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Radiology

TECHNICAL DEVELOPMENT • VASCULAR AND INTERVENTIONAL RADIOLOGY

[AQ1] # Intravenous MR Lymphangiography: Feasibility in a Swine Model and Proof-of-concept in Patients

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Background: Visualization of the hepatic and mesenteric lymphatics remains challenging despite recent advances in lymphatic imaging, including dynamic contrast-enhanced MR lymphangiography (DCMRL).

Purpose: To assess the feasibility of intravenous contrast-enhanced MR lymphangiography (IV-MRL) in a swine model and a pilot patient group.

Materials and Methods: Systemic and portal venous and lymph samples were collected from two swine after intravenous administration of gadolinium (Gd)-based contrast agents (Gd tetraazacyclododecane tetraacetic acid and Gd ethoxybenzyl diethylenetriamine pentaacetic acid; $n = 1$ each), and Gd quantification was performed. IV-MRL and DCMRL were performed in a separate animal, and the signal intensity (SI) of the lymphatic and vascular structures was measured. In a pilot human study, conducted between September 2024 and August 2025, lymphatic enhancement was assessed by comparing the SI ratios of the thoracic duct (TD) to the inferior vena cava at 1 and 20 minutes after the contrast agent administration. Within-subject differences between time points were analyzed using paired *t* tests.

Results: The body fluid sampling study showed that the Gd concentration in the lymph peaked at 20–30 minutes and exceeded those of the portal and systemic veins, indicating the presence of the "lymphatic phase." IV-MRL revealed enhancement of not only the TD and cisterna chyli but also the hepatic and mesenteric lymphatics during the phase. The human pilot study ($n = 16$; mean age of 56.6 years ± 24.7 [SD]; 11 men) showed a [AQ4] significant increase in TD/inferior vena cava SI ratio from 0.49 ± 0.21 at 1 minute to 1.47 ± 0.32 at 20 minutes (all values are means ± SDