of 0.00-0.20, slight agreement; values of 0.21-0.40, fair agreement; values of 0.41-0.60, moderate agreement; values of 0.61-0.80, substantial agreement; and values of 0.81-1.00, almost perfect agreement [27].

This study was approved by the Institutional Review Board of Siriraj Hospital, Mahidol University (ID No.: SI 351/2022).

Table 1. MR Protocols.

Protocol A (Routine MR knee protocol)	Axial	- Proton density fat-suppressed (PDFS) - T2 weighted (T2W) - 3D_WATS
	Sagittal	- Proton density weighted (PDW)
	Sagittal oblique (parallel to the lateral condyle of the femur)	- Dual PD & T2W - 3D_WATSc
	Coronal oblique (parallel to the medial and lateral condyle of the femur)	- PDFS - T1 weighted (T1W)
	Oblique coronal ACL	- T2W - T2 fat-suppressed (T2-FS)
Protocol B (Routine MR knee protocol + Oblique axial ACL)	Routine MR knee protocol as above	
	Oblique axial ACL	- Proton density weighted (PDW)

Table 2. MR Parameters.

Sequence	Repetition Time (msec)	Echo Time (msec)	Section Thickness (mm)	Field of View (cm)	Matrix (mm x mm)	Echo Train Length (ETL)	Number of Excitations (NEX)	Acquisition time (min)
Axial Oblique PDW FSE	3000-3500	25	2	15x15	350x350	10	1	2.5
Sagittal Oblique T2W FSE	3000-4600	120	3	15x15	450x350	15	1	3
Sagittal Oblique PDW FSE	3000-4600	10	3	15x15	450x350	15	1	3
Sagittal Oblique PDW FSE FS	2400-4000	15	3	19x15	400x350	8	1	2.5
Coronal Oblique T2W FSE	2200-4000	80	2	17x15	400x300	15	1	2.5
Coronal Oblique T2W FSE FS	3100-3600	60	2	15x15	300x300	15	1	2.5

Note. – PDW, proton density-weighted; FSE, fast spin-echo; T2W, T2-weighted. Axial oblique refers to the axial plane of the ACL; sagittal oblique refers to the sagittal plane parallel to the lateral condyle of the femur; coronal oblique refers to the coronal plane parallel to the medial and lateral condyle of the femur.

Results

Under arthroscopy, 37 of the 144 knees (25.7%) had a normal ACL, 8 (5.6%) had a partial ACL tear and 99 (68.8%) had a complete ACL tear. Of the 8 knees with partial ACL tears, 3 cases (37.5%) had an isolated posterolateral bundle (PLb) tear while only 1 case (12.5%) had an anteromedial bundle (AMb) tear.

Based on MR imaging interpretation by the MSK radiologist (reader 2), Protocol A identified 35 knees (24.3%) with a normal ACL, 17 knees (11.8%) with a partial ACL tear, and 64 knees (44.4%) with a complete ACL tear. Using Protocol B, 36 knees (25.0%) were classified as normal, 44 knees (30.6%) as partial ACL tears, and 92 knees (63.9%) as having complete ACL tears (Figure 3 and (Figure 4).

Similarly, the radiology resident (reader 1) reported 35 knees (24.3%) as normal, 27 knees (18.8%) as having partial tears, and 76 knees (52.8%) as having complete tears using Protocol A, whereas Protocol B demonstrated 39 knees (27.1%) with a normal ACL, 33 knees (22.9%) with partial tears, and 79 knees (54.9%) with complete tears.

Of the 36 knees interpreted as normal by reader 2 using Protocol A, 5 knees were found to have ACL tears on arthroscopy (13.9%) (3 partial tears and 2 complete tears). After using Protocol B, the number of arthroscopic-MR finding discrepancies slightly decreased to 4 out of 35 knees (11.4%) (2 partial tears and 2 complete tears) but without a significant difference. Meanwhile, for reader 1, the proportion of MR-arthroscopic findings discrepancies was similar between protocols A and B and was comparatively greater than that of reader 2. Of the 35 knees interpreted as normal by reader 1 using Protocol A, 6 knees had ACL tears on arthroscope (17.1%) (2 partial tears and 4 complete tears). Similarly, the discrepancy proportion was 7 out of 39 knees after using Protocol B (17.9%) (2 partial tears and 5 complete tears).

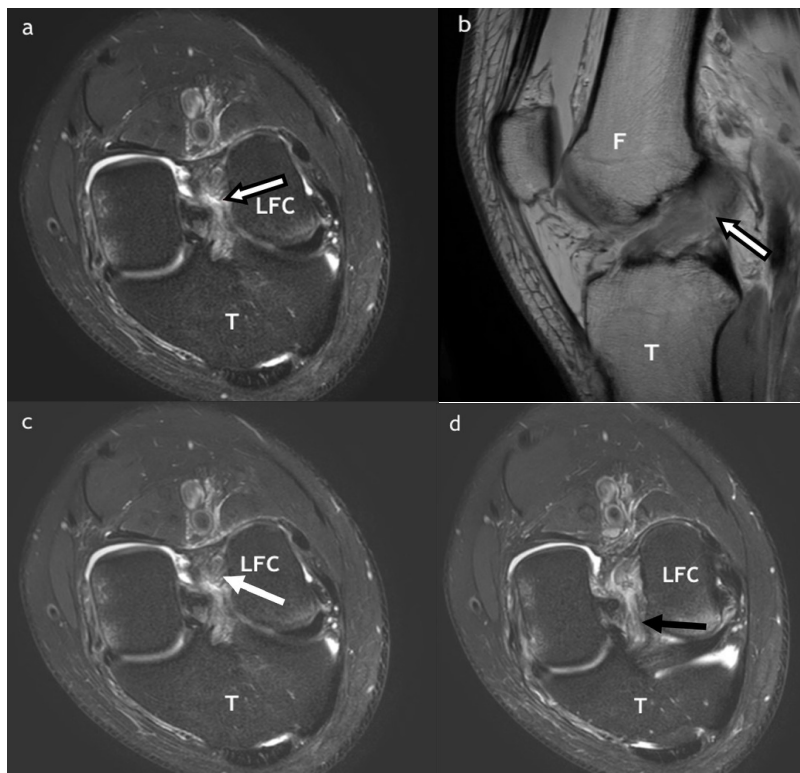


Figure 3. Example of the assessment of a complete ACL tear in a 19-year-old man with a knee injury using the routine knee MRI protocol. MRI findings were confirmed with arthroscopy.

(a) Oblique coronal T2W SPAIR and (b) sagittal T2W MR images show increased signal intensity and disruption of the ACL near the femoral insertion site (white arrow with a black outline). (c, d) Oblique coronal images demonstrating the posterolateral bundle (PLb) (white arrow) and the anteromedial bundle (AMb) (black arrow), respectively.

LFC, lateral femoral condyle; T, tibia; F, femur.

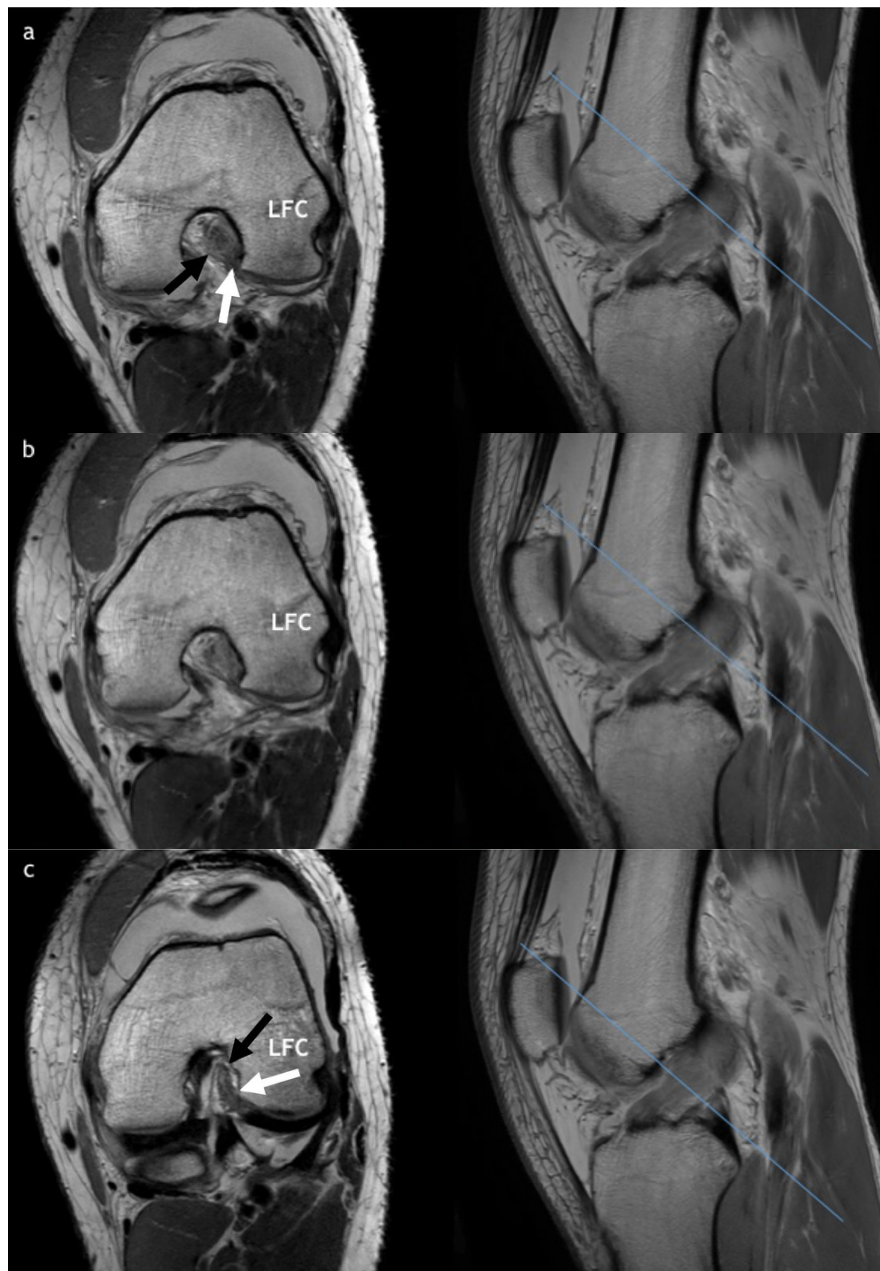


Figure 4. Three consecutive oblique axial intermediate-weighted MR images of the ACL show the same case as Figure 3. Image b shows the level of disruption of both the posterolateral bundle (white arrow) and the anteromedial bundle (black arrow) just below the femoral insertion. Images a and c show the ACL just above (a) and just below (c) the level of disruption.
LFC, lateral femoral condyle, respectively.

Accuracy for the diagnosis of complete or partial tears of the ACL (as a whole):

The sensitivity, specificity, PPV, NPV and accuracy of Protocols A and B for the diagnosis of ACL tears are shown in Table 3. The overall diagnostic accuracy of MR imaging using Protocol B was slightly higher than that of Protocol A for both readers (91.7 VS 90.3 % for reader 1 and 93.1% VS 92.4% for reader 2 respectively). Compared with Protocol A, Protocol B improved reader 1's specificity for detecting ACL tears (to 86.5 % in Protocol B from 78% in Protocol A) but with the cost of lower sensitivity (to 93.5 % in Protocol B from 94.3% in Protocol A). In contrast, Protocol B provided better sensitivity for reader 2 to detect ACL tears (to 96.3 % in Protocol B from 95.3% in Protocol A) while the other parameters, including specificity remained constant. Nonetheless, none of these differences between Protocols A and B parameters reached statistical significance.

Accuracy for the diagnosis of partial tears of the ACL:

The sensitivity, specificity, PPV, NPV and accuracy of Protocols A and B for the diagnosis and differentiation of partial from complete ACL tears are shown in Table 4. The specificity, PPV and accuracy of MR imaging using Protocol B for the diagnosis of partial tears were higher than those obtained with Protocol A for both readers, with the specificity and accuracy for reader 2 reaching statistical significance ($P=0.000$). Nevertheless, the differences in PPV and the other accuracy parameters between Protocol A and B for reader 1 did not reach statistical significance. Figures 5 and 6 illustrate an example of a case with an isolated partial ACL bundle tear.

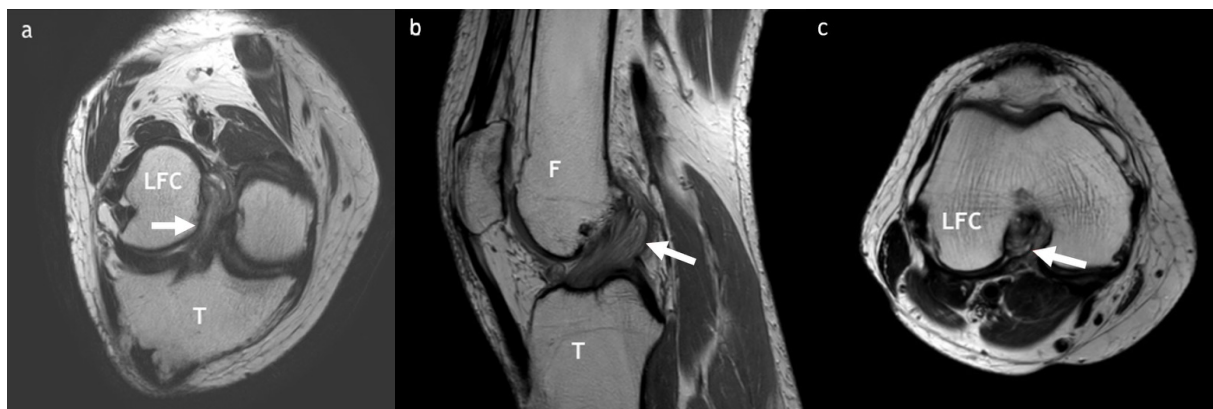


Figure 5. Example of the assessment of an isolated ACL bundle tear demonstrated on MRI and confirmed by arthroscopy. (a) Oblique coronal T2-weighted image, (b) sagittal proton density-weighted image, and (c) true axial T2-weighted image demonstrate increased signal intensity (SI) along the posterolateral bundle (PLb) (white arrows). LFC, lateral femoral condyle; T, tibia; F, femur.



Figure 6. The same case as shown Figure 5 showing three consecutive oblique axial intermediate-weighted MR images of the ACL at different levels along the ligament course: (a) the proximal, (b) the middle, and (c) the distal portion of the ACL. Increased SI along the PLb (white arrows) without fiber course disruption suggests a partial tear. The anteromedial bundle (AMB) demonstrates a normal course and SI (black arrows). LFC = lateral femoral condyle.

Accuracy for the diagnosis of isolated ACL bundle tear:

From a total of 8 knees with partial ACL tears identified on arthroscopy, 3 cases (37.5%) were reported to have an isolated posterolateral bundle (PLb) tear while only 1 case (12.5%) had an anteromedial bundle (AMb) tear. The retrospective arthroscopic reports of the remaining 4 cases with partial ACL tears did not specifically state the bundle tear in detail.

The sensitivity, specificity, PPV, NPV and accuracy of Protocols A and B for the diagnosis of isolated ACL bundle tears are shown in Table 5. The specificity and overall accuracy of MR imaging using Protocol B for the diagnosis of isolated PLb tears were higher than those obtained with Protocol A for both readers, although these differences did not reach statistical significance. Meanwhile, the accuracy parameters for the diagnosis of isolated AMb tears were similar between Protocols A and B for both readers.

Inter-observer agreement:

Using weighted kappa statistics, there was substantial agreement for the MR findings in both Protocols A and B between the readers. With the addition of oblique axial imaging in Protocol B, the interobserver agreement slightly increased from a kappa value of 0.651 to 0.752.

There was no significant difference between the readers' MR interpretations for the diagnosis of ACL tears overall whether they used Protocol A or B ($p > 0.05$). However, when it came to differentiating partial from complete ACL tears, reader 1 statistically had better specificity ($p=0.001$) and accuracy ($p=0.003$) than reader 2 using Protocol A. In contrast, with the addition of oblique axial MR imaging in Protocol B, reader 2's diagnostic performance in differentiating partial from complete ACL tears was statistically better than that of reader 1 in terms of both specificity ($p=0.000$) and accuracy ($p=0.000$).

Table 3. MR detectability for ACL tear (as a whole).

	TP	FP	FN	TN	Sensitivity	Specificity	PPV	NPV	Accuracy (%)	p-value
Reader1										
Pro A	101	8	6	29	94.3	78	92.7	82.9	90.3	1.0 (sense) 0.25 (spec)
Pro B	100	5	7	32	93.5	86.5	95	82	91.7	0.69 (accu)
Reader2										
Pro A	102	6	5	31	95.3	83.8	94.4	86.1	92.4	1.0 (sense) 1.0 (spec)
Pro B	103	6	4	31	96.3	83.8	94.5	88.6	93.1	1.0 (accu)

Note-- P-values represent the comparison of diagnostic performance between Protocol A and Protocol B for each reader in detecting ACL tears and differentiating partial from complete ACL tears.

Table 4. MR differentiation of ACL partial tears from complete tears.

	TP	FP	FN	TN	Sensitivity	Specificity	PPV	NPV	Accuracy (%)	p-value
Reader1										
Pro A	2	22	6	77	25	77.8	8.3	92.8	73.8	1.0 (sense) 0.69 (spec)
Pro B	2	20	6	79	25	79.8	9.1	92.9	75.7	0.69 (acc)
Reader2										
Pro A	3	35	5	64	37.5	64.7*	7.9	92.8	62.6**	1.0 (sense) 0.000(spec)
Pro B	3	9	5	90	37.5	90.9*	25	94.7	86.9**	0.000(accu)

*, ** statistical significant p=0.000

Note-- P-values represent the comparison of diagnostic performance between Protocol A and Protocol B for each reader in detecting ACL tears and in differentiating partial from complete ACL tears.

Table 5. MR Diagnostic performance for detecting isolated ACL bundle tears.

Bundle	Reader	Protocol	TP	FP	FN	TN	Sensitivity	Specificity	Accuracy (%)	p-value
PL	Reader1	A	1	10	2	131	33.3	92.9	91.7	73.8
PL		B	1	8	2	133	33.3	94.5	93.2	73.8
PL	Reader2	A	0	4	3	137	0	97.2	95.1	73.8
PL		B	0	1	3	140	0	99.3	97.2	73.8
AM	Reader1	A	0	1	1	142	0	99.3	98.6	73.8
AM		B	0	1	1	142	0	99.3	98.6	73.8
AM	Reader2	A	0	0	1	143	0	100	99.3	73.8
AM		B	0	0	1	143	0	100	99.3	73.8

PL, posterolateral bundle; AM, Anteromedial bundle; TP, True positive; FN, False negative; TN, True negative; FP, False positive.

Discussion

Diagnosing partial ACL tears with conventional MRI has traditionally been challenging, mainly because of the oblique course of this bundle. Early studies [6,13,16-19,26] advocated the diagnostic value of the oblique-axial MR imaging for detecting partial ACL tears and suggested its potential role in surgical planning.

Ng AWH et al [6] reported in 2011 that oblique axial intermediate-weighted imaging improved the visualization of the ACL bundles in the majority of cases. The same author also found that the addition of this view to the standard knee MRI protocol increased the sensitivity and accuracy for the diagnosis of partial ACL tears from 33% to 87% and from 74% to 87% respectively while the specificity remained unaltered [19].

A few later studies on the oblique axial view for the diagnosis of isolated AM and PL bundle tears also obtained similar supporting evidence. For instance, a prospective study by Ng AWH et al in 2013 demonstrated that adding this view increased the sensitivity of AM bundle tear detection from 29% to 71% and that of PL bundle tear detection from 30% to 60%. Similarly, Kamal HA et al. in 2015 reported an increase in sensitivity from 80% to 88% and accuracy from 86% to 90% for detecting AM bundle tears. The sensitivity and accuracy for diagnosis of PL bundle tears also improved from 79% to 89% and from 81% to 90% respectively.

To our knowledge, oblique axial ACL imaging is not currently part of the standard knee MRI protocol in Thailand. Some centres have incorporated this view into routine practice because it can be easily acquired without the need for knee repositioning.

In our study population, both readers reported a similar proportion of partial ACL tear cases (11.8%-30.6% and 18.8%-22.9%) based on MR images compared with the incidence reported in prior studies (11-27%) [1,3-5]. However, an important issue to address is that the proportion of partial ACL tears retrieved from arthroscopic records at our institution was only 5.6%. One possible explanation for this low number is that the treatment option for this group of partial ACL tears is highly individualized and depends on multiple clinical factors. Nonetheless, this number also reflects that our institution's preferred treatment method for partial ACL tears is mostly conservative.

With the addition of oblique axial imaging of the ACL, our study found no diagnostic benefit over the standard knee MRI protocol for the diagnosis of ACL tears overall (Table 3). Both protocols demonstrated a high diagnostic accuracy of over 90% for both readers. These high accuracy values are consistent with previous studies using the standard knee MRI protocol for detecting overall ACL tears [15,18-19,21-25]. Additionally, with the standard MRI protocol, our study also found a similar specificity for the diagnosis of partial ACL tears (64.7%-77.8%) as compared to that reported in prior studies whose specificity ranged about 62-79%. However, the sensitivity in this study (25%-37.5%) for diagnosis of the same group is less than the previous studies (40%-77%). This low sensitivity value may be attributed to the small sample size of partial tear cases diagnosed by arthroscope, which served as the gold standard reference.

Interestingly, unlike the increased sensitivity reported by Ng AWH et al. [6], our study found that the addition of oblique axial imaging to the standard knee MRI protocol significantly improved specificity and overall diagnostic accuracy for the experienced musculoskeletal radiologist (reader 2) in detecting partial ACL tear lesions and distinguishing them from complete tears ($p=0.000$). The specificity rose from 64.7% to 90.9% while the accuracy rose from 62.6% to 86.9%. Moreover, the performance of the MSK radiologist appeared to be significantly superior to that of the radiology resident after the addition of the oblique axial image ($p=0.000$ for both specificity and accuracy). Meanwhile, the specificity and accuracy of the less experienced radiology resident after the addition of oblique axial imaging were only slightly higher than those of the standard knee MRI protocol and did not reach statistical significance ($p=0.69$). We speculate that this finding may differ in a larger cohort study. Nonetheless, these results suggest that the experience of the interpreter may play an important role in maximizing the diagnostic value of the oblique axial view.

For the detection of a normal ACL, the addition of oblique axial imaging did not show significant diagnostic value over the standard protocol as shown by the NPV in the Tables 3 and 4. However, it is noteworthy that most of the arthroscopic-MR discrepancy cases identified by reader 2 were partial tear cases (50-60%), considering that this group of patients made up a small proportion of the study population (5.6%). After the addition of oblique axial imaging, reader 2 correctly identified an arthroscopic-proven partial ACL tear case that had previously been interpreted as normal using Protocol A (Fig.5). In a larger cohort study, this additional imaging plane may potentially be helpful to a certain extent for delineating partially torn ACLs from normal ones. In clinical practice, MRI findings should also be interpreted in conjunction with clinical examination and arthroscopic correlation. Evaluation of ligament alignment and signal intensity may provide additional information for assessing functional ACL insufficiency.

This study has several limitations. Although the addition of oblique axial imaging improved specificity and accuracy for the experienced reader, the increase in diagnostic performance for the less experienced reader did not reach statistical significance. This finding may be related to the relatively small cohort size, and different results may be observed in a larger study population.

In addition, our investigation of individual ACL bundle tears was limited by several factors. The number of isolated bundle tear cases obtained from retrospective arthroscopic reports in our institution over the selected 3-year period was small. While most partial ACL tears at our institution underwent conservative management, detailed documentation regarding the degree of partial tear or the specific bundle involved was often lacking in the reports. As a result, only 4 out of 8 partial ACL tear cases in the study population were specifically identified as isolated AM or PL bundle tears.

Another limitation of our study relates to the imperfection of the arthroscopic reports used as the gold standard. Since this was a retrospective study, not all patients with MRI-detected partial ACL tears underwent arthroscopy and thus were excluded from the study population. It was also not possible to require all patients with ACL tears detected on MRI to further undergo arthroscopy within a short time interval. While the average time interval between MRI and arthroscopy in the study by Ng AWH et al [6] study was 46 days (range 5-80 days), the time interval in this study ranged from 9 days to 1 year and 4 months. One possible explanation for this wide interval is that part of the study period coincided with the COVID-19 pandemic, during which many elective surgeries were rescheduled and delayed accordingly. The longer the interval between MRI and arthroscopy, the greater the possibility that partial ACL tears initially identified from MRI to progress to complete tears or heal. These limitations due to the retrospective nature of the study are similar to those in other retrospective studies by Ng AWH

et al in 2012 [6] and Volokhina et al in 2015 [13], which also faced limitations from little statistical power from their small cohorts. Another reason why arthroscopy is an imperfect gold standard is its inability to detect intrasubstance tears, which would otherwise be seen as partial ACL tears on MR imaging. A prospective study with a larger cohort would be helpful for further validation of our results.

Regarding the MRI interpretation process, we only analyzed images on a qualitative basis. Although our inter-reader agreement was substantial, the visual analysis may lead to subjective interpretation by the inexperienced radiologists. Besides, due to the retrospective nature of our work, along with the absence of a control group, this could have led to bias by positively influencing the interpretation of cases of uncertainty. Lastly, the two readers in this study may not be enough to represent the performance of other MSK radiologists or radiology residents in routine clinical practice as a whole. Further studies with more readers both from the MSK radiologists and the radiology residents would be desirable.

Conclusion

While the current routine knee MRI protocol presents high accuracy for the detection of ACL tears as a whole, the addition of oblique axial ACL imaging improves diagnostic performance in detecting partial ACL tears, particularly by increasing sensitivity for less experienced readers. This additional sequence is easy to acquire and may be considered a useful adjunct to routine knee MRI protocols for ACL evaluation.

Author contributions

(I) Conception and design: A Pisanuwongse, T Taveepattanangkul, N Lektrakul; (II) Administrative support: A Pisanuwongse; (III) Provision of study materials or patients: A Pisanuwongse, T Taveepattanangkul, N Lektrakul; (IV) Collection and assembly of data: A Pisanuwongse, T Taveepattanangkul; (V) Data analysis and interpretation: A Pisanuwongse, T Taveepattanangkul; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Original Article

Impact of discontinuing routine corticosteroid premedication on contrast reaction rates in high-risk patients: A clinical audit

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Abstract

Background: Recent guidelines question the efficacy of routine corticosteroid premedication for patients with asthma or multiple drug allergies undergoing contrast-enhanced computed tomography (CECT), citing limited evidence of its effectiveness.

Objective: To evaluate the incidence of documented contrast reactions following the cessation of routine corticosteroid premedication in high-risk patients.

Materials and Methods: A retrospective single-centre audit was conducted from September 2021 to April 2022, including 527 patients undergoing CECT. Routine corticosteroid premedication was discontinued for high-risk patients (those with known asthma or multiple drug allergies, defined as allergies to three or more drug classes), except for individuals with confirmed contrast media allergies. Demographic and clinical data, including reaction severity, were collected using REDCap. Reaction rates between premedicated and non-premedicated groups were compared using appropriate statistical tests for categorical and continuous variables.

Results: Of 527 patients, 82 received premedication and 445 did not. Reaction rates were 1.2% (1/82) in the premedicated group and 0.4% (2/445) in the non-premedicated group ($p = 0.4$). All observed reactions were mild (grade 1–2), consisting mainly of urticaria, with no severe reactions recorded in either group. Demographics were comparable between groups.

Conclusion: Discontinuing routine corticosteroid premedication for high-risk patients was not associated with a statistically significant increase in contrast reactions in this audit and aligns with current guideline recommendations from professional bodies. However, due to the small number of events and the retrospective design, these findings should be interpreted with caution. Further studies are needed to confirm the safety of this approach in broader patient populations.

Keywords: Allergies, Contrast media, Contrast reactions, Corticosteroid premedication, High-risk patients.

Introduction

Each year, approximately 300 million computed tomography (CT) procedures are performed worldwide, with an annual increase of 4% [1]. The majority of these are contrast-enhanced CT (CECT) scans, which are widely used for diagnosing and monitoring a range of medical conditions [2]. Iodinated contrast media (ICM) are among the most commonly administered drugs globally, used in about 75 million examinations annually, with adverse reactions occurring in 1% to 3% of cases [3]. While most reactions are mild and self-limiting, severe or life-threatening events can still occur [4].

Adverse effects of ICM, often referred to as contrast allergies, are classified by reaction type, severity, or mechanism [5]. Reactions are categorized by onset as acute (within 60 minutes), delayed (1 hour to 1 week), or late (more than a week) [6]. Acute reactions are further classified as mild, moderate, or severe [4]. Delayed reactions affect about 2% of patients, and are typically mild cutaneous hypersensitivity reactions occurring hours to days after contrast exposure [4,5]. Both delayed and late reactions are generally self-limiting and typically require only symptomatic treatment [7].

ICM, introduced in the 1920s, initially consisted of ionic, high-osmolar contrast materials, which carried higher risks of acute reactions [7]. Risk factors for contrast reactions include multiple drug allergies (MDA defined as allergies to three or more drug classes [8]), asthma, and comorbidities such as heart disease or diabetes.

Premedication with corticosteroids was strongly advised in the 1980s and 1990s, reflecting the higher risk associated with earlier contrast agents. However, the efficacy of corticosteroid premedication in high-risk patients remains controversial, with limited scientific evidence supporting its effectiveness [9]. Studies show that adverse reactions can still occur despite premedication, and corticosteroid use may also be associated with potential adverse effects such as transient hyperglycaemia, leukocytosis, and increased susceptibility to infection in certain patients [10]. These findings have prompted increasing scrutiny of routine corticosteroid prophylaxis and contributed to evolving guideline recommendations regarding its use.

The introduction of low-osmolar contrast media (LOCM) significantly reduced adverse event rates, leading to updated guidelines from the American College of Radiology (ACR) [4] and the European Society for Urogenital Radiology (ESUR) [11], which recommend premedication only for patients with a known history of contrast media reactions. Our institution previously administered routine corticosteroid prophylaxis to premedication to high-risk patients, including those with asthma or multiple drug allergies, following a regimen similar to that used for patients with known ICM allergies. To align with recommendations from professional bodies such as the ACR and ESUR, we adopted a policy of discontinuing premedication for these patients. We conducted a clinical audit to evaluate the incidence of acute contrast reactions following the discontinuation of routine corticosteroid premedication in high-risk patients without a prior contrast media allergy during the implementation of this protocol change.

Materials and methods

This audit was conducted at a single tertiary academic institution and reflects real-world implementation within this centre. Ethics approval and consent were waived by the local institution, given its observational, retrospective, and non-interventional nature. Patient records were de-identified prior to analysis.

From September 2021 to April 2022, our institution implemented a change in the corticosteroid premedication protocol for contrast-enhanced CT (CECT) scans. Previously, high-risk patients - including those with asthma and multiple drug allergies - routinely received premedication, and scans were postponed if the regimen was incomplete. This protocol reflected earlier institutional practice derived from historical literature and prior contrast safety recommendations, when prophylactic corticosteroids were more widely used for patients considered at increased risk of contrast reactions [12]. Under the new protocol, premedication is reserved only for patients with documented

contrast media allergies. Other high-risk groups no longer receive routine premedication, although referring clinicians may still prescribe premedication at their discretion. Because premedication could therefore be prescribed according to clinician judgement rather than random allocation, the premedicated group may have included patients perceived to be at higher risk of contrast reactions, introducing potential selection bias. This change aimed to reduce unnecessary steroid use while maintaining safety for patients with documented contrast allergies.

Premedication cessation for patients with multiple drug allergies (MDA), excluding those with contrast media allergies, was implemented simultaneously across all patient settings—including emergency, inpatient, and outpatient—from September 13, 2021, onwards.

For asthmatic patients, the process was implemented in two phases: Phase 1 (November 30–December 31, 2021): Premedication was discontinued for emergency and inpatient asthmatic patients, with intravenous contrast administered as needed under constant medical supervision. Phase 2 (January 1–March 31, 2022): Premedication was discontinued for outpatients with asthma. Intravenous contrast was administered only after screening for asthma control using a simple questionnaire detailed in Appendix 1. Only patients with well-controlled or partly-controlled asthma proceeded without premedication. Patients with uncontrolled asthma identified through the screening questionnaire were required to be rescheduled unless premedication had already been prescribed by the referring clinician and taken by the patient prior to the scheduled CT scan. This screening method, coupled with a new 30-minute post-injection observation period, was well-suited to busy outpatient environments and addressed patients' limited access to immediate medical care after leaving the facility.

Our institution uses three low-osmolar iodinated contrast media (LOCM): Iohexol 350 mgI/mL (Omnipaque, GE Healthcare), Iopromide 370 mgI/mL (Ultravist, Bayer), and Iopamidol 370 mgI/mL (Iopamiro, Bracco). The choice and use of these agents reflect procurement and supply considerations, as well as radiologist preference. Contrast volume and administration rate are determined by protocol, with boluses of 50–90 mL administered at 1–5 mL/second using a power injector.

Data were collected using the Research Electronic Data Capture (REDCap) system and included patient demographics (age, sex, ethnicity), medical history (asthma, drug allergies), risk factors, premedication status, and contrast media type. Only acute contrast reactions occurring before patients left the radiology department were included; delayed and late reactions were excluded.

Adverse reaction severity was classified according to the ACR Manual on Contrast Media Version 2024, with patients categorized as having mild, moderate, or severe reactions (Table 1). Patients with multiple symptoms were assigned the highest severity grade. Physiologic reactions such as nausea, vomiting, altered taste, perspiration, warmth, flushing, and anxiety were classified as side effects and did not require documentation or intervention by radiologists.

Table 1. *Classification of adverse reactions in response to contrast media.*

Severity Level	Signs and Symptoms
Mild	Mild urticaria, rashes, skin edema, itchiness, nasal congestion, slight throat irritation, mild swelling of eyes and face
Moderate	Diffuse urticaria, erythema, wheezing, bronchospasm (mild or without hypoxia), dyspnea, mild hypotension, chest pain, hypertension, facial edema, laryngeal edema, tachycardia or bradycardia, prolonged nausea or vomiting
Severe	Generalized edema, facial edema with dyspnea, arrhythmia, profound hypotension, anaphylactic shock, unresponsiveness, convulsions or seizures

Continuous variables are reported as means $\pm$ standard deviations or medians where appropriate. Categorical variables were compared using Pearson's chi-squared test or Fisher's exact test when expected cell counts were small. Continuous variables were compared using the Wilcoxon rank-sum test. A two-tailed p-value of <0.05 was considered statistically significant. Statistical analyses were performed using R (version 3.4.1+) and SAS (version 9.4+). Multivariable regression analysis was not performed because the very low number of adverse events limited the statistical power for reliable model estimation.

Results

During the implementation phase, data were collected from 527 consecutive patients: 82 received premedication (as prescribed by referring clinicians), and 445 underwent contrast-enhanced CT scans without premedication under the updated protocol. The characteristics of the study cohort are summarized in Table 2.

The mean patient age was 64.8 years (SD = 16.6) in the premedication group and 63.6 years (SD = 17.7) in the non-premedication group, with no significant difference ($p = 0.75$, Wilcoxon rank-sum test). The premedication group had a higher proportion of female patients (61%, $n=50$) compared to the non-premedication group (51%, $n=229$), but this difference was not statistically significant ($p = 0.11$, Pearson's Chi-squared test).

Table 2. Baseline characteristics of patients.

Variables	With premedication, N = 82 ¹	Without premedication, N = 445 ¹	p-value
Age	64.82 (16.62)	63.62 (17.70)	0.75 ²
Gender			0.11 ³
Female	50 (61%)	229 (51%)	
Male	32 (39%)	216 (49%)	
Ethnicity			0.019 ⁴
Chinese	50 (61%)	262 (59%)	
Indian	5 (6.1%)	77 (17%)	
Malay	25 (30%)	90 (20%)	
Others	2 (2.4%)	16 (3.6%)	
Patient type			<0.001 ³
Emergency	3 (3.7%)	39 (8.8%)	
Inpatient	71 (87%)	293 (66%)	
Outpatient	8 (9.8%)	113 (25%)	
Patient history			0.88 ³
Asthma	52 (63%)	288 (65%)	
Asthma & Multiple drug allergy	22 (27%)	121 (27%)	
Multiple drug allergy	8 (9.8%)	36 (8.1%)	
Allergic reaction	1 (1.2%)	2 (0.4%)	0.40 ⁴

¹Mean (SD); n (%). ²Wilcoxon rank sum test. ³Pearson's Chi-squared test. ⁴Fisher's exact test.

Both groups were predominantly Chinese, with Malays and Indians also represented. The premedication group comprised 61% Chinese (n=50), 30% Malay (n=25), 6.1% Indian (n=5), and 2.4% others (n=2). The non-premedication group included 59% Chinese (n=262), 20% Malay (n=90), 17% Indian (n=77), and 3.6% Others (n=16). While the proportion of Chinese patients was similar between groups, the premedication group had a higher proportion of Malay patients and a lower proportion of Indian patients. A statistically significant difference in ethnic distribution was observed between groups (p=0.019). However, the study was not designed or powered to evaluate ethnicity as an independent risk factor for contrast reactions, and therefore this finding should be interpreted with caution.

Patient distribution across imaging centres differed between groups ($p < 0.001$). Emergency service patients were under-represented in the premedication group (3.7% vs 8.8% in the non-premedication group), while inpatient service patients were over-represented (87% vs 66% in the non-premedication group). Conversely, a higher proportion of outpatient cases was observed in the non-premedication group (25% vs 9.8%). Patient histories of asthma and MDA were similar between groups, with no statistically significant difference ($p = 0.88$, Pearson's Chi-squared test). Approximately 63% of the premedication group ($n = 52$) and 65% of the non-premedication group ($n = 288$) had asthma without MDA. Patients with both asthma and MDA comprised 27% in both groups ($n = 22$ in the premedication, $n = 121$ non-premedication group). The smallest subgroup, those with MDA but no asthma, accounted for 9.8% ($n = 8$) in the premedication group and 8.1% ($n = 36$) in the non-premedication group.

Table 3. *Distribution of asthma control status among patients with asthma in the outpatient setting.*

Variables	With premedication, N = 8 ¹	Without premedication, N = 113 ¹	<i>p-value</i>
Asthma control status			<0.0012
Uncontrolled	3 (37.5%)	9 (8%)	
Partly-controlled	4 (50%)	0 (0%)	
Well-controlled	1 (12.5%)	104 (92%)	

¹*n (%)*. ²*Fisher's exact test.*

During Phase 2 implementation, asthma control among outpatients was assessed using a structured screening questionnaire (Appendix 1). Asthma control status differed significantly between the premedication and non-premedication groups ($p = 0.0014$). Most patients in the non-premedication group had well-controlled asthma (104 patients, 23.0%), whereas only one patient (1.2%) in the premedication group was classified as well-controlled. In contrast, partly controlled asthma was observed in four patients (4.9%) in the premedication group compared with nine patients (2.0%) in the non-premedication group, and three patients (3.7%) in the premedication group were classified as having uncontrolled asthma, while none were recorded in the non-premedication group (Table 3).

Of the three patients who experienced acute allergic reactions, two had both asthma and multiple drug allergies, and one had asthma alone. The overall reaction rate was 0.6% (3/527), with 1.2% (1/82) in the premedication group and 0.4% (2/445) in the non-premedication group. Two patients (one from each group) experienced mild reactions presenting with pruritus, localized urticaria, and nausea. One patient in the non-premedicated group developed a severe reaction characterized by facial edema with dyspnea and arrhythmia. All reactions occurred shortly after contrast administration and were managed conservatively within the radiology department with antihistamines and supportive care. Symptoms resolved following treatment, and no escalation of care or advanced resuscitative intervention was required. There was no statistically significant difference in allergic reaction rates between groups (Fisher's exact test, $p = 0.40$). While the observed rate was slightly higher than the 0.3% reported by the ACR for low-osmolar contrast media [4], the small number of events limits meaningful comparison and interpretation of these rates.

Discussion

Our audit of discontinuing steroid premedication for contrast-enhanced CT scans in patients with asthma or multiple drug allergies found no statistically significant difference in acute allergic reaction rates between the premedication (1.2%) and non-premedication (0.4%) groups. While the overall reaction rate (0.6%) was slightly higher than the 0.3% reported by the ACR for low-osmolar iodinated contrast media [4], the small number of events and unbalanced group sizes limit meaningful comparison. Our findings are consistent with recent literature and suggest that routine premedication may not be necessary for patients with asthma or multiple drug allergies, provided they have no known contrast media allergy [13]. However, due to methodological limitations, these results should be interpreted with caution.

Previous studies, such as Katayama et al. (1990) [12], reported higher adverse reaction frequencies in premedicated patients receiving non-ionic contrast media, regardless of risk level. Our study showed a similar trend, but the small number of events and substantial disparity in group sizes preclude definitive conclusions. The lack of statistical significance suggests that this observed difference could be due to chance. This likely reflects that premedication was predominantly used for patients perceived to be at higher risk, even if these patients were not always accurately identified. It is also possible that the higher reaction rate observed in the premedicated group reflects selection bias, as premedication was more likely to be prescribed for patients perceived by clinicians to be at greater risk of contrast reactions. This limitation reflects the real-world nature of the audit, where treatment decisions were determined by clinical judgement rather than randomized allocation.

The observed trend therefore likely reflects clinicians preferentially prescribing premedication to patients perceived to be at higher risk, rather than a direct effect of the premedication itself. These findings align with recent literature questioning the efficacy of routine corticosteroid prophylaxis and support results reported by Mervak et al. (2015) [9] and Schrijvers et al. (2019) [14], which found no significant reduction in moderate-to-severe adverse reactions.

Demographic analysis revealed some patterns, but the study was not powered to draw meaningful statistical inferences regarding age, sex, or ethnicity. While we found no significant age differences between groups, previous studies have shown that elderly subjects experience higher rates of severe reactions and reaction-related deaths [15]. The higher proportion of females in the premedication group was noted; whether this reflects a greater predisposition to contrast media reactions among females or other factors cannot be determined from this study. Racial distribution varied, with more Malay patients in the premedication group, but our study cannot determine whether ethnicity is a significant risk factor. These observations may warrant further investigation in larger studies.

The higher proportion of inpatients in the premedication group may reflect a more cautious approach by requesting clinicians. While there is no solid evidence to support the use of rapid prophylaxis regimens, these are often administered in urgent and emergent situations due to their perceived safety and potential to reduce reaction risk [16]. The higher proportion of outpatients in the non-premedication group likely reflects updated CT scan instructions, which now specify that premedication is not required unless patients have confirmed contrast allergies. (Appendices 2 and 3 show the comparison of the old and new instructions).

In addition, asthma control among outpatients differed significantly between the premedication and non-premedication groups. Most patients undergoing CT without premedication had well-controlled asthma, whereas patients receiving premedication were more likely to have partly controlled or uncontrolled asthma. This likely reflects clinician decision-making during the implementation phase, where patients perceived to have poorer asthma control may have been preferentially prescribed premedication despite the revised protocol. These findings highlight the pragmatic nature of the audit and suggest that treatment decisions were influenced by clinical judgement rather than strict protocol adherence, introducing the possibility of selection bias between groups. While premedication may reduce the incidence of mild adverse reactions, it does not lower the incidence of moderate-to-severe reactions or reaction-related deaths [7]. Current evidence does not support the use of premedication to reduce immediate ad-

verse reactions in high-risk patients, including those with a history of severe reactions [14]. Conversely, the side effects of steroid premedication are well-documented and include transient leucocytosis and hyperglycaemia, the latter being particularly concerning for diabetic patients [4,9,17].

The same study by Mervak et al. (2015) [9] found that the number needed to treat (NNT) to prevent one adverse reaction of any severity is 69 (95% CI, 39–304). Most strikingly, the NNT increases substantially for more severe outcomes: to prevent one severe reaction, 569 patients must be treated (95% CI, 389–1083), and to prevent one lethal reaction, 50,000 patients must be treated [18]. These findings suggest that premedication has limited effectiveness, particularly in preventing severe or fatal reactions.

From a practical standpoint, the requirement for premedication can lead to logistical challenges and potential delays in care. Davenport et al. (2016) [18] demonstrated that premedication was associated with increased hospital stays, longer wait times for CT scans, and a higher incidence of hospital-acquired infections compared to non-premedicated controls.

Several limitations warrant consideration. The main limitation is the significant size disparity between the premedicated and non-premedicated groups, reflecting the real-world implementation of the new protocol. The low number of adverse events limits statistical power and definitive conclusions about premedication and reaction rates. Our analysis was also limited by incomplete data on potential confounders such as contrast media volume, injection rate, and individual patient risk factors. While some studies have explored these factors, there is insufficient evidence to establish a clear link between contrast volume or flow rate and the risk of acute allergic reactions. The single-centre, retrospective design introduces potential selection bias, as group allocation was determined by protocol implementation rather than randomization. Our focus on acute reactions may have overlooked delayed and late reactions occurring after discharge. Although the data were collected between September 2021 and April 2022, institutional protocols for contrast administration and premedication have remained unchanged since that time, and the findings remain consistent with current ACR and ESUR guideline recommendations regarding selective corticosteroid premedication. These limitations underscore the need for larger, prospective, multi-centre studies to validate our findings and provide more robust evidence for clinical practice guidelines.

Conclusion

In this retrospective study with significant methodological limitations, the discontinuation of routine premedication with corticosteroid was not associated with a detectable increase in acute contrast reactions. These findings are consistent with recent literature questioning the efficacy of routine premedication and support current guideline recommendations from professional bodies such as the American College of Radiology (ACR) and the European Society of Urogenital Radiology (ESUR), which advocate a more selective approach to corticosteroid premedication. However, due to the small number of events, unbalanced group sizes, and other methodological limitations, these results should be interpreted with caution. Eliminating unnecessary premedication may improve operational efficiency within radiology departments by streamlining CT scheduling and reducing delays in care. Nevertheless, further research, ideally prospective, randomized, and multi-center is needed to confirm the safety of this approach and to identify more precise risk factors for contrast reactions. Such research could help develop more nuanced and personalized premedication guidelines, further refining patient care in radiology.

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Availability of data

Anonymized data required for this study may be made available by the author(s) upon reasonable request.

Supplementary Documents

Appendix 1. Asthma screening questionnaire.

Assessment for Asthma Control					
Asthma symptom control			Level of Asthma Control		
In the past 4 weeks, has the patient had:	Yes	No	Well Controlled	Partly Controlled	Uncontrolled
Daytime asthma symptoms more than twice/week?					
Any night waking due to asthma?					
SABA reliever for symptoms more than twice/week?			None of these	1-2 of these	3-4 of these
Any activity limitation due to asthma?					

Appendix 2. Outpatient preparation instructions for CT scan used BEFORE the implementation period.

GUIDE TO COMPUTED TOMOGRAPHY (CT) FOR OUT-PATIENT

General Preparation for all CT examinations with Intravenous contrast medium administration.

1. Please **inform the doctor / staff** attend to you if you:
 - a) are a **diabetic** and are taking the medicine called **METFORMIN (Glucophage)**.
The doctor or staff will advise you to discontinue the drug for **2 days after** the scan. (The use of iodine-based contrast media may result in a transient impairment of renal function, which may precipitate lactic acidosis in diabetics who are taking **METFORMIN**). If you are on diabetic medicine **other than METFORMIN**, you will be advised to omit the anti-diabetic drug on the day of the examination. This is because you need to fast for four hours prior to your scan.
 - b) are **asthmatic** (or have a **history of asthma**) or have **multiple drug allergies** (more than two). The doctor will have to prescribe **prednisolone 30 mg tablets**. These need to be taken **12 hours (1st dose) at _____ and 2 hours (2nd dose) at _____** before your scan.
 - c) are **pregnant** or **likely to be pregnant**.
2. Please fast for 4 hours before the scan. You may continue to take all prescribed medications (**except** for diabetic medicine – please refer to Note 1a.)
3. Depending on the type of scan, we may have to give you an injection of contrast medium for this examination. The nurse will insert a needle into your vein so that we can administer contrast during the scan.
4. If you are **below 21 years old**, please bring your parent or guardian with you. We need someone to sign the consent form if an injection is required for your scan.
5. On the day of your appointment, please report to **the respective appointment counter** for registration **20 minutes before** your appointment time.
6. Please submit the original request form on the appointment day and make payment for the scan. You may pay by cash, NETS, Medisave, and other major Credit Cards.
7. Please bring along all **X-rays, ultrasound, MRI films** and any previous **CT images** if they were not performed at SGH.

The actual scan will take about 20 to 30 minutes depending on the area being scanned. However, we might not be able to stick to the appointment time strictly due to emergency cases that may arise. We seek your understanding should you encounter any delays as priority is given to emergency cases.

Appendix 3. Outpatient preparation instructions for CT scan used DURING the implementation period.

GUIDE TO COMPUTED TOMOGRAPHY (CT) FOR OUT-PATIENT

BEFORE THE EXAM

1. If you are **pregnant** or **likely to be pregnant**, please inform us so we can reschedule your appointment.
2. If you have had a previous **allergic reaction** to **CT contrast media**, a doctor should have prescribed you **prednisolone 30mg tablets** to take **12 hours (1st dose)** and **2 hours (2nd dose)** before your scan.

Please inform us if you are **allergic** and have **not** been prescribed prednisolone.

Examples of CT contrast media include: Iohexol (Omnipaque), Iopamidol (Isovue), Iopromide (Ultravist), Ioversol (Optiray), Ioxilan (Oxilan), and Iodixanol (Visipaque).

3. Please **fast for 4 hours** before the scan. You may continue to take all prescribed medications (*except* for diabetic medication).
4. Please **drink** 250mL of water at **2 hours** and **1 hour** before your CT exam (before coming to the department).
5. If possible, please **try not to empty your bladder** after the second drink. For patients with a urinary bag, please clamp the bag.

AT OUR DEPARTMENT

1. On the day of your appointment, please report to the respective appointment counter for registration 20 minutes before your appointment time.
2. Please inform the staff attending to you if you:
 - a) are **diabetic** and are taking the medicine called **METFORMIN (Glucophage)**.
 - b) are on **blood thinning** medications.
 - c) are **asthmatic** or have a **history of asthma**. Please bring along your prescribed rescue inhaler into the CT room on the day of the scan.
 - d) have had a previous **allergic reaction** to **CT contrast media**.
 - e) are **pregnant** or **likely to be pregnant**.
3. Depending on the type of scan, we may have to give you an injection. The nurse will insert a needle into your vein so that we can administer contrast media during the scan.

Depending on the indication for the scan, you *may* be asked to drink oral contrast 2 hours before the CT scan **in our department**. Oral contrast solution can only be prepared in our department. Please allow for a potential additional **2-hour wait** and plan accordingly.

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Original Article

Diagnostic accuracy of computed tomography for acute appendicitis: Comparison among in-training, junior, and senior radiologists

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Abstract

Background: Computed tomography (CT) is widely used for diagnosing acute appendicitis, but the impact of radiologist experience on diagnostic accuracy remains unclear. This study compares the diagnostic performance of in-training, junior, and senior radiologists to assess whether experience influences accuracy and interobserver agreement.

Materials and Methods: A retrospective study analyzed CT scans of 196 patients suspected of having acute appendicitis from January to December 2020. Three radiologists—in training, junior, and senior—interpreted the scans independently. The diagnostic performance of each reader was compared based on pathological or clinical follow-up. Diagnostic accuracy indices were calculated for each reader, and interobserver agreement was assessed.

Results: CT demonstrated high diagnostic accuracy across all reader groups. The senior radiologist achieved the highest accuracy (94.4%; 95% CI, 90.2-97.2), followed by the junior radiologist (93.9%; 95% CI, 89.5-96.8) and the in-training radiologist (91.3%; 95% CI, 86.5-94.9), with no statistically significant differences. The AUROC values were 0.944

for the senior radiologist, 0.938 for the junior radiologist, and 0.912 for the in-training radiologist. Interobserver agreement was excellent, with Fleiss' kappa of 0.864 (95% CI, 0.806-0.921).

Conclusion: CT showed high diagnostic performance for acute appendicitis across different levels of radiologist experience in this cohort. Junior and senior radiologists demonstrated slightly higher numerical accuracy than the in-training radiologist, mainly due to fewer false-negative interpretations. These findings suggest comparable CT diagnostic results among in-training, junior, and senior radiologists, while emphasizing the importance of careful assessment of subtle or atypical cases.

Keywords: Acute appendicitis, Computed tomography, Diagnostic accuracy, Experience, Radiology training.

Introduction

Acute appendicitis is a frequently encountered cause of abdominal pain in emergency departments and requires prompt surgical intervention. Failure to diagnose or delays in diagnosis can lead to severe health complications and even death [1]. Worldwide, there are approximately 100 to 230 cases of acute appendicitis per 100,000 person-years, with the incidence rising in newly developed countries [2, 3]. Additionally, during the COVID-19 pandemic, the proportion of complicated appendicitis cases has increased [4].

Clinical evaluation remains a crucial first step in diagnosing acute appendicitis, particularly in cases with atypical presentations. The Alvarado score, introduced by Dr. Alfredo Alvarado in 1986, is a widely used clinical scoring system that helps assess the likelihood of appendicitis based on a combination of symptoms, signs, and laboratory findings [5, 6]. A score of 7 or higher suggests a high probability of appendicitis, often warranting surgical intervention. While the Alvarado score has a high sensitivity for ruling out appendicitis, its specificity is lower, necessitating imaging in ambiguous cases [6, 7].

CT has revolutionized the diagnosis of acute appendicitis, with reported sensitivity and specificity exceeding 95% and 94%, respectively [8-11]. Due to its superior diagnostic performance, CT is now included in national guidelines in multiple countries [12-14]. Key imaging findings for appendicitis include an appendiceal diameter >6 mm (93% sensitivity, 100% specificity), periappendiceal fat stranding (100% sensitivity, 80% specificity), and focal cecal thickening (69% sensitivity, 100% specificity) [15].

Radiologist experience is a crucial factor influencing the accuracy of CT interpretation. Several studies have shown that less experienced radiologists have lower sensitivity and specificity in diagnosing acute appendicitis [16]. In most medical centers, initial CT interpretations are conducted by in-training residents, particularly in emergency settings [17-19]. However, misinterpretation by less experienced radiologists may lead to false-negative or false-positive diagnoses, resulting in unnecessary surgeries or missed cases of appendicitis [20].

Studies have shown that structured training programs and continuous radiology education improve diagnostic accuracy among in-training radiologists [21]. The critical question remains: Does a radiologist's experience significantly impact the accuracy of diagnosing acute appendicitis? If expertise is a significant factor, hospitals should prioritize ensuring that board-certified radiologists interpret CT scans for suspected appendicitis.

This study aimed to compare the diagnostic performance and interobserver agreement of CT interpretation for acute appendicitis among in-training, junior, and senior radiologists.

Materials and methods

Study Design and Population

This retrospective, cross-sectional diagnostic accuracy study was conducted at a university hospital. The study compared the diagnostic accuracy of a second-year in-training radiologist with that of two board-certified abdominal radiologists, one with eight years of experience and the other with 20 years of experience. The authors assessed diagnostic accuracy by reanalyzing CT images stored in the hospital's Picture Archiving and Communication System (PACS).

The study encompassed patients aged ≥ 18 years who presented with acute abdominal pain and were referred for CT evaluation due to suspected acute appendicitis between January 2020 and December 2020. We identified cases using a structured search strategy that included the following terms: "abdominal," "pain," "appendicitis," "RLQ pain," or "lower abdominal pain" in the hospital's electronic medical records.

Patients were excluded if they had a history of appendectomy, known intra-abdominal malignancy, trauma, pregnancy, or insufficient post-treatment follow-up data for diagnostic validation. Figure 1 illustrates the study workflow, including patient selection, exclusion criteria, imaging interpretation, and the validation process.

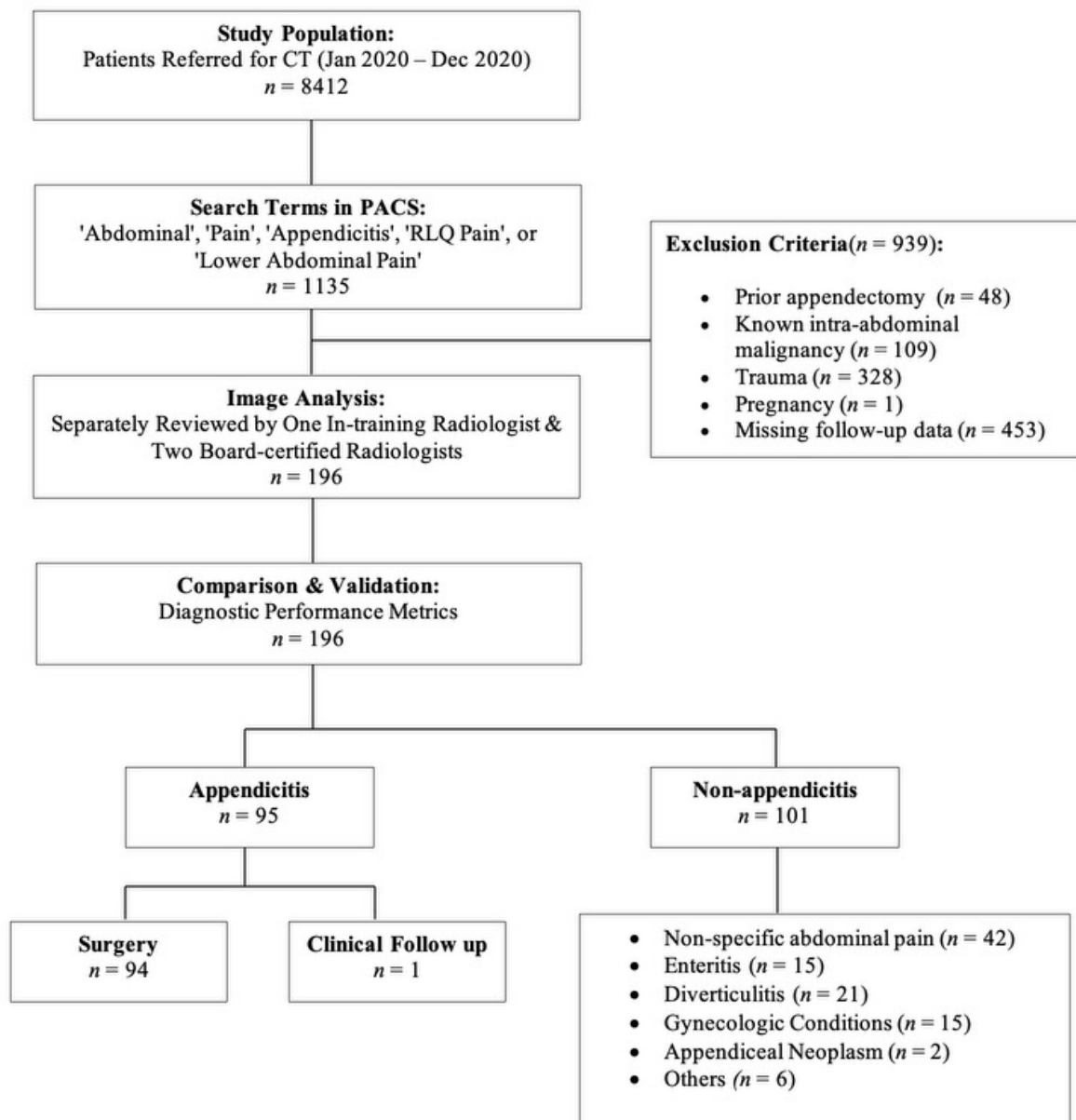


Figure 1. Study flow diagram outlining patient selection, exclusion criteria, imaging interpretation, and validation. Of 1,135 patients referred for abdomino-pelvic CT, 196 met the inclusion criteria, including 95 patients with appendicitis and 101 patients without appendicitis. Final diagnoses in the non-appendicitis group included non-specific abdominal pain ($n = 42$), enteritis ($n = 15$), diverticulitis ($n = 21$), gynecologic conditions ($n = 15$), appendiceal neoplasm ($n = 2$), and other diagnoses ($n = 6$). CT images were retrospectively analyzed, with diagnoses validated against pathology or clinical follow-up.

CT Imaging Protocol

All patients underwent contrast-enhanced abdominal CT scans using one of three multidetector CT systems: SOMATOM® Definition (Siemens Healthcare, Forchheim, Germany), SOMATOM® Force (Siemens Healthcare, Forchheim, Germany), or Philips IQon (Philips Healthcare, Best, The Netherlands). The standardized CT protocol included a plain scan of the upper abdomen (if clinically indicated for stone evaluation) and a portal venous phase post-contrast scan covering the entire abdomen.

Intravenous iodinated contrast agents were administered according to patient body weight, up to a maximum dose of 100 mL. The contrast agents included iodixanol (320 mg I/mL), iohexol (350 mg I/mL), ioversol (350 mg I/mL), and iopamidol (370 mg I/mL). Portal venous phase images were acquired approximately 60 seconds after contrast injection. No oral or rectal contrast material was used.

Image reconstruction involved axial images with 2-mm and 5-mm thicknesses, as well as coronal and sagittal images with 5-mm thicknesses. No delayed phase scans were performed. Although some scans were acquired using dual-energy spectral CT systems, only conventional-like (mixed-energy) images were analyzed to ensure the generalizability of the results across different CT systems.

Image Analysis

All CT scans were independently reviewed by a second-year radiology resident and two board-certified abdominal radiologists with 8 and 20 years of experience, respectively. The retrospective readers were blinded to the final diagnosis, histopathologic results, clinical outcome, and original CT report. The basic clinical indication was available to reflect routine clinical CT interpretation. Readers evaluated predefined CT features and assigned a four-level diagnostic confidence score:

- 1 = confidently negative for appendicitis, including a normal appendix or an alternative diagnosis without CT findings of appendicitis
- 2 = probably negative for appendicitis, including a visualized appendix without convincing inflammatory change or minimal equivocal findings considered insufficient for the diagnosis of appendicitis
- 3 = probably positive for appendicitis, including equivocal but suspicious appendiceal enlargement, wall enhancement, or periappendiceal inflammatory change
- 4 = confidently positive for appendicitis, based on typical CT findings of acute appendicitis, complicated appendicitis, abscess, or perforation

Before image interpretation, all readers received standardized written instructions describing the four-level confidence scoring system. Although scores 2 and 3 both represented equivocal cases, score 2 was assigned when the overall CT findings were considered insufficient to support appendicitis, whereas score 3 was assigned when the imaging findings were equivocal but the overall assessment favored appendicitis based on the reader's integrated assessment of all predefined CT features. This approach was intended to reflect routine clinical decision-making rather than strict quantitative imaging thresholds.

Scores 2 and 3 were used to reflect equivocal or indeterminate real-world interpretations. For the primary diagnostic accuracy analysis, the four-level scores were dichotomized according to the clinically actionable diagnostic impression:

Scores 1-2 = negative for appendicitis

Scores 3-4 = positive for appendicitis

ROC curve analysis was performed using this dichotomized diagnostic output. Therefore, the reported AUROC values represent discrimination at the clinically relevant decision threshold used in routine practice. This approach reflects real-world reporting behavior, in which radiologists ultimately provide a binary impression for clinical management: appendicitis or no appendicitis.

The initial CT report was defined as the original clinical radiology report issued during routine patient care before retrospective image review. In our institutional workflow, emergency CT examinations were initially interpreted by the on-duty radiology resident and subsequently reviewed according to routine departmental practice. The initial CT report was analyzed separately as a real-world clinical comparator and was not included as one of the three blinded retrospective reader interpretations. Examples of images illustrating these criteria are shown in Figure 2.

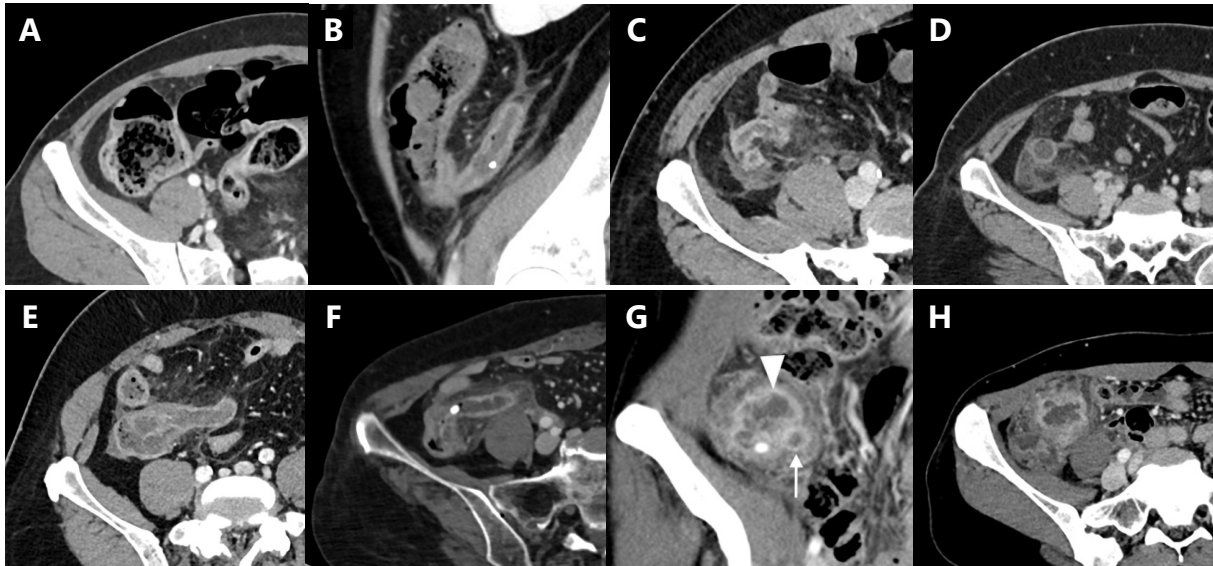


Figure 2. CT findings for diagnosing acute appendicitis.

(A) Normal appendix with a normal size and wall thickness. (B) Acute suppurative appendicitis, confirmed by tissue pathology, showing an enlarged, fluid-filled appendix. (C) Appendiceal wall hyperenhancement, a key finding in acute appendicitis. (D) Periappendiceal fat stranding, indicative of inflammatory changes surrounding the appendix. (E) Cecal wall swelling, representing reactive changes in the adjacent cecum. (F) Appendicolith at the appendix base, a potential obstructive factor in appendicitis. (G) Ruptured appendix, showing a dilated appendix (arrow) with a fluid collection likely representing an abscess (arrowhead). (H) Another case of appendiceal abscess, demonstrating a thick-walled fluid collection adjacent to the appendix.

Reference Standard

For patients who underwent surgery, histopathologic examination of the resected appendix served as the definitive reference standard. For patients managed non-operatively, clinical follow-up through documented outpatient visits or inpatient observation was used to confirm the absence of appendicitis. All non-surgical patients had a minimum follow-up period of 7 days, during which one of the following clinical criteria was required to classify the case as not having appendicitis:

1. Complete resolution of abdominal pain without surgical intervention;
2. No subsequent diagnosis of appendicitis or related complications within the follow-up window; and
3. No readmission to the hospital with right lower quadrant pain.

Cases without sufficient clinical follow-up were excluded to maintain the reliability of the reference standard.

Statistical Analysis

Descriptive statistics were used to summarize demographic and clinical characteristics. Continuous variables were reported as means with standard deviations or medians with interquartile ranges, as appropriate. Categorical variables were reported as numbers and percentages. Comparisons between patients with and without appendicitis were performed using the Student's t-test or Mann-Whitney U test for continuous variables and the chi-square test or Fisher's exact test for categorical variables, as appropriate.

Diagnostic performance was calculated for each reader and for the initial CT report, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, and the area under the receiver operating characteristic curve (AUROC). Because the primary diagnostic output was dichotomized as positive or negative for appendicitis, ROC analysis was performed using the binary diagnostic classification. Ninety-five percent confidence intervals (95% CIs) were calculated for diagnostic indices. Diagnostic accuracy values were compared among readers using the chi-square test.

Interobserver agreement among readers was assessed using percent agreement, pairwise Cohen's kappa, and multi-rater Fleiss' kappa. Kappa values were interpreted as follows: less than 0.20, poor agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, good agreement; and 0.81-1.00, excellent agreement.

All statistical analyses were performed using STATA version 19.0 (StataCorp, College Station, TX, USA). A p-value less than 0.05 was considered statistically significant.

Results

A total of 1,135 patients underwent CT evaluation for acute abdominal pain. After applying the inclusion and exclusion criteria, 196 patients were included, with 95 (48.5%) diagnosed with acute appendicitis and 101 (51.5%) classified as having no appendicitis. Among the 101 patients without appendicitis, the final diagnoses were nonspecific abdominal pain (n = 42), enteritis (n = 15), diverticulitis (n = 21), gynecologic conditions (n = 15), appendiceal neoplasm (n = 2), and other diagnoses (n = 6).

Patient Characteristics

The patient characteristics of the study population are summarized in Table 1. Age, sex distribution, underlying diseases, clinical symptoms, and physical examination findings were generally comparable between patients with and without appendicitis. The appendicitis group had significantly higher WBC counts, neutrophil percentages, and Alvarado scores. Urinalysis findings did not significantly differ between groups.

Table 1. Patient characteristics of the included patients evaluated for acute appendicitis.

Parameters	Appendicitis n=95 (48.5%)	Not appendicitis n=101 (51.5%)	p-value
Age (year, mean)	48.23 (19.49)	49.65(20.76)	0.62
Sex			
Male	34(35.79)	35(34.65)	0.88
Female	61(64.21)	66(65.35)	
Underlying			
DM	4(4.21)	11(10.89)	0.07
Hypertension	19(20.0)	25(24.75)	0.27
Immunocompromised	0(0%)	1(0.99)	0.52
Others	30(31.58)	57(56.44)	0.001
Symptoms			
RLQ pain	70(73.68)	66(65.35)	0.13
Fever	23(24.21)	28(27.72)	0.35
Nausea or vomiting	44(46.32)	48(47.52)	0.49
Diarrhea	21(22.11)	21(20.79)	0.48
Physical signs			
Body temperature (degree Celsius, median)	36.9(1)	36.8(1.1)	0.71
RLQ tenderness	93(97.89)	100(99.01)	0.48
Rebound tenderness	37(38.95)	34(33.66)	0.27
Blood test			
WBC count (cells per cc, median)	13,600(5910)	11,260(5365)	0.003*
Neutrophil (percent, median)	83(11.6)	79.9(13.65)	0.01*
Alvarado Score (median)	7(2)	6(3)	0.02*
Urinalysis			
WBC > 5-10 cell/HPF	15(15.79)	18(17.82)	0.43
RBC > 5-10 cell/HPF	21(22.11)	25(24.75)	0.40

Abbreviations: DM, Diabetes mellitus; RLQ, right lower quadrant; WBC, white blood cell; RBC, red blood cell

The numbers in parentheses represent the standard deviations (SD) for the means, interquartile ranges (IQR) for the medians, and proportional percentages for counting data.

Continuous variables with non-normal distributions were compared using the Mann-Whitney U test.

Diagnostic Performance

The diagnostic performance of the in-training radiologist, junior radiologist, senior radiologist, and initial CT report is summarized in Table 2. All readers demonstrated high diagnostic performance for acute appendicitis. The senior radiologist achieved the highest accuracy among the three retrospective readers (94.4%; 95% CI, 90.2-97.2), followed by the junior radiologist (93.9%; 95% CI, 89.5-96.8) and the in-training radiologist (91.3%; 95% CI, 86.5-94.9). The differences among the readers were not statistically significant ($p = 0.133$).

The in-training radiologist had 11 false-negative and 6 false-positive interpretations, the junior radiologist had 7 false-negative and 5 false-positive interpretations, and the senior radiologist had 6 false-negative and 5 false-positive interpretations. To evaluate the consistency of missed diagnoses across experience levels, a case-level analysis of false-negative interpretations was performed. All 6 false-negative cases identified by the senior radiologist were also misclassified as false negatives by both the junior and in-training radiologists. The junior radiologist missed 1 additional case (for a total 7 false-negative cases), which was also missed by the in-training radiologist. The in-training radiologist missed 4 unique cases that were correctly diagnosed as positive by both the junior and senior radiologists. All false-negative cases missed by the more experienced readers were also missed by the less experienced readers, suggesting that greater experience may improve the detection of subtle cases. Therefore, the modest numerical difference in performance was mainly attributable to fewer false-negative interpretations among the more experienced readers. The initial CT report showed 95 true-positive, no false-negative, 8 false-positive, and 93 true-negative interpretations, corresponding to an accuracy of 95.9% (95% CI, 92.1-98.2).

Table 2. *Diagnostic performance of CT for acute appendicitis according to reader group.*

Metric	In-Training Radiologist	Junior Radiologist	Senior Radiologist	Initial CT Report
True positive	84	88	89	95
False negative	11	7	6	0
False positive	6	5	5	8
True negative	95	96	96	93
Sensitivity (%)	88.4 (80.2-94.1)	92.6 (85.7-97.0)	93.7 (86.8-97.6)	100.0 (96.2-100.0)
Specificity (%)	94.1 (87.5-97.8)	95.0 (88.8-98.4)	95.0 (88.8-98.4)	92.1 (85.0-96.5)
PPV (%)	93.3 (86.1-97.5)	94.6 (87.9-98.2)	94.7 (88.0-98.3)	92.2 (85.3-96.6)
NPV (%)	89.6 (82.2-94.7)	93.2 (86.5-97.2)	94.1 (87.6-97.8)	100.0 (96.1-100.0)
Accuracy (%)	91.3 (86.5-94.9)	93.9 (89.5-96.8)	94.4 (90.2-97.2)	95.9 (92.1-98.2)
AUROC	0.912 (0.873-0.952)	0.938 (0.905-0.972)	0.944 (0.911-0.976)	0.960 (0.934-0.987)

The ROC analysis for each reader and the initial CT report is shown in Figure 3. The AUROC values were 0.912 for the in-training radiologist, 0.938 for the junior radiologist, 0.944 for the senior radiologist, and 0.960 for the initial CT report. Although the more experienced radiologists showed slightly higher numerical performance, the differences were not statistically significant. These findings suggest that CT diagnostic performance was comparable across different levels of radiologist experience in this cohort.

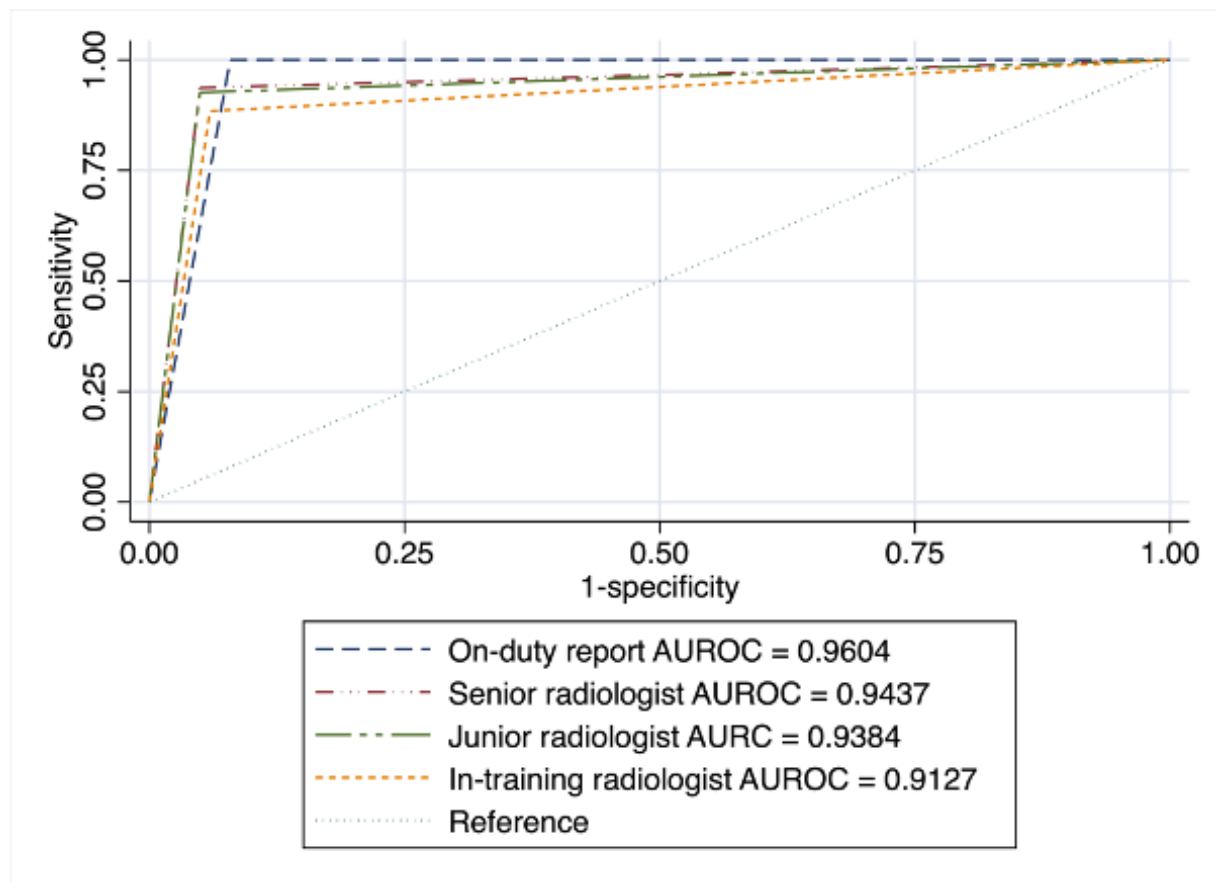


Figure 3. Receiver operating characteristic (ROC) curves for diagnosing acute appendicitis using CT. The AUROC values are shown for each interpretation: initial CT report (0.960), senior radiologist (0.944), junior radiologist (0.938), and in-training radiologist (0.912).

Interobserver Agreement

Interobserver agreement among the three readers was excellent. The overall percent agreement was 93.2% (95% CI, 90.4-96.1%). The multi-rater agreement analysis showed a Fleiss' kappa of 0.864 (95% CI, 0.806-0.921), indicating excellent reproducibility of CT interpretation for acute appendicitis. Pairwise Cohen's kappa values were also excellent: 0.867 (95% CI, 0.727-1.000) for the in-training versus junior radiologists, 0.857 (95% CI, 0.717-0.997) for the in-training versus senior radiologists, and 0.867 (95% CI, 0.727-1.000) for the junior versus senior radiologists.

Discussion

This study showed high diagnostic performance of CT for acute appendicitis across different levels of radiologist experience. Among the three retrospective readers, the senior radiologist achieved the highest accuracy, followed by the junior radiologist and the in-training radiologist. However, the differences were not statistically significant. Therefore, our findings should not be interpreted as evidence that radiologist experience has no effect, but rather that CT interpretation showed comparable diagnostic performance among in-training, junior, and senior radiologists in this selected cohort. The high overall performance observed in this study is consistent with the established role of CT as a reliable imaging modality for suspected acute appendicitis. Current ACR Appropriateness Criteria support CT as an important imaging test in adult patients with right lower quadrant pain and suspected appendicitis, particularly when clinical findings are equivocal or when alternative diagnoses need to be assessed [22]. A Cochrane review also reported high diagnostic performance of CT for acute appendicitis in adults, supporting its use as a robust diagnostic tool in routine clinical practice [23]. The 2020 WSES Jerusalem guidelines elaborate the diagnostic workup of acute appendicitis as a combined clinical, laboratory, and radiological process, reflecting the real-world need to integrate imaging with clinical judgment [24].

The prevalence of appendicitis in our cohort was 48.5%, which likely reflects the retrospective search strategy and case selection rather than the prevalence in the general emergency department population. This is relevant because PPV and NPV are affected by disease prevalence. Therefore, the predictive values in this study should be interpreted in the context of a selected group of patients who underwent CT for suspected appendicitis, rather than as estimates for all patients presenting with abdominal pain.

Clinical findings, laboratory markers, and clinical scoring systems remain useful for initial triage, but they were not the primary focus of this study. In our cohort, WBC count, neutrophil percentage, and Alvarado score were higher in patients with appendicitis, but overlap between the appendicitis and non-appendicitis groups remained. This supports the practical role of CT in patients with equivocal or overlapping clinical presentations. The WSES guidelines similarly state that clinical scores can guide risk stratification and imaging decisions, but the diagnostic workup still relies on integration of clinical, laboratory, and imaging findings [24].

Although overall accuracy was high for all readers, the numerical differences between experience levels were mainly due to false-negative interpretations. The in-training radiologist had 11 false-negative interpretations, compared with 7 for the junior radiologist and 6 for the senior radiologist. This pattern suggests that experience may

be most relevant in cases with subtle or early inflammatory changes rather than in typical appendicitis.

Analysis of the overlap in false-negative cases showed that all 6 cases missed by the senior radiologist were also missed by the junior and in-training radiologists. In contrast, 4 additional cases missed by the in-training radiologist were correctly identified by both board-certified radiologists. These findings suggest that greater reader experience may improve the detection of subtle or early appendicitis cases that are more likely to be missed by less-experienced readers, rather than resulting in readers missing completely different cases. The two cases shown in Figure 4 illustrate this finding, in which subtle features, such as minimal wall thickening, limited periappendiceal inflammation, or subtle enhancement without marked dilatation, were missed by the in-training and junior radiologists but correctly identified by the senior radiologist. Educational efforts for residents should therefore focus on equivocal cases, including mildly enlarged appendices, subtle wall thickening or enhancement, minimal periappendiceal fat stranding, tip appendicitis, and atypical appendix locations.

False-positive interpretations were less frequent and were similar among the three retrospective readers, with 6 false-positive interpretations by the in-training radiologist and 5 each by the junior and senior radiologists. Two examples are shown in Figure 5. These cases highlight the importance of considering alternative diagnoses when appendiceal wall thickening, luminal dilatation, or cecal involvement is present, particularly when the imaging findings or clinical presentation are not typical for uncomplicated appendicitis.

The initial CT report showed the highest sensitivity and negative predictive value, with no false-negative interpretations, but had more false-positive interpretations than the retrospective readers. This finding likely reflects real-world emergency reporting behavior, in which radiologists may favor sensitivity to avoid missing acute appendicitis. While this approach is clinically understandable, it may reduce specificity and increase false-positive diagnoses. The initial CT report should therefore be interpreted as a real-world clinical comparator rather than a direct measure of individual reader expertise.

Interobserver agreement among the three retrospective readers was excellent, with an overall percent agreement of 93.2% and a Fleiss' kappa of 0.864. This supports the reproducibility of CT-based diagnosis of acute appendicitis when standardized CT criteria are applied. However, excellent agreement does not eliminate the importance of experience. Rather, it suggests that most cases in this cohort had sufficiently clear CT findings to allow consistent interpretation across readers, while subtle cases remained more challenging for less experienced readers.

This study has several limitations. First, the retrospective design may have introduced selection bias. Clinical management may also have been influenced by the initial CT report, and mild uncomplicated appendicitis treated conservatively or cases not clinically recognized as appendicitis may not have been captured. Second, the sample size was relatively small, and no formal sample size calculation was performed before the study. Third, the reference standard was mixed, using histopathology in surgical cases and clinical follow-up in non-operative cases. Among the non-appendicitis group, 8 patients had normal appendiceal pathology, whereas the remaining cases were classified based on clinical follow-up and/or alternative CT-based diagnoses. Fourth, although final diagnostic categories were available for the non-appendicitis group, detailed clinical outcomes and diagnostic confirmation methods for each alternative diagnosis were limited by the retrospective nature of the study. The original 1-4 confidence score distribution and the time interval between CT and surgery were also not uniformly available for re-analysis. Finally, the institutional imaging pathway was not strictly CT-first or ultrasound-first; CT was performed at the discretion of the attending physician. This may limit generalizability to institutions with different appendicitis workup pathways.

Overall, CT showed high and comparable diagnostic performance for acute appendicitis among in-training, junior, and senior radiologists in this cohort. Experienced radiologists demonstrated a small numerical advantage, mainly due to fewer false-negative interpretations. These findings support the role of resident participation in emergency CT interpretation when appropriate supervision is available, while emphasizing the need for focused teaching on subtle and atypical presentations of appendicitis.

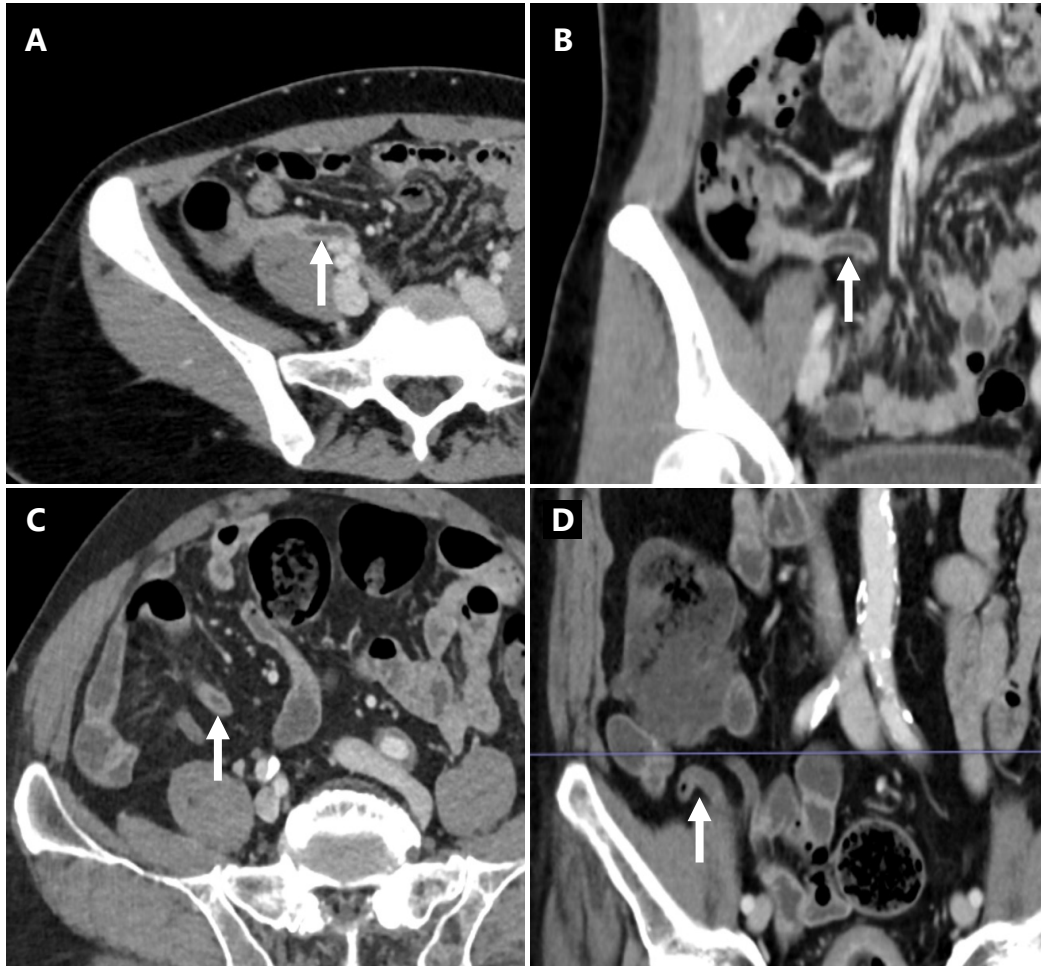


Figure 4. Two examples of false-negative CT Diagnoses of Acute Appendicitis.

Case 1 (A&B): An adult woman presented with right lower quadrant (RLQ) pain. Axial (A) and coronal (B) contrast-enhanced CT images demonstrate a normal-caliber appendix (0.5 cm in diameter) with subtle mural thickening and mild hyperenhancement (arrow), which were overlooked by the in-training and junior radiologists but correctly identified by the senior radiologist. Histopathological examination confirmed acute interstitial appendicitis.

Case 2 (C&D): An adult man presented with right lower quadrant (RLQ) pain. Axial (C) and coronal (D) contrast-enhanced CT images demonstrate a non-dilated appendix with subtle mural thickening and mild hyperenhancement (arrow), without significant periappendiceal inflammatory change. These subtle findings were missed by the in-training and junior radiologists but correctly identified by the senior radiologist. Histopathological examination confirmed acute interstitial appendicitis.

Both cases represent false-negative CT interpretations by the in-training and junior radiologists.

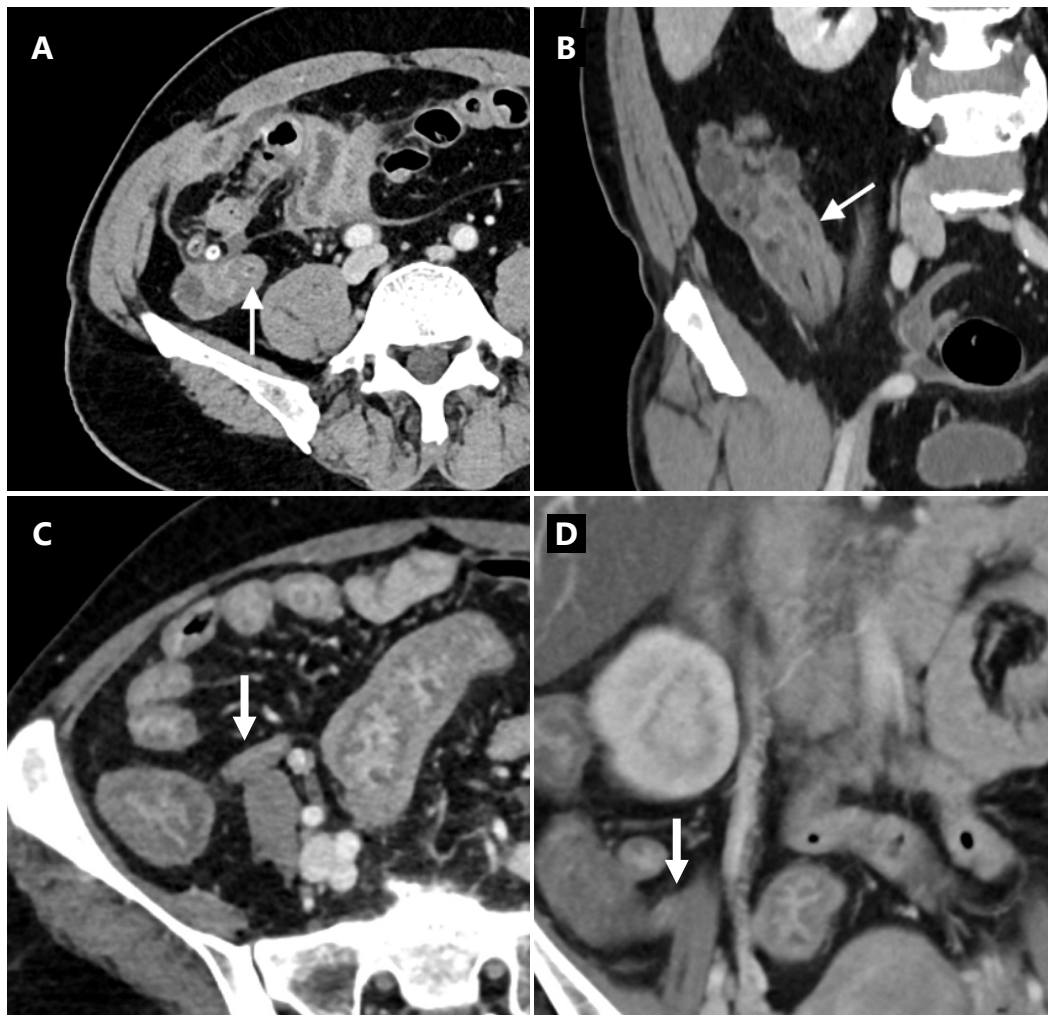


Figure 5. Two examples of false-positive CT Diagnoses of Acute Appendicitis.

Case 1 (A&B): An adult man presented with right lower quadrant (RLQ) abdominal pain. Axial (A) and coronal (B) contrast-enhanced CT images demonstrate appendiceal wall thickening and hyperenhancement (arrow) with associated cecal wall thickening, mimicking acute appendicitis. However, pathological examination confirmed a high-grade appendiceal mucinous neoplasm (HAMN), representing a false-positive CT diagnosis of acute appendicitis.

Case 2 (C&D): An adult woman presented with generalized abdominal pain. Axial (C) and coronal (D) contrast-enhanced CT images demonstrate mild appendiceal wall thickening and hyperenhancement (arrow) without appendiceal dilatation (a normal appendiceal caliber). Diffuse long-segment colonic wall thickening is also present, consistent with colitis. The appendiceal findings were considered secondary inflammatory involvement rather than primary acute appendicitis. Following treatment for colitis, follow-up CT demonstrated a normal appendix.

Conclusion

CT demonstrated high overall diagnostic performance for acute appendicitis across all levels of radiologist experience, with no statistically significant differences in accuracy. However, case-level analysis of false-negative interpretations showed that more experienced radiologists identified some subtle or early appendicitis cases that were missed by the in-training radiologist. These findings support the feasibility of independent resident interpretation of emergency CT examinations under appropriate supervision, while emphasizing the continued value of experienced radiologists in challenging or equivocal cases.

Conflict of Interest

The authors declare no conflicts of interest.

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Ethics Approval

This study was approved by the Research Ethics Committee, Faculty of Medicine, Chiang Mai University (Approval No. 354/2022, Study Code: RAD-2565-09224; Project Code: RAD-2569-0877). The initial approval was granted with expedited review on October 18, 2022. The study approval was subsequently extended, with continued approval granted from August 17, 2026 to August 16, 2027. An amendment was approved on August 10, 2026 to update the investigator/author information. The requirement for informed consent was waived because the study was retrospective. All data were anonymized before analysis. The study was conducted in accordance with the Declaration of Helsinki and ICH-GCP guidelines.

Author Contributions

P.C. contributed to study design, statistical analysis, data interpretation, manuscript preparation, and literature search. N.J. contributed to study design, data collection, data interpretation, manuscript preparation, and literature search. S.P. contributed to study design, data collection, and manuscript preparation. N.Ji. contributed to data collection. W.N.C. contributed to data interpretation and manuscript revision. A.A. contributed to data collection, data interpretation, manuscript revision, and supervision. All authors read and approved the final manuscript.

Data Availability Statement

The data used in this study are not publicly available under the PDPA Act of Thailand but can be accessed upon official request to the corresponding author.

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Case Report

A case series of right-sided congenital diaphragmatic hernia with liver herniation and non-contralateral mediastinal shift: Imaging clues and the diagnostic challenge of hepatopulmonary fusion

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Abstract

Right-sided congenital diaphragmatic hernia (CDH) with liver herniation typically produces contralateral mediastinal shift; its absence presents a diagnostic imaging challenge and raises concern for hepatopulmonary fusion (HPF). We report three infants with right-sided CDH and liver herniation non-contralateral mediastinal shift, including two cases of HPF and one non-HPF case attributable to severe pulmonary hypoplasia. This series demonstrates that non-contralateral mediastinal shift, although classically associated with HPF, is not pathognomonic. We highlight the complementary roles and limitations of radiography, ultrasonography, and contrast-enhanced CT in suggesting HPF preoperatively. These cases refine the radiologic clues for this rare presentation and underscore the importance of meticulous multimodality imaging to inform surgical planning and anticipate operative complexity.

Keywords: Hepatopulmonary fusion, Non-contralateral mediastinal shift, Right-sided congenital diaphragmatic hernia.

Introduction

Congenital diaphragmatic hernia (CDH) is a rare congenital anomaly, occurring in approximately 2.4–4.2 per 10,000 births, and results from the failure of fusion between the transverse septum and pleuroperitoneal folds during the 8th–10th weeks of gestation, leading to herniation of abdominal viscera into the thoracic cavity and subsequent pulmonary hypoplasia [1–4]. The majority of CDH cases are posterolateral (Bochdalek) defects and are predominantly left-sided, whereas right-sided and bilateral defects are less common [1,5–7]. In right-sided CDH with liver herniation, the mass effect typically produces a contralateral mediastinal shift; however, rare cases with non-contralateral mediastinal shift pose a diagnostic challenge and raise the possibility of severe right lung hypoplasia or hepatopulmonary fusion (HPF) [8]. HPF is an exceptionally uncommon anomaly, reported in approximately 3 in 1,000 right-sided CDH cases, characterized by abnormal fusion between the herniated liver and right lung and frequently associated with aberrant pulmonary vasculature, which increases surgical complexity and adversely affects outcomes [9,10]. Pre-operative imaging often fails to definitively identify HPF, and many cases are diagnosed intraoperatively. However, careful multimodality imaging, particularly through detailed evaluation of anatomic and vascular relationships, may facilitate preoperative recognition and guide surgical planning [6,11,12]. Between 2014 and 2025, our institution encountered three cases of right-sided CDH with liver herniation and non-contralateral mediastinal shift, including two with HPF and one without, which form the basis of this report, emphasizing the imaging approaches and findings relevant to the diagnosis.

Case summary

Case 1

A term male newborn delivered by cesarean section for breech presentation developed respiratory distress at birth, requiring intubation. Initial chest-abdominal radiographs showed near-complete opacification of the right hemithorax with air-filled bowel loops and a mild contralateral mediastinal shift, suggesting right-sided CDH with liver and bowel herniation (Figure 1A). A follow-up radiograph further supported the diagnosis, demonstrating a well-defined elevated hepatic contour within the thorax, an abnormally high right hemidiaphragm, the absence of visible herniated bowel loops, and non-contralateral mediastinal shift (Figure 1B).

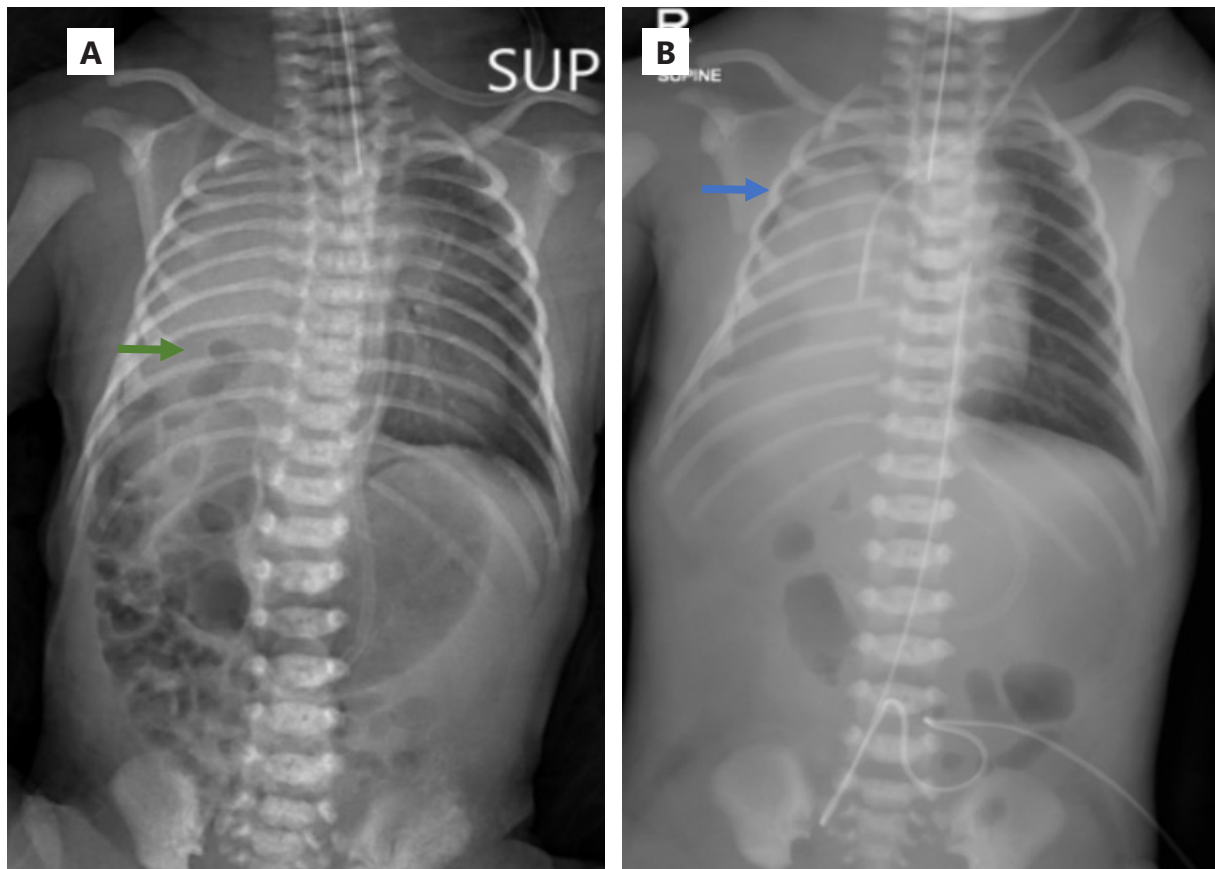


Figure 1. Chest-abdominal radiographs of a term newborn with dyspnea: (A) Day of life (DOL) 1, the radiograph showed near-total right hemithoracic opacification with air-filled bowel loops (green arrow) and a mild contralateral mediastinal shift, consistent with liver and bowel herniation. (B) On DOL 2, the follow-up radiograph showed a sharply elevated hepatic contour (blue arrow) with non-contralateral mediastinal shift and minimal to no visible herniated bowel loops.

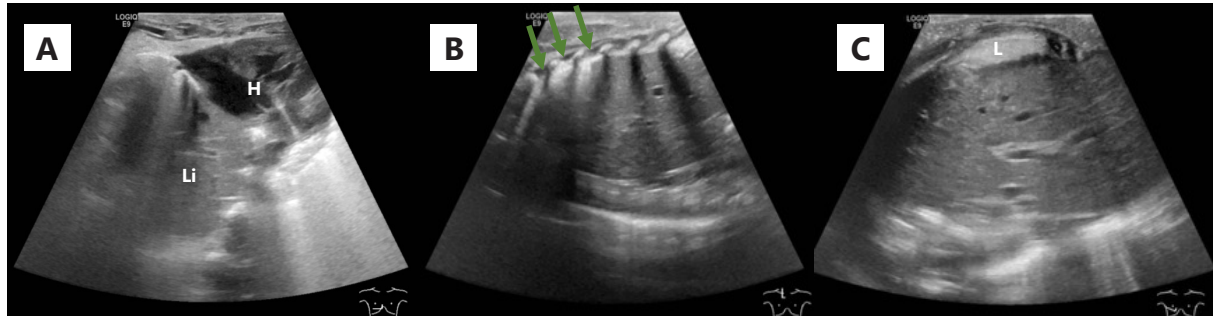


Figure 2. *US demonstrated an abnormally elevated right hepatic lobe within the right hemithorax, directly abutting the aerated right lung and heart, with no identifiable right hemidiaphragm (A). Aerated lung tissue (green arrows) was seen interposed between two portions of the herniated liver (B). The liver was seen in close contact with the atelectatic right lung within the hemithorax (C).*
Li = liver; H = heart; L = lung.

Chest ultrasonography (US) confirmed intrathoracic displacement of the right hepatic lobe with absence of the right hemidiaphragm, partial interposition of aerated right lung, and close apposition of hepatic tissue to the non-aerated lung. Hepatic venous drainage into the inferior vena cava (IVC) was preserved (Figure 2).

Intraoperatively, a right hemidiaphragmatic defect with herniation of the right hepatic lobe and fusion to hypoplastic right lung tissue was observed. Partial repair with a patch was performed on DOL 15.

At 10 months, CT angiography demonstrated an atelectatic right lung in direct contact with and inseparable from the herniated right hepatic tissue. The right pulmonary artery was hypoplastic, and the right pulmonary vein was absent (Figure 3). The right hemidiaphragm remained absent, while the portal and hepatic veins drained normally into the IVC.

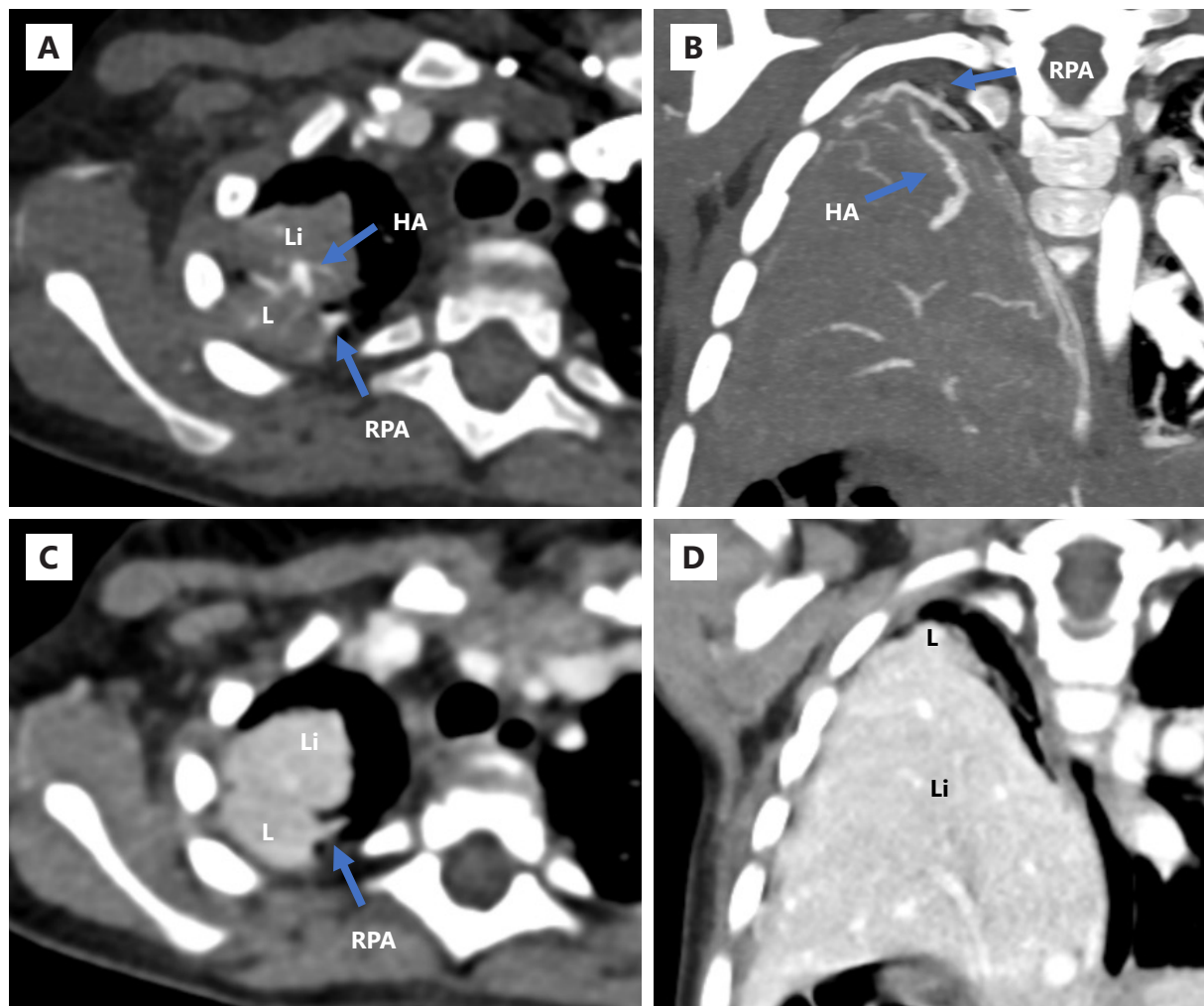


Figure 3. CT angiography of a 10-month-old infant with right-sided CDH and HPF, status post partial repair of the diaphragmatic defect on DOL 15, showed an enhancing atelectatic right lung conforming to the dome of the herniated right hepatic lobe within the right hemithorax on both the arterial (A,B) and venous (C,D) phases. The lung parenchyma received its vascular supply from a branch of the hypoplastic right pulmonary artery.

L = lung; *Li* = liver; *RPA* = right pulmonary artery; *HA* = hepatic artery.

Persistent elevation of the right hemidiaphragm with right-sided opacity representing the herniated hepatic lobe and HPF remained evident on the follow-up radiographs. The patient has experienced recurrent episodes of pneumonia and bronchitis and requires home oxygen therapy.

Case 2

A term male newborn presented with tachypnea after birth. Chest radiographs demonstrated a lobulated contour with elevation of the right hemidiaphragm, suspicious for liver herniation, with adjacent pulmonary opacification and a non-contralateral mediastinal shift (Figure 4A).

Preoperative chest CT performed on the same day demonstrated marked elevation of the right hemidiaphragm with superior herniation of the right hepatic lobe into the right hemithorax, abutting a hypoplastic right lung supplied by a diminutive right pulmonary artery. A suspected anomalous pulmonary venous channel draining via the hepatic vein into the right atrium was noted (Figure 4B-D). A right-sided aortic arch with an aberrant left subclavian artery and a Kommerell diverticulum was also observed.

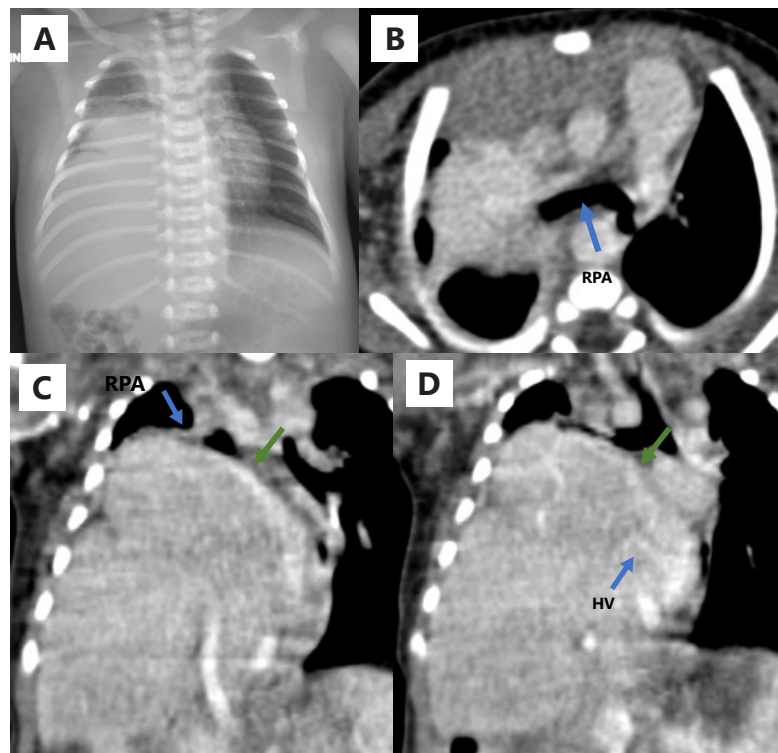


Figure 4. Preoperative chest radiograph (A) of a term male newborn with tachypnea after birth showed a lobulated contour and elevation of the right hemidiaphragm with adjacent pulmonary opacification, a small aerated portion of the right upper lobe, and a non-contralateral mediastinal shift. Preoperative chest CT (B-D) revealed marked elevation of the right hemidiaphragm with the herniated right hepatic lobe extending into the right hemithorax. The right lung was hypoplastic and supplied by a hypoplastic right pulmonary artery (RPA). A suspected anomalous pulmonary venous channel (green arrow) joined the hepatic vein (HV) and drained into the right atrium.

A diagnosis of right-sided CDH was made, and surgical repair was performed on the following day. Intraoperative findings confirmed right-sided CDH with HPF, evidenced by a right posterolateral diaphragmatic defect with herniation of the liver adherent to the right lower lobe pulmonary tissue. An arterial branch supplying the right lower lung was visualized; however, its origin was indeterminate. There was absence of the IVC with azygos continuation. The suprahepatic IVC was formed by the confluence of hepatic veins and an anomalous right pulmonary vein. Surgical management included separation of the fused lung and liver tissues followed by patch repair of the diaphragmatic defect (Figure 5A,B). Postoperative chest CT showed a clear distinction between the surgically separated pulmonary and hepatic tissues on the venous phase due to their different degrees of enhancement, whereas their similar enhancement of the tissues in certain portions on the arterial phase resulted in the partial inseparability (Figure 5C-F). Additional vascular anomalies were identified on postoperative CT, including a small right pulmonary vein draining into the left atrium and pleuropulmonary collateral vessels supplying the right basal lung from the right inferior phrenic artery (Figure 5G).

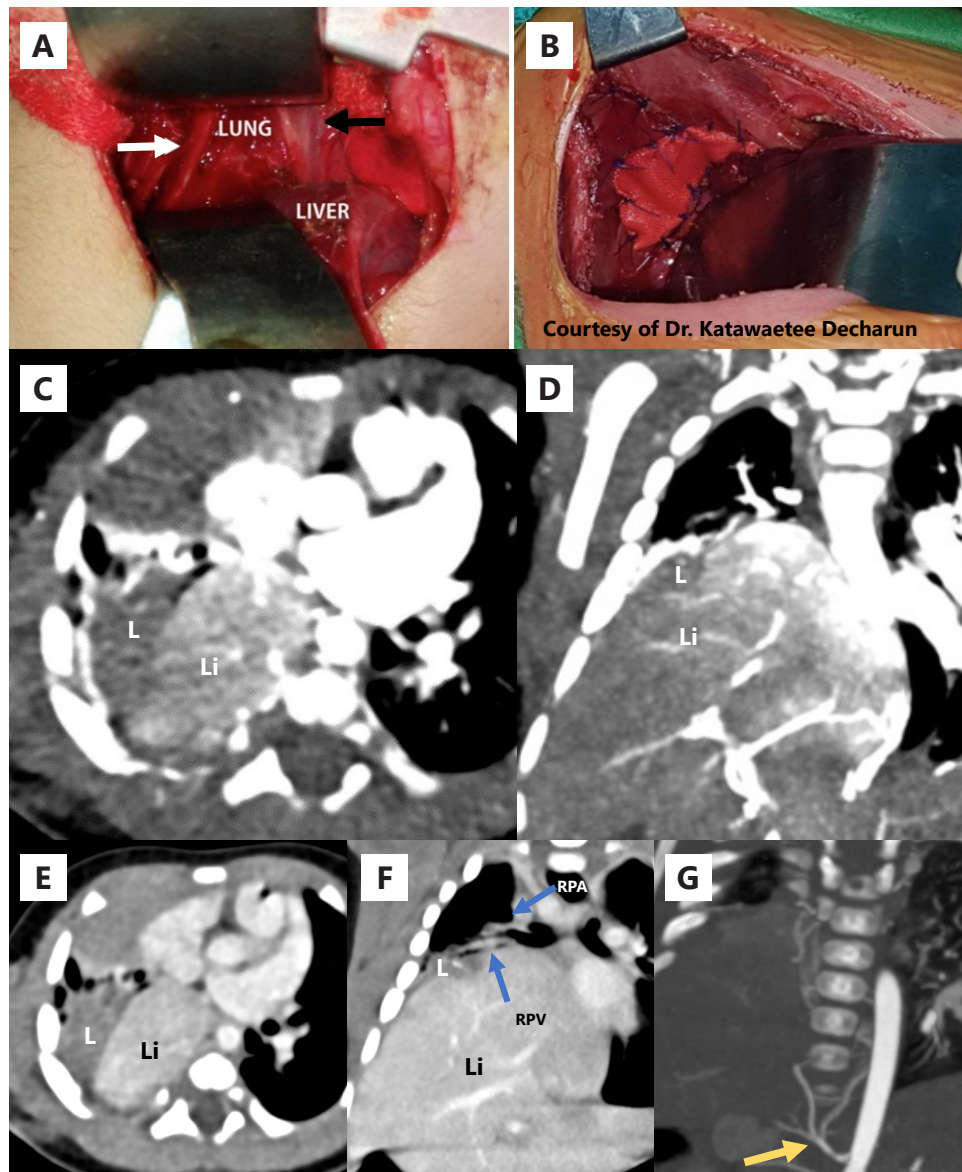


Figure 5. Intraoperative photographs (A,B) demonstrated a medially positioned arterial branch (white arrow) supplying the right lower lung, although its origin could not be identified. A draining vein (black arrow) was also observed. Patch repair of the diaphragmatic defect was performed following separation of the lung and liver tissues. Postoperative chest CT showed a partially indistinct interface between the surgically separated pulmonary and hepatic tissues on the arterial phase due to their similar enhancement (C,D). On the venous phase (E,F), the tissues were better delineated owing to the differential enhancement. Pleuropulmonary collateral vessels supplying the right basal lung from the right inferior phrenic artery were seen (G, yellow arrow). Li = liver; L = lung; RPA = right pulmonary artery; RPV = right pulmonary vein.

Postoperative chest radiographs continued to show elevation of the right hemidiaphragm, and subsequent ultrasonography confirmed right diaphragmatic paralysis (Figure 6). The patient has remained clinically stable, with only a single episode of pneumonia and reactive airway symptoms since surgery.

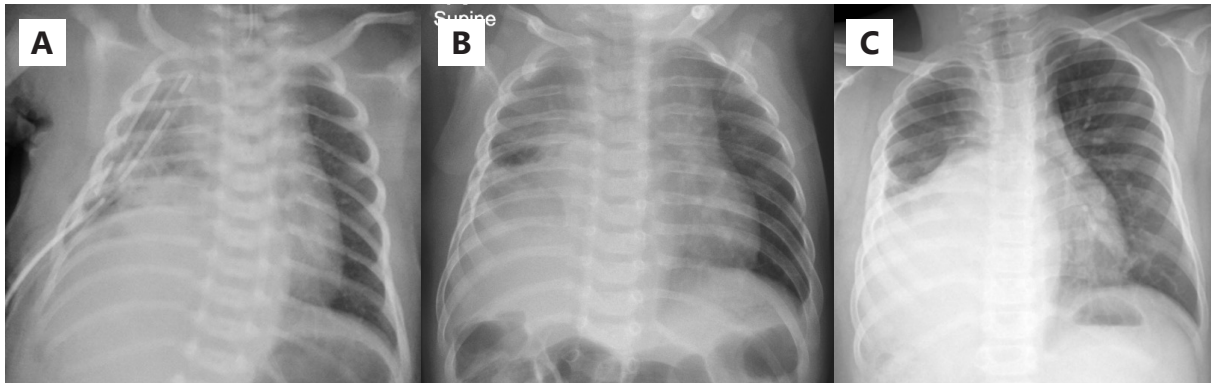


Figure 6. Chest radiograph obtained a few hours after surgery (A) showed an elevated right hemidiaphragm with right lung opacity and right pleural effusion following placement of an intercostal drainage catheter placement, consistent with postoperative changes. Follow-up radiographs at 3 months (B) and 6 years (C) demonstrated a persistently elevated right hemidiaphragm with a slight interval increase in the volume of the hypoplastic aerated right lung. Patchy opacities in the right lower lung zone likely represented atelectasis and possible pleural effusion. Right diaphragmatic paralysis was subsequently confirmed on ultrasound.

Case 3

A 4-month-old male infant with right-sided CDH and multiple congenital anomalies including global developmental delay, right hemifacial microsomia, right ear deformity, cleft lip, atrial septal defect, and anorectal malformation with rectourethral fistula status post colostomy, was referred to our institute for further surgical management.

Chest radiograph demonstrated right hemithoracic opacification with a non-contralateral mediastinal shift (Figure 7A). US showed herniation of the liver into the right thoracic cavity. An acute angulation between the intraabdominal and intrathoracic portions of the liver, the "waist sign", suggested a large diaphragmatic defect. No aerated right lung was identified, raising suspicion for right lung agenesis or marked hypoplasia with atelectasis (Figure 7B,C).

Chest CT at 6 months confirmed herniation of the right hepatic lobe into the right hemithorax, with only a small volume of atelectatic lung at the apex supplied by a hypoplastic right pulmonary artery (Figure 8).

Intraoperative findings revealed a posterior diaphragmatic defect involving nearly the entire right hemidiaphragm with herniation of the liver, which remained covered by a sac, into the right thoracic cavity. The herniated liver was successfully reduced into the abdominal cavity. The sac was opened, partially revised, and closed, followed by repair of the right diaphragmatic defect.

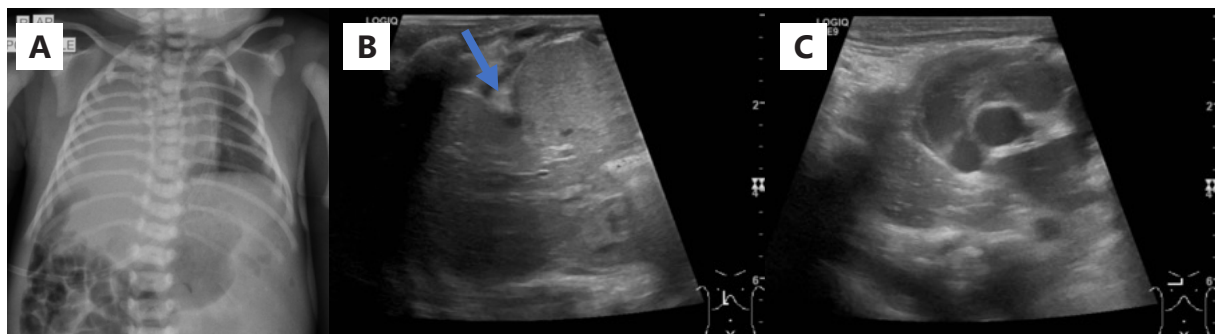


Figure 7. Chest radiograph showed right hemithoracic opacification with cardiac dextroposition (A). Ultrasound demonstrated liver herniation into the right thoracic cavity with acute angulation between the intraabdominal and intrathoracic portions of the liver or 'waist sign' (arrow), and no visible aerated right lung (B). The heart was located within the right hemithorax (C).

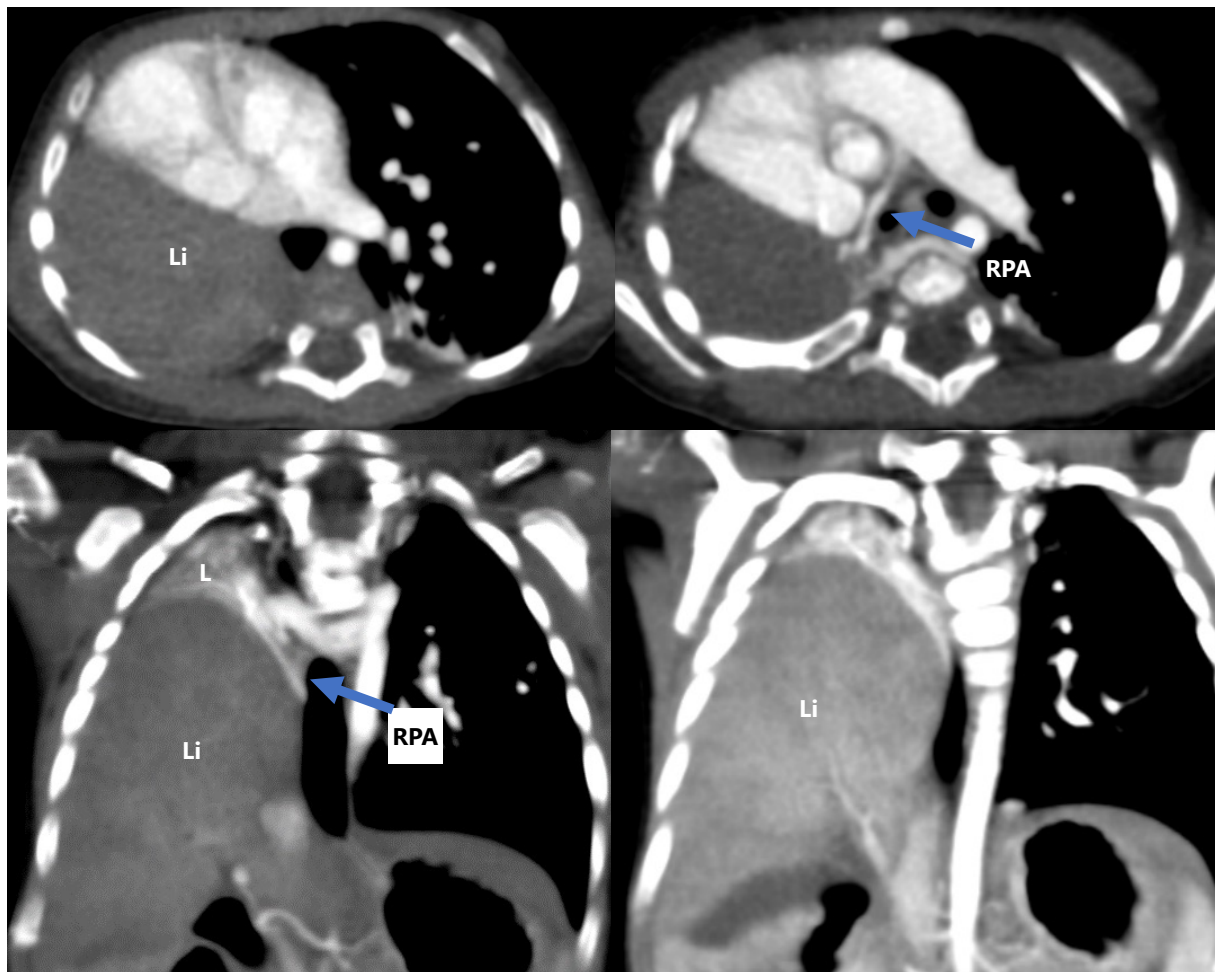


Figure 8. Chest CT at 6 months showed superior herniation of the right hepatic lobe (Li) into the right hemithorax, posterior to the heart. A small, compressed, atelectatic right lung remnant (L) was seen superiorly and was supplied by a hypoplastic right pulmonary artery (RPA).

A postoperative chest radiograph consistently showed persistent volume loss of the right hemithorax with compensatory hyperinflation of the left lung, consistent with a severe degree of right lung hypoplasia. The patient was discharged with home oxygen via nasal cannula. At the most recent follow-up, at age 7 months, he demonstrated adequate weight gain, clear sputum, and intermittent cyanosis. No further clinical information was available due to loss to follow-up.

Discussion

Imaging approaches for the rare presentation of right-sided CDH with liver herniation and non-contralateral mediastinal shift as well as the recognition of preoperative imaging features suggestive of HPF are challenging but can be valuable for operative planning and management, with important implications for patient outcomes.

Initial chest radiographs in our cases demonstrated typical features of right-sided CDH, including right hemithoracic opacification with tubular lucencies representing herniated bowel loops. These findings support chest radiography as an essential first-line modality for evaluating CDH and neonatal respiratory distress. Large or near-total opacification of the right hemithorax, often with an unusually elevated, curved right hemidiaphragm, raises suspicion for liver herniation and a relatively large diaphragmatic defect.

It has been recognized that right-sided CDH with liver herniation typically produces a contralateral mediastinal shift due to its mass effect. Non-contralateral mediastinal shift is therefore unusual and has prompted consideration of HPF [13], as in our cases. Although many reported HPF cases demonstrated non-contralateral mediastinal shift, following literatures indicated variability in this finding. A 2010 report described a case of right-sided CDH with HPF presenting with contralateral mediastinal shift, attributed to the size of the diaphragmatic defect and the degree of bowel herniation [14]. Concordantly, in our Case 1, the mild contralateral shift on day 1, when air-filled bowel loops were present, evolved to a non-contralateral shift on day 2 with persistent liver herniation and no visible bowel. In addition, a 2019 review found HPF cases to be evenly distributed between non-contralateral and contralateral mediastinal shift [9]. One of our cases was non-HPF at surgery, indicating that non-contralateral mediastinal shift in right-sided CDH with liver herniation is not specific for HPF and may reflect severe lung hypoplasia. Nonetheless, HPF should be considered in all cases of right-sided CDH [15] and should be strongly suspected when this atypical imaging pattern is present, highlighting the value of radiography in early recognition and in guiding further imaging.

US is a readily available adjunct for evaluating herniated organs and diaphragmatic integrity. In Case 3, the “waist sign,” confirmed right-sided CDH with liver herniation into the right hemithorax; however, no right lung was visualized, limiting assessment for HPF and suggesting severe hypoplasia or agenesis. In contrast, Case 1 showed the right hepatic lobe herniating into the thorax, abutting the aerated lung and heart, with an absent right hemidiaphragm and aerated lung tissue interposed between the

hepatic portions - findings compatible with previously reported US findings of HPF [16]. These observations emphasize the value of US in diagnosing right-sided CDH and suggesting HPF.

Given the variability of mediastinal shift in HPF, this feature alone has limited diagnostic value [9]. Additional clues, particularly anomalous hepatopulmonary vasculature, are essential for raising suspicion for HPF. While US may show hepatic veins and IVC drainage, assessment is often limited. Contrast-enhanced CT is better suited for comprehensive evaluation.

Previously reported CT findings of HPF include anomalous right pulmonary vasculature and close contact at the lung-liver interface. However, details regarding enhancement patterns and imaging phases remain sparse. As a result, no definitive CT criteria have been established for the reliable diagnosis of HPF [9, 17]. In our HPF cases, CT demonstrated an atelectatic lung closely conforming to and inseparable from the herniated liver, with similar enhancement, as most evident on the venous phase. After surgical separation, the hepatic and pulmonary tissues showed distinct venous-phase enhancement, whereas arterial-phase similarity rendered them partially indistinguishable. In contrast, the non-HPF case showed a well-defined interface between the liver and the atelectatic lung. These observations support the concept that HPF may be suggested by inseparable hepatic and pulmonary tissues with similar enhancement, particularly on venous-phase CT, although caution is warranted given the small sample size and the nonuniform imaging protocols.

Additional CT features of HPF included right lung hypoplasia with a small right pulmonary artery and non-visualization of the right hemidiaphragm. CT suggested anomalous venous drainage in Case 2 was confirmed intraoperatively. Although small vessels and the origin of the aberrant systemic arterial supply to the right lower lung were not fully characterized, CT provided crucial anatomic information. While intraoperative confirmation remains the most reliable diagnostic method [9], the imaging clues and proposed features identified in our study highlight the value of preoperative CT in suggesting HPF and guiding surgical planning.

MRI may provide additional value in suspected HPF by demonstrating the loss of the normal interface between hepatic and pulmonary tissues and by delineating anomalous venous drainage; however, its role remains limited by the small number of reported cases and the lack of established diagnostic criteria [8, 11, 16, 18].

Postoperative radiographs showed persistent right hemithoracic opacity and hemidiaphragmatic elevation, reflecting lung hypoplasia, atelectasis, diaphragmatic paralysis, or postoperative changes related to partial diaphragmatic repair with residual HPF tissue. These findings underscore the importance of clinicoradiologic correlation.

Limitations include the small number of cases inherent to this rare condition, the retrospective nature of the image review, inconsistent CT protocols, and the lack of assessment of the role of MRI. Further studies with larger cohorts, standardized imaging protocols, and the incorporation of MRI findings, would be valuable for validating these observations and establish reliable imaging clues for distinguishing HPF from non-HPF entities.

Conclusion

Right-sided CDH with liver herniation and non-contralateral mediastinal shift is uncommon and has been recognized as a typical scenario for HPF; however, our series demonstrates that this pattern is not specific and may reflect severe pulmonary hypoplasia. Radiography, ultrasound, and CT are valuable for diagnosis and evaluation, and HPF should be considered in all such cases regardless of mediastinal shift, with non-contralateral mediastinal shift warranting heightened suspicion. Ultrasound may provide supportive findings, while CT is particularly useful for assessing anatomical relationships and detecting anomalous hepatopulmonary vasculature, although no definitive preoperative CT criteria exist. Our findings suggest that a conforming or inseparable liver-lung interface on contrast-enhanced CT may be a potential clue to HPF, but this observation requires further validation. At present, intraoperative assessment remains the most reliable diagnostic method, and the integration of clinical context with imaging findings is essential for optimal management.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgement

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Classic Case

Congenital corrected transposition of the great arteries manifesting in adult: A classic case

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Abstract

Congenitally corrected transposition of the great arteries (CCTGA) is a rare congenital anomaly characterized by atrioventricular and ventriculoarterial discordance, in which the morphologic right ventricle supports systemic circulation, often leading to progressive dysfunction and heart failure in adulthood. We report the case of a 33-year-old man presenting with progressively worsening dyspnea. Chest radiography demonstrated cardiomegaly with dextrocardia and features of pulmonary interstitial edema. Multimodality imaging—including transthoracic echocardiography, coronary CT angiography, and cardiac MRI—was essential in confirming CCTGA and assessing secondary right ventricular failure. This case highlights the critical role of early recognition and comprehensive imaging in guiding management and optimizing outcomes in adult patients with this rare congenital condition.

Keywords: Congenitally Corrected Transposition of the Great Arteries (CCTGA), Dextrocardia, Heart Failure, Multimodality Cardiac Imaging, Systemic Right Ventricle.

Introduction

Transposition of the great arteries (TGA) is a congenital cardiac anomaly characterized by ventriculoarterial discordance, in which the aorta arises from the right ventricle (RV) and the pulmonary artery (PA) arises from the left ventricle (LV) [1].

TGA is classified into two types: complete or dextro-transposition (D-TGA) and congenitally corrected transposition (CCTGA) or levo-transposition (L-TGA). CCTGA is rare, accounting for less than 1% of all congenital heart defects [1]. It differs from D-TGA by the presence of both atrioventricular and ventriculoarterial discordance (Figure 1). Atrioventricular (AV) discordance refers to the connection of the right atrium to the left ventricle and the left atrium to the right ventricle. Despite physiologically normal circulation, the morphologic right ventricle sustains systemic output and is chronically exposed to systemic pressures, predisposing it to progressive dysfunction and eventual failure [1].

Here, we report a classic case of CCTGA diagnosed in adulthood, presenting with acute dyspnea and heart failure. Detailed evaluation included chest radiography, coronary CT angiography, and cardiac MRI.

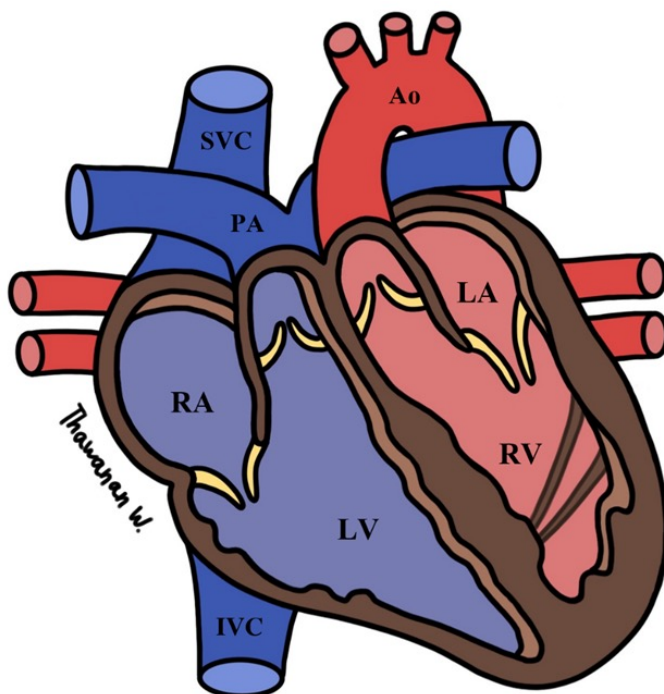


Figure 1. The illustration shows the anatomy of the heart and great arteries in congenitally corrected transposition of the great arteries (CCTGA). The pulmonary artery (PA) originates from the left ventricle (LV) and the aorta (Ao) originates from the right ventricle (RV). The right atrium (RA) connects to the LV and the left atrium (LA) connects to the RV. IVC = inferior vena cava.

Case summary

A 33-year-old man with no known underlying disease presented with progressive dyspnea and a change in functional class over the past month. Physical examination revealed fine crepitations in both lungs without cardiac murmurs. ECG showed sinus bradycardia with absent septal Q waves in the lateral leads, reversed R-wave progression, and widespread T-wave inversions (I, II, III, aVF, aVL, V2–6). Laboratory testing revealed markedly elevated NT-proBNP (9,267 pg/mL). Chest radiography demonstrated cardiomegaly with dextrocardia, bulging of the right cardiac border, prominent hila, and mild blunting of both costophrenic angles (Figure 2). Although these findings are nonspecific, the combination of dextrocardia and cardiomegaly in an adult with heart failure should raise suspicion for an underlying congenital cardiac anomaly and prompt further cardiac evaluation.

Transthoracic echocardiography demonstrated situs solitus with dextrocardia, atrio-ventricular (AV) and ventriculoarterial (VA) discordance, and a dilated systemic right ventricle (RV) with an ejection fraction of 30%, confirming acute heart failure secondary to CCTGA. The patient was admitted for intravenous diuretics and further imaging evaluation.

Coronary CT angiography and cardiac MRI confirmed dextrocardia with L-transposition of the great arteries (L-TGA). The aorta originated from the morphologic RV and the pulmonary artery from the morphologic LV (VA discordance). The right atrium drained into the morphologic LV and the left atrium into the morphologic RV (AV discordance). There was no left main coronary artery; the LAD and LCX arose separately from the right-facing aortic cusp, while the RCA originated from the left-facing cusp (Figure 3). Cardiac MRI further demonstrated severe RV dilatation with moderate systolic dysfunction and concentric RV hypertrophy, consistent with RV cardiomyopathy secondary to congenital heart disease (Figure 4). Following intravenous diuretics, the patient's symptoms improved, and he was discharged on oral diuretics. On follow-up, his clinical status improved, but cardiac function showed no recovery. He is currently on the waiting list for cardiac transplantation.

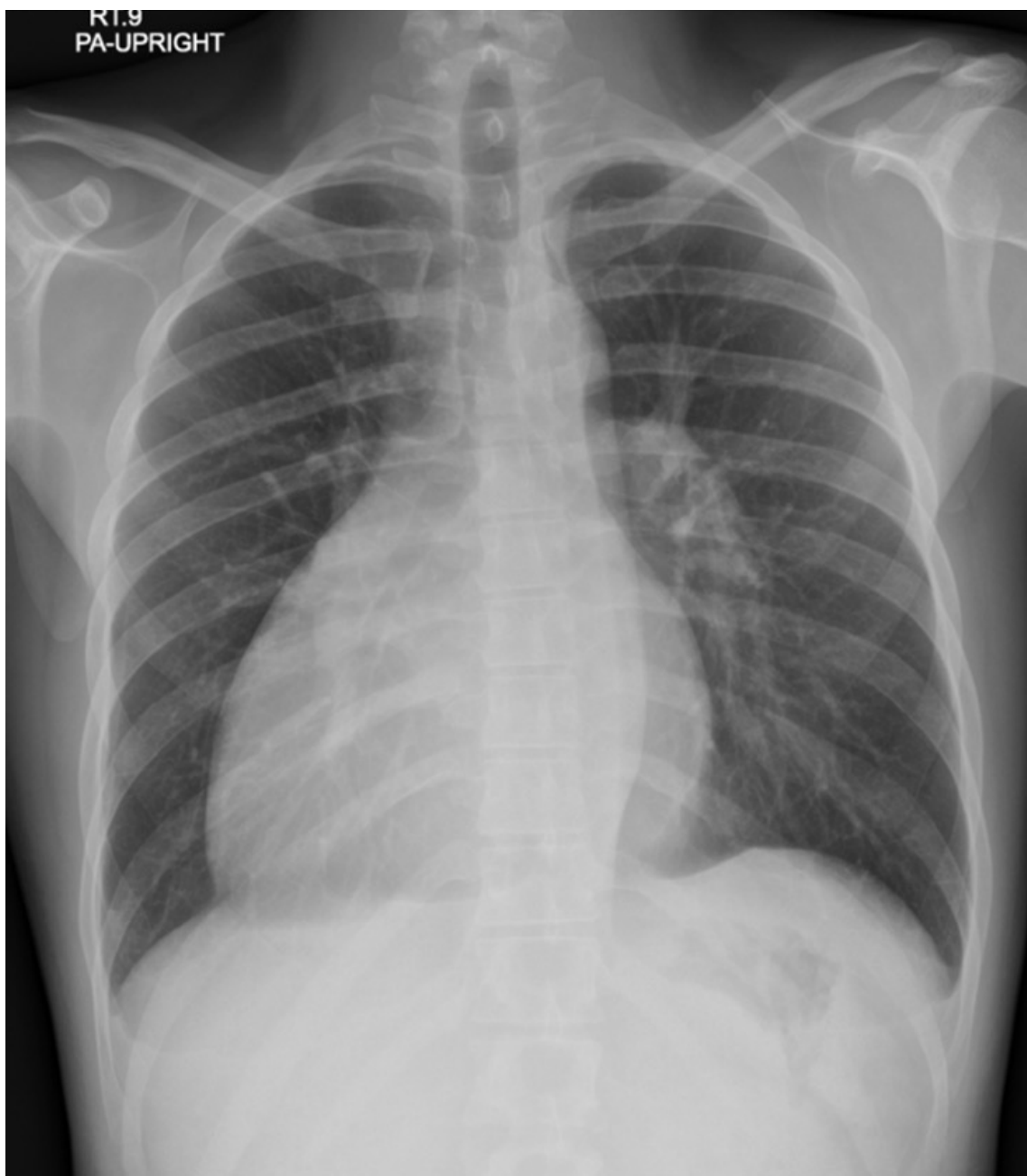


Figure 2. *PA upright chest radiograph demonstrates cardiomegaly with dextrocardia, bulging of the right cardiac border, prominent hila, and mild blunting of both costophrenic angles.*

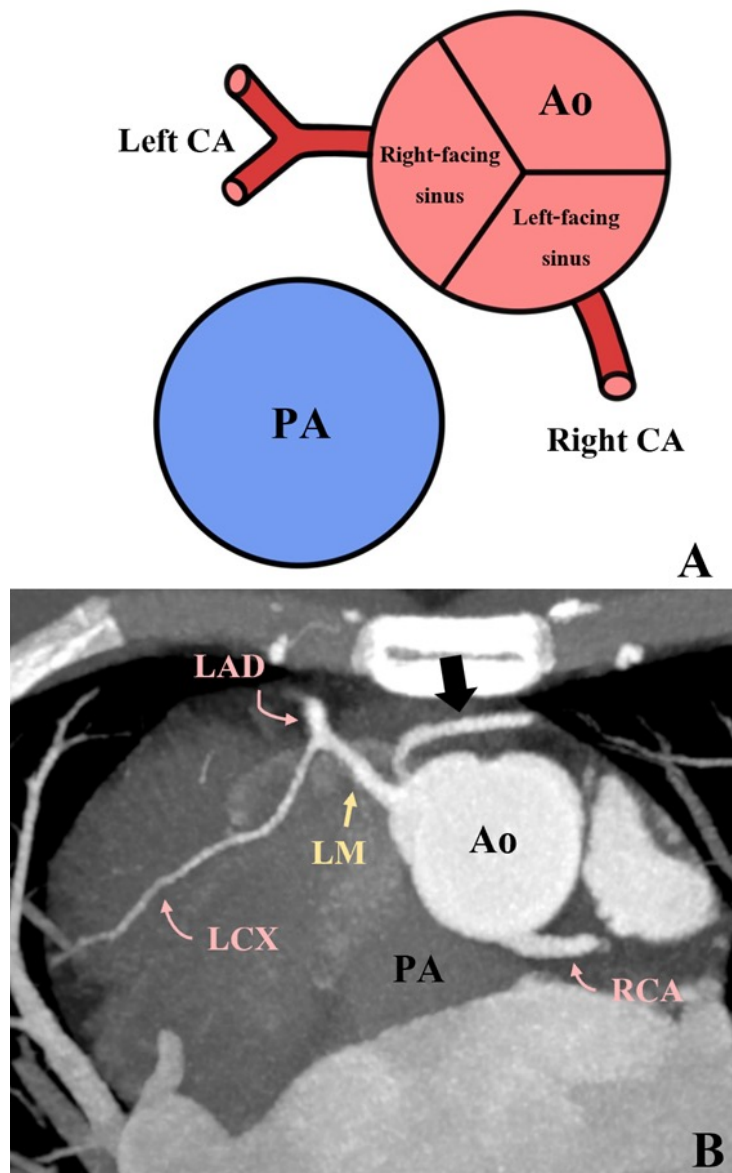


Figure 3. Coronary anatomy of the patient with CCTGA. (A) Illustration of the anatomy of the coronary arteries in CCTGA. CA = coronary artery. (B) MIP cardiac CT image at the level of the aortic sinus of Valsalva, the left anterior descending artery (LAD) and the left circumflex artery (LCX) originate from the left main coronary artery (LM) which arises from the right-facing sinus. The LAD courses anteriorly in the interventricular groove and the LCX courses in the right atrioventricular groove. The right coronary artery (RCA) originates from the left-facing sinus and travels along the left atrioventricular groove. In this patient, another coronary artery branch (black straight arrow) arises directly from the right-facing sinus and supplies the free wall of the right ventricle.

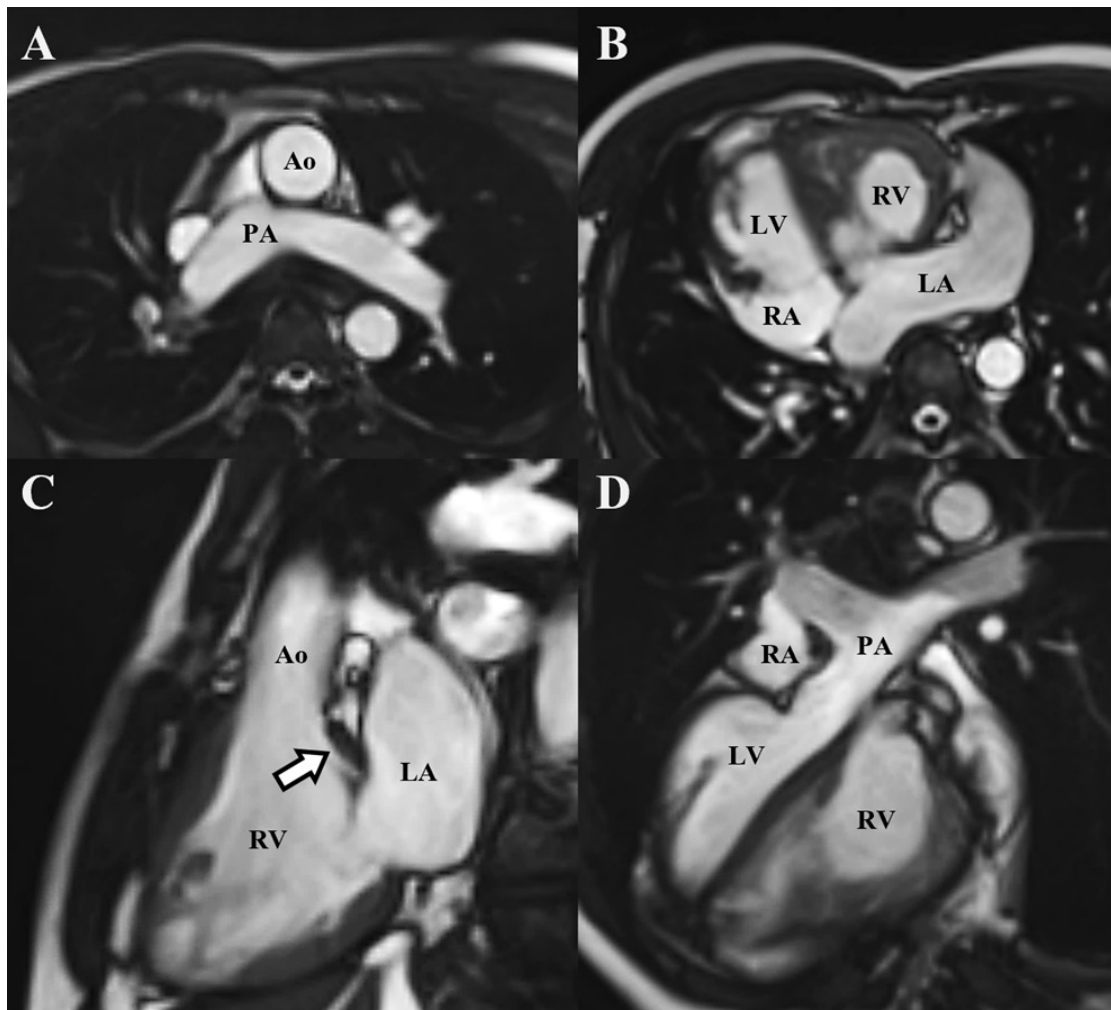


Figure 4. Cardiac MRI of the patient with CCTGA. (A) Axial SSFP MR image, anterior and leftward positioning of the aorta (Ao) relative to the main pulmonary artery (PA) is observed. (B) Axial SSFP MR image illustrates the right atrium (RA) connected to the left ventricle (LV) and the left atrium (LA) connected to the right ventricle (RV). The morphologic LA demonstrates finger-like appearance of the LA appendage. (C) Sagittal SSFP MR image illustrates a muscular band (arrow) between the atrio-ventricular and semilunar valves of the left-sided ventricle, representing the morphologic RV (D) SSFP MRI in the four-chamber view illustrates that the morphologic LV connects to the PA. Coarse inter-ventricular septum of the morphologic RV is also noted.

Discussion

Congenitally corrected transposition of the great arteries (CCTGA) was first described by the Australian pathologist Von Rokitsansky in 1875 [2]. The condition results from abnormal embryonic looping of the primary heart tube which undergoes a left-sided loop (L-loop) instead of the normal right-sided loop (D-loop). This abnormal looping produces atrioventricular discordance, in which each atrium connects to a morphologically mismatched ventricle. In addition, abnormal torsion of the aortopulmonary septum leads to ventriculoarterial discordance (transposition of the great vessels). As a result, the right atrium, mitral valve, and morphologic left ventricle receive deoxygenated systemic venous blood and connect to the posteriorly located pulmonary artery. Conversely, the left atrium, tricuspid valve, and morphologic right ventricle receive oxygenated pulmonary venous blood and connect to the aorta, which is positioned anterior and leftward to the pulmonary artery.

CCTGA can occur in either situs solitus or situs inversus, depending on the viscerotrial arrangement [3]. Cardiac position is usually levocardia or mesocardia, while dextrocardia is seen in approximately 20% of cases, including our patient. Coronary anatomy may also follow a mirror-image pattern [1]. In our patient, the left coronary artery arose from the right-facing sinus and coursed through the right atrioventricular groove posterior to the mitral valve. The right coronary artery originated from the left-facing sinus, ran between the left atrium and right ventricle, and supplied only the systemic right ventricle.

Most patients with CCTGA have associated congenital heart defects that influence their clinical presentation and long-term prognosis. Ventricular septal defect is present in up to 80% of cases, while other common anomalies include pulmonary stenosis, left ventricular outflow tract obstruction (LVOTO), Ebstein anomaly, situs inversus, and dextrocardia [4]. Isolated CCTGA, which accounts for only 1–2% of cases, is usually asymptomatic in childhood due to physiologically corrected circulation without mixing or shunting of blood [5].

Despite this apparent compensation, the morphologic right ventricle is not structurally suited to support the systemic circulation in the long run. Chronic exposure to high afterload and systemic pressures induces myocardial remodeling, initially causing right ventricular hypertrophy and progressing to dilatation. Pathological hypertrophy, combined with microcirculatory impairment, results in inadequate perfusion of the hypertrophied systemic right ventricle—particularly because it is supplied solely by the right coronary artery. Over time, this leads to progressive right ventricular dysfunction and

eventual heart failure. In adults with CCTGA, heart failure occurs in approximately 37% of cases, typically presenting with dyspnea, orthopnea, paroxysmal nocturnal dyspnea, peripheral edema, and jugular venous distension [2]. Elevated N-terminal pro-B-type natriuretic peptide (NT-proBNP) levels may aid diagnosis, as observed in our patient.

Imaging plays an important role in both diagnosis and management. The choice of modality depends on clinical context and resource availability. Transthoracic echocardiography is usually the first-line investigation, providing information on cardiac morphology, ventricular and valvular function, and hemodynamics. For more detailed evaluation, coronary CT angiography (CTA) and cardiac MRI play complementary roles in pre- and postoperative assessment, offering high-resolution visualization of cardiovascular anatomy, coronary artery origins, ventricular function, and myocardial morphology [6].

In our patient, coronary CTA and cardiac MRI confirmed both atrioventricular and ventriculoarterial discordance, establishing the diagnosis of CCTGA. Additional findings included severe right ventricular dilatation, moderately impaired systolic function, and severe concentric hypertrophy, consistent with right ventricular cardiomyopathy secondary to systemic pressure loading. Recognition of morphologic ventricular characteristics was crucial for diagnosis: the morphologic right ventricle was identified by the presence of a moderator band, coarse trabeculation, a muscular infundibulum between the atrioventricular and arterial valves, and papillary muscle attachment to both the septum and free wall [1]. In contrast, the morphologic left ventricle showed fine trabeculation, smooth septal contour, fibrous continuity between the atrioventricular and arterial valves, and absence of a moderator band. The aorta was located anterior and leftward of the pulmonary artery, arising from the morphologic right ventricle, confirming the classic anatomy of CCTGA.

Management strategies depend on associated lesions and clinical presentation. In symptomatic patients with heart failure due to right ventricular dysfunction, initial treatment follows the approach used for morphologic left ventricular failure, with medical therapy initiated when EF is less than 40% [2]. In our patient, diuretics were prescribed as first-line therapy. Surgical approaches include either conventional repair or anatomical correction. The conventional approach addresses associated defects without correcting the discordance, leaving the right ventricle as the systemic ventricle. Anatomical repair, by contrast, can be achieved using a double switch operation or a Senning–Rastelli procedure [1]. Ultimately, cardiac transplantation may be required, particularly in terminal heart failure, as in our patient.

Conclusion

Congenitally corrected transposition of the great arteries (CCTGA) is a rare congenital cardiac anomaly that may remain undetected until adulthood, when patients often present with systemic right ventricular failure. Multimodality imaging, including echocardiography, coronary CT angiography, and cardiac MRI, plays a crucial role in diagnosis, delineation of anatomic relationships, and assessment of ventricular function. Our case highlights the value of advanced imaging in confirming CCTGA in adults and in guiding clinical management, including the need for timely referral for transplantation in cases of progressive systemic RV dysfunction.

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Tribute

Three honours across three professional communities: Emeritus Professor Dr. Kwan Hoong Ng and the regional evolution of radiology and medical physics

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Three honours in a single year

Within a period of little more than three weeks in 2026, Emeritus Professor Kwan Hoong Ng received three major professional honours from three distinct communities.

At the 24th Asian Oceanian Congress of Radiology in Singapore, held from 20–23 August 2026, he was awarded the **Asian Oceanian Society of Radiology (AOSR) Gold Medal**. On 11 September, in Busan, Republic of Korea, he received the **Asia-Oceania Federation of Organizations for Medical Physics (AFOMP) Lifetime Achievement Award**. The following day, in Ipoh, Malaysia, the **Malaysian Medical Association (MMA) Gold Medal** added a third recognition.

The convergence is notable not simply because of the number of honours, but because they originate from different professional communities: radiology, medical physics, and the wider medical profession. Collectively, they provide an unusual perspective on a career that has developed across disciplinary and national boundaries, and alongside the transformation of medical imaging and medical physics in Asia-Oceania.

The AOSR Gold Medal is the Society's highest honour for an individual from the Asia-Oceania region who has rendered outstanding and exceptional service to the development, teaching, or practice of radiology. The AFOMP Lifetime Achievement Award recognises a distinguished career in medical physics and service to the profession and community. The MMA Gold Medal, in turn, has historically been described by the Association as its most meritorious award, recognising contributions that may encompass leadership, nation building, scientific achievement, and improvements in health and society.

Seen together, the three awards reflect an important feature of contemporary radiology: progress increasingly occurs not within a single profession, but at the interface between professions.

A medical physicist within the world of radiology

Professor Ng is a medical physicist by training and Emeritus Professor in the Department of Biomedical Imaging, Faculty of Medicine, Universiti Malaya, Kuala Lumpur, Malaysia. His academic interests have included medical imaging, breast imaging and breast density, radiation dosimetry and protection, computing and artificial intelligence, medical physics education and risk communication. Over four decades at Universiti Malaya, his work has extended from research and teaching to professional development and regional capacity building.

This breadth is important because medical physics is integral to modern radiology while frequently remaining less visible than its clinical components. Image quality, optimisation, radiation dose, equipment performance, safety standards, and the responsible introduction of emerging technologies all depend on the interaction of radiologists, radiographers, medical physicists, engineers, and other professionals.

Professor Ng's career has taken place within this interface. His contributions to the radiological community have included education, research, radiation protection, and the development of safety initiatives. He has also been involved in training generations of radiologists, clinical oncologists, and medical physicists.

The 2026 AOSR Gold Medal is therefore particularly significant. Its presentation to a medical physicist recognises that the advancement of radiology extends beyond image interpretation itself. The scientific and safety infrastructure around imaging is equally fundamental to its quality and effectiveness.

The AOSR Gold Medal: building a culture of safety



Professor Ng's most visible contribution within AOSR has been the development of **AsiaSafe**.

He formally proposed AsiaSafe to AOSR in 2017 and became its founding chair. The initiative was conceived to foster a culture of safety in medical imaging and radiation medicine across the Asia-Oceania region. He has subsequently represented AOSR in international organizations and initiatives involving radiation protection and safety, including the International Atomic Energy Agency and International Commission on Radiological Protection. He has also participated in AOSR efforts addressing magnetic resonance imaging safety and artificial intelligence in radiology.

These activities reflect a broader evolution within radiology. Safety is no longer confined to radiation dose or equipment quality assurance. Contemporary imaging requires attention to multiple interacting domains: radiation protection, magnetic resonance safety, contrast safety, data governance, artificial intelligence, workforce education, and risk communication.

AsiaSafe is therefore relevant not simply as an individual initiative, but as an example of regional cooperation in handling a common professional challenge. Countries in the Asia-Oceania region differ substantially in resources, healthcare structures, and access to technology, yet the principles of safe imaging must remain applicable across these environments.

For ASEAN radiology, this type of regional framework is particularly valuable. It allows experience, standards, and educational resources to be shared while recognising that implementation must be adapted to local circumstances.

AFOMP: from individual expertise to regional institutions



The AFOMP Lifetime Achievement Award highlights another dimension of Professor Ng's career: institution building.

His association with regional medical physics predates AFOMP itself. Professor Ng was a founding member and the founding president of the **Southeast Asian Federation of Organizations for Medical Physics (SEAFOMP)**. SEAFOMP was formally recognised as a regional chapter of the International Organization for Medical Physics in 2000, initially bringing together medical-physics organisations from Indonesia, Malaysia, the Philippines, Singapore, and Thailand. Brunei and Vietnam subsequently joined.

The aims were practical: to improve communication and cooperation between medical physicists, advance professional standards, strengthen education and training, and create opportunities for scientific exchange across Southeast Asia. These objectives were particularly important at a time when medical physics was developing unevenly across the region.

Professor Ng was also among those involved in the foundation of **AFOMP**, extending this model of cooperation across Asia and Oceania. As a co-founder of the Federation, he contributed to the development of a regional professional community that brought together medical physics organisations across a much larger and more diverse geographical area. AFOMP has since become an important platform for scientific exchange, professional development, education, and collaboration among medical physicists throughout the Asia-Oceania region. Professor Ng's long association with the organisation gives the 2026 Lifetime Achievement Award particular significance: it represents recognition from a professional community that he himself helped to build.

More recently, he established the **ASEAN College of Medical Physics (ACOMP)**, founded in 2014 as a regional platform for education and training in medical physics. ACOMP provides structured opportunities for medical physicists across Southeast Asia to strengthen their knowledge, develop professional skills, and learn from experts within and beyond the region. By bringing participants from different ASEAN countries together, it also creates professional networks that continue beyond individual courses. In this way, ACOMP complements organisations such as SEAFOMP and AFOMP by translating regional collaboration into practical education and capacity building for the next generation of medical physicists.

The AFOMP Lifetime Achievement Award therefore recognises more than a body of scientific work. In Professor Ng's case, it also reflects his contribution in building the professional structures through which medical physics has developed in Southeast Asia and the wider Asia-Oceania region.

MMA Gold Medal: contribution to the wider benefit of society



Where the AOSR and AFOMP awards originate from communities closely connected with Professor Ng's principal fields of work, recognition by the **Malaysian Medical Association (MMA)** places his contributions within a broader national and societal context.

The MMA Gold Medal is awarded to a member for outstanding contribution in areas that may include nation building, leadership, world-class medical or scientific research, innovation in addressing healthcare or social challenges, or achievements that have had a meaningful impact at a personal, national, or international level. Its criteria therefore extend beyond academic distinction alone, encompassing the translation of expertise into wider benefit for society.

This is particularly relevant to Professor Ng's career. Much of medical physics ultimately serves objectives that are clinical and societal rather than purely technological: improving diagnosis, ensuring the safe and appropriate use of radiation, supporting the introduction of new technologies, protecting patients and healthcare professionals, and strengthening the systems within which healthcare is delivered. His work in radiation protection, professional education, regional capacity building, and risk communication reflects this broader orientation.

The boundaries between scientific disciplines and clinical medicine have also become progressively less distinct. Artificial intelligence, quantitative imaging, advanced imaging systems, and precision radiation techniques increasingly require expertise extending beyond conventional professional silos. Medical physicists, radiologists, engineers, and clinicians may approach these technologies from different perspectives, but their effective integration is central to safe and effective patient care.

The MMA Gold Medal therefore adds an important dimension to the other two honours. It recognises Professor Ng's contributions not only within radiology and medical physics, but also in the wider context of leadership, healthcare development, and the application of science in ways that can influence professional practice and society.

An ASEAN contribution

The development of medical imaging in Southeast Asia has occurred against substantial differences in healthcare resources, workforce capacity, technological access, and professional structures. Yet many of the challenges facing the region—education, quality assurance, radiation safety, responsible adoption of new technologies, and workforce development—are shared.

Professor Ng's work with SEAFOMP, ACOMP, AFOMP, and AsiaSafe (AOSR) has consistently addressed these shared challenges through professional networks rather than through a single institution or country.

Regional professional organisations create mechanisms by which countries can learn from each other's experience while developing local capacity. They also provide younger professionals with access to mentors, scientific exchange, and professional communities that may not otherwise be available within their own institutions.

Professor Ng's career illustrates how regional progress in medical imaging and medical physics depends not only on technological advancement, but also on the development of professional capacity. Trained professionals, strong institutions, safety cultures, educational networks, and sustained opportunities for collaboration are all essential components of that progress. His work across multiple regional organisations has contributed to building this shared professional infrastructure across Southeast Asia and the wider Asia-Oceania region.

Scholarship, communication and the next generation

The three awards also sit within a longer record of recognition. Professor Ng was named by the International Organization for Medical Physics among 50 medical physicists who had made outstanding contributions to the field, received the IOMP Marie Skłodowska-Curie Award in 2018, and received Malaysia's Merdeka Award for Outstanding Scholastic Achievement in 2020.

His interests have nevertheless continued to evolve with the profession. Artificial intelligence, responsible innovation, radiation and magnetic resonance safety, risk communication, and professional education remain active areas of his resonance imaging safety work.

Communication has also extended beyond academic publishing. In addition to scientific writing, Professor Ng is a regular newspaper columnist and contributor, writing for a broader readership on science, artificial intelligence, ethics, education, and reflections on everyday life. Recent columns have appeared regularly in Malaysian publications including Malay Mail and Star. This aspect of his work is secondary to his scientific career but consistent with his longstanding interest in communicating complex ideas beyond specialist audiences.

Three honours and a wider perspective

Awards inevitably look backwards. They recognise work already undertaken and contributions already made. The concentration of three major honours in 2026, however, also provides an opportunity to consider the direction in which radiology and medical physics are moving.

The AOSR Gold Medal highlights the increasingly multidisciplinary nature of radiology. The AFOMP Lifetime Achievement Award highlights the importance of education, professional organization, and regional institution building. The MMA Gold Medal places these contributions within the wider context of medicine and society.

For ASEAN to be replaced by Asia-Oceania, the larger lesson is that the advancement of radiology depends on more than acquiring increasingly sophisticated technology. It also requires the less visible infrastructure around that technology: appropriately trained professionals, scientific rigour, standards, safety culture, mentorship, communication, and sustained cooperation across borders.

Professor Kwan Hoong Ng's career has intersected with each of these elements. The three honours conferred in 2026 recognise different aspects of that career. Taken together, the three honours recognise not only Professor Ng's scientific contributions, but also a broader legacy of institution building, professional development, mentoring, and regional collaboration that has helped shape medical physics and radiology across Asia-Oceania.

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President, Malaysian Society of Radiologists

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ASEAN Movement in Radiology

Magnetic resonance imaging capacity expansion in Vietnam: National import trends and implications for health system planning (2023–2025)

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Abstract

Background: Magnetic resonance imaging (MRI) is a core diagnostic modality supporting advanced clinical service. In Vietnam, increasing healthcare investment has driven expansion in MRI capacity, yet comprehensive multi-year analyses remain limited.

Objective: To analyze MRI system, import trends in Vietnam from 2023 to 2025, focusing on MRI capacity expansion, technology diffusion, regional distribution, and implications for health system planning.

Materials and Methods: National import data on MRI systems from 2023 to 2025 were reviewed and classified by year, magnetic field strength, manufacturer, region, and type of healthcare provider. Descriptive analyses were performed to evaluate temporal trends and market characteristics.

Results: A total of 257 MRI systems were imported during 2023–2025. The 1.5T MRI remained dominant, accounting for 67.3% of the imported systems, while 3.0T systems increased markedly from 6 units in 2023 to 22 units in 2025. In 2025, Northern Vietnam accounted for 71.6% of newly imported 1.5T and 3.0T systems. Private healthcare providers represented 50.0% of installations and showed a higher proportion of 3.0T adoption than public hospitals. Distribution of imported MRI systems by manufacturer was significantly uneven ($\chi^2 = 105.36$, $df = 5$, $p < 0.001$), with manufacturers GE and Siemens together accounting for 62.2% of imported MRI systems.

Conclusion: Vietnam's MRI diagnostic capacity continues to expand rapidly with a clear shift toward higher-field MRI technologies. This evolution underscores the need for strategic imaging investment and coordinated health system planning, in Vietnam and the wider ASEAN region.

Keywords: ASEAN, Diagnostic capacity, Field strength, Health policy, Health system planning, Magnetic Resonance Imaging, MRI imports, Technology diffusion, Vietnam.

Introduction

Magnetic resonance imaging (MRI) has revolutionized diagnostic medicine, establishing itself as an indispensable tool for non-invasive evaluation across oncology, neurology, and musculoskeletal disorders [1,2]. As global healthcare systems evolve, the demand for high-resolution imaging infrastructure has expanded exponentially, particularly in emerging market economies within the Asia Pacific region [3,4]. Driven by macroeconomic growth, expanding health insurance coverage, and a demographic shift toward an aging population, Vietnam represents one of the fastest-growing medical device markets in Southeast Asia [5,6]. Beyond its diagnostic value, MRI represents a major health technology investment that reflects the technological maturity of healthcare systems. The adoption and diffusion of advanced imaging technologies are increasingly used as indicators of healthcare modernization and system capacity development. Health technology assessment (HTA) frameworks emphasize that medical equipment deployment should be evaluated not only from technical and clinical perspectives but also from organizational, economic, and policy perspectives [7,8].

Historically, the procurement of advanced diagnostic equipment in middle-income countries has faced significant structural constraints, including high capital expenditure, infrastructure limitations, and a shortage of specialized biomedical personnel [2]. However, recent clinical shifts emphasize a transition from lower field strengths toward

high-field configurations, such as 1.5T and 3.0T systems, which offer superior signal-to-noise ratios, shorter scan times, and enhanced functional imaging capabilities [7]. Understanding MRI adoption patterns may provide evidence for national imaging capacity planning, health technology prioritization, and equitable allocation of diagnostic resources across regions. Health technology assessment literature recognizes diffusion patterns of medical devices as an important component of healthcare planning and policy development. Evaluating the distribution of MRI technology may therefore contribute to evidence-based decision-making for future healthcare investments [9]. Despite the strategic importance of this technology, public empirical research tracking multi-year biomedical import trends, distribution equity, and private versus public purchasing behaviors in Vietnam remains scarce. This study analyzes comprehensive national MRI import datasets from 2023 to 2025 to evaluate growth patterns, technological composition, geographic distribution, and market shares among primary manufacturers, establishing an empirical baseline for healthcare infrastructure planning. In addition, this study provides evidence to support health system planning, equitable allocation of diagnostic imaging resources, and future public health policy in Vietnam. By situating MRI market dynamics within broader health system needs, the findings contribute to strategic decision-making and long-term capacity building in diagnostic imaging services.

Materials and methods

Official national import statistics were analyzed descriptively. MRI systems were classified by year of import, magnetic field strength (<1.5T, 1.5T, and 3.0T), and manufacturer. Import data were obtained from the official Vietnam Customs database using MRI-related HS codes 90181300. Access to the dataset was granted through formal authorization, and the data were purchased from the Customs authority [10]. The dataset was subsequently cleaned and analyzed by the authors to ensure accuracy and consistency.

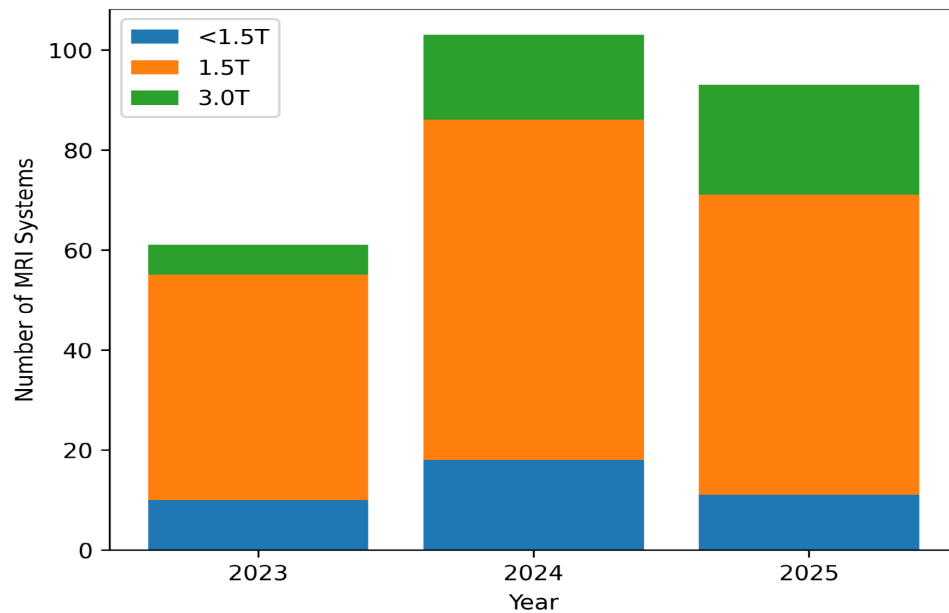
Descriptive analysis was performed to examine trends and the market structure of imported MRI systems. Statistical analyses were conducted using R software (version 4.3.2; R Foundation for Statistical Computing, Vienna, Austria). MRI system categories—defined by magnetic field strength (<1.5T, 1.5T, and 3.0T) and manufacturer—were treated as categorical variables and summarized as frequencies and percentages by year. Differences in the distribution of MRI system categories across years (2023–2025) and manufacturers were assessed using the chi-square test of independence.

Results

A total of 257 MRI systems were included in the analysis, with annual imports increasing from 61 systems in 2023 to 103 systems in 2024, followed by a slight decline to 93 systems in 2025.

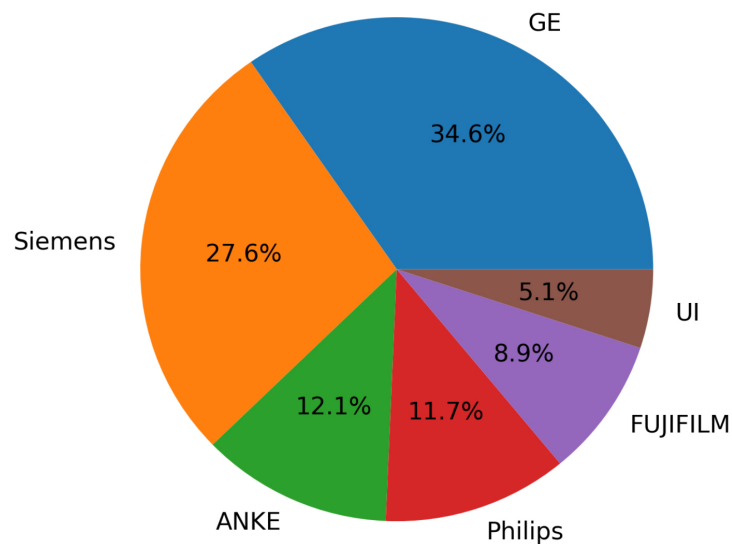
- Field-strength distribution: Across all years, 1.5T systems constituted the majority (173/257; 67.3%). The proportion of 3.0T systems increased progressively over time, reflecting a gradual technological shift toward higher-performance imaging platforms.
- Manufacturer market share: GE (89/257; 34.6%) and Siemens (71/257; 27.6%) together accounted for more than half of total imports (62.2%). Other contributors included ANKE, Philips, FUJIFILM, and United Imaging, each representing smaller but notable segments of the market.
- Regional and ownership distribution in 2025
Out of the 93 MRI systems imported in 2025, customs data confirmed the installation of 88 systems within the year. It is likely that five systems were imported toward the end of 2025 but only installed in early 2026, and therefore their locations were not included in the statistics.
Among the 88 installed systems, Northern Vietnam accounted for 63 units (71.6%), while Southern Vietnam accounted for 25 units (28.4%). Private health-care providers installed 44 systems (50.0%), with a higher proportion of 3.0T units (31.8%) compared to public hospitals (22.7%).

Comparative analysis using the chi-square test showed no statistically significant difference in the overall distribution of field-strength categories across the three years ($\chi^2 = 7.42$, $df = 4$, $p = 0.115$). Despite the lack of statistical significance, descriptive trends were evident. Specifically, the number of 1.5T systems peaked in 2024 before declining in 2025, while 3.0T systems demonstrated a steady increase across the study period. This pattern suggests a gradual transition toward higher-field MRI technology, consistent with global trends in advanced diagnostic imaging. In terms of manufacturer dynamics, GE and Siemens maintained dominant positions throughout, while emerging contributions from other vendors highlight a diversifying market landscape.



Year	<1.5T	1.5T	3.0T	Total
2023	10	45	6	61
2024	12	79	12	103
2025	8	49	22	93
Total	30	173	40	257

Figure 1. MRI imports in Vietnam by field strength (2023–2025). Stacked bar chart illustrating annual distribution of < 1.5T, 1.5T, and 3.0T systems. A progressive increase in 3.0T systems is observed over time.



Manufacturer	Share (%)	Number of Systems
GE	34.60%	89
Siemens	27.60%	71
ANKE	12.10%	31
Philips	11.70%	30
FUJIFILM	8.90%	23
United Imaging (UI)	5.10%	13
Total	100%	257

Figure 1. *Distribution of imported MRI systems by manufacturer (2023–2025 total). GE and Siemens together account for the majority of MRI imports, with additional contributions from ANKE, Philips, FUJIFILM, and United Imaging.*

The distribution of imported MRI systems differed significantly among manufacturers ($\chi^2 = 105.36$, $df = 5$, $p < 0.001$). GE accounted for the largest share of imported systems (34.6%), followed by Siemens (27.6%). Together, these two manufacturers represented 62.2% of all imported MRI systems, indicating a highly concentrated manufacturer market structure.

Discussion

The expansion of MRI infrastructure should be interpreted not only as technological growth but also as an indicator of strengthening diagnostic capacity within the Vietnamese health system. The Vietnamese MRI market demonstrates both quantitative expansion and qualitative technological transition. From a health technology assessment perspective, the observed increase in MRI installations reflects not only market growth but also accelerated adoption of advanced diagnostic technologies within the healthcare system. Technology diffusion is commonly influenced by clinical demand, investment capacity, organizational readiness, and expected healthcare benefits [9]. The increasing adoption of higher-field MRI systems may indicate growing demand for advanced diagnostic capability and greater investment in imaging infrastructure across Vietnam [7].

The data reveals a distinct divergence in procurement behavior between public and private healthcare facilities. The higher adoption rate of 3.0T MRI systems in the private sector may indicate greater flexibility in capital investment and faster uptake of emerging technologies. Similar patterns have been reported in health technology adoption studies, where private healthcare providers often serve as early adopters of advanced medical equipment due to fewer budgetary constraints and stronger competitive incentives [11,12]. This trend may contribute to technological innovation but could also widen disparities in access to advanced imaging services between healthcare sectors [9,12].

Policy Implications for Health Technology Planning

The empirical findings of this study yield several critical implications for strategic health technology planning, macro-level resource allocation, and healthcare policy formulation in Vietnam.

First, the profound surge in national MRI imports observed between 2023 and 2025 signifies an accelerating clinical demand for advanced diagnostic imaging modalities. This quantitative expansion aligns with the systemic modernization of Vietnam's healthcare infrastructure, the widespread institutionalization of imaging-guided clinical pathways, and rising consumer expectations for high-precision diagnostics. This rapid influx underscores the urgent need for evidence-based Health Technology Assessment (HTA) frameworks to systematically evaluate the clinical efficacy, cost-effectiveness, and long-term societal value of these capital-intensive investments [7,8].

Second, the stark geographical asymmetry in MRI procurement indicates latent regional disparities regarding patient access to high-tier diagnostic infrastructure. The disproportionate concentration of newly imported systems within Northern Vietnam in 2025, relative to the Southern and Central regions, poses a structural challenge to the

principle of healthcare equity. While this disparity is partially driven by localized macroeconomic variables and concentrated public-private hospital developments, it highlights the necessity for centralized regulatory oversight. Future provincial and national healthcare planning must utilize geographical information system (GIS) mapping of existing imaging density, regional disease burdens, and referral networks to establish a more balanced and equitable distribution of high-cost medical equipment [8].

Third, the rising trajectory of 3.0T MRI adoptions reflects a qualitative technological transition toward ultra-high-field imaging platforms. From a clinical governance perspective, while 3.0T configurations offer superior signal-to-noise ratios and advanced functional capabilities in neuroradiology, oncology, and cardiovascular imaging, they also demand substantial ancillary support systems. The diffusion of ultra-high-field MRI necessitates synchronized national investments in advanced pedagogical training for radiologists and biomedical engineers, rigorous quality assurance (QA) protocols, standardized safety guidelines (e.g., specific absorption rate [SAR] monitoring), and sustainable long-term lifecycle maintenance planning [7].

Fourth, the pronounced leadership of the private healthcare sector in absorbing 3.0T technologies demonstrates that private providers act as primary drivers and early adopters of disruptive medical innovations in Vietnam. Facilitated by flexible capital procurement models and strong market-driven competitive incentives, the private sector rapidly bridges the technological gap [11]. However, this asymmetric diffusion risks widening the quality-of-care gap between public and private tiers. Policymakers should devise strategic regulatory or public-private partnership (PPP) mechanisms to leverage private-sector imaging capacity, ensuring that low-income demographics can also benefit from advanced non-invasive diagnostics [12].

Finally, the sustained market concentration among a limited cohort of global medical device manufacturers (specifically GE HealthCare and Siemens Healthineers) presents both structural advantages and regulatory risks. While manufacturer concentration ensures high technological standardization, established maintenance ecosystems, and reliable technical support, it potentially limits long-term cost-optimization. Regulatory bodies and hospital procurement committees should maintain a transparent, highly competitive bidding environment to stimulate technological diversity, enhance cost-effectiveness, and maximize return on investment. Ultimately, this longitudinal analysis establishes that a *laissez-faire* approach to medical device procurement may exacerbate regional and cross-sectoral imbalances. Integrating systematic data-driven monitoring of health technology diffusion into national healthcare planning is paramount to achieving optimized resource allocation, safeguarding equity, and sustaining the modernization of diagnostic services across Vietnam [9,12].

Table 1. *Key findings, health technology implications, and policy recommendations for MRI capacity expansion in Vietnam (2023-2025).*

Core Empirical Finding	Strategic Health Technology Implication	Recommended Policy/Planning Intervention
Profound surge in national MRI imports (2023–2025)	Escalating clinical reliance on advanced diagnostics; rising infrastructure expenditure.	Institutionalize mandatory HTA guidelines for large-scale hospital capital equipment procurement.
Accelerated shift toward ultra-high-field 3.0T systems	Qualitative technological upgrading; expansion of high-precision subspecialty imaging.	Develop specialized workforce training programs and national MRI quality assurance protocols.
Private sector dominance in high-field (3.0T) adoption	Asymmetric innovation diffusion; private providers acting as early technological adopters.	Formulate strategic Public-Private Partnerships (PPPs) to enhance universal access to high-tier diagnostics.
Marked geographic clustering in Northern Vietnam (2025)	Severe regional polarization and potential inequities in diagnostic resource access.	Implement needs-based regional quota systems and capacity mapping for future import licensing.
Duopolistic market control by major global manufacturers	High technological standardization but restricted pricing competition.	Foster a transparent, competitive procurement environment to optimize capital expenditures.
Rapid nationwide expansion of total MRI infrastructure	Increased operational risks, lifecycle costs, and burden on technical personnel.	Mandate long-term total cost of ownership (TCO) evaluation and standardized safety frameworks.

MRI Capacity in Regional Context

MRI availability is commonly assessed using the number of MRI units per million population, an internationally recognized indicator of diagnostic imaging capacity. OECD data demonstrate substantial variation in MRI density across countries, ranging from more than 50 units per million population in Japan and over 30 units per million population in South Korea to considerably lower levels in many middle-income healthcare systems [13].

Although comprehensive national MRI inventory data are not currently available in Vietnam, the marked increase in MRI imports observed during 2023–2025 suggests ongoing expansion of national imaging capacity. Nevertheless, the concentration of newly installed systems in selected regions indicates that equitable access to advanced diagnostic imaging may remain an important challenge.

From a health technology assessment perspective, monitoring MRI density and geographic distribution is essential for optimizing healthcare resource allocation, reducing regional disparities, and supporting evidence-based planning of future imaging infrastructure. The findings of the present study provide an important foundation for future national assessments of MRI capacity and technology diffusion in Vietnam [8,13].

Future studies should estimate MRI units per million population and compare Vietnam with other ASEAN countries to support evidence-based health planning. Such comparative analyses would establish regional benchmarks, highlight disparities in diagnostic imaging capacity, and guide strategic investment priorities for Vietnam's healthcare system.

Limitations

This study has several limitations. First, the analysis relied exclusively on official import data from the Vietnam Customs database. While these records accurately capture the entry of MRI equipment into the market, they do not reflect real-world clinical utilization, patient throughput, or regional workforce capacity. Second, the dataset may not account for secondary market transactions, refurbished systems, or informal procurement channels. Classification was limited to field strength and manufacturer, with no information on coil configurations, software versions, or advanced imaging capabilities. Third, the study focused only on imports between 2023 and 2025, offering a short-term perspective on market dynamics; longer observation periods are needed to assess sustained trends. Finally, although descriptive and chi-square analyses provide useful insights into distribution patterns, more advanced econometric or longitudinal approaches would strengthen understanding of the causal drivers of MRI adoption in Vietnam and across ASEAN.

Conclusion

Vietnam's diagnostic imaging capacity (2023–2025) reflects rapid infrastructure expansion, marked by a strong shift toward 3.0T systems, significant private sector investment, and geographic concentration in the North. These dynamics highlight both opportunities and challenges for equitable access, sustainable financing, and workforce readiness. The trajectory toward higher field technologies underscores the need for strategic imaging investment, coordinated health system planning, and regional collaboration across ASEAN to ensure balanced distribution and long term healthcare equity.

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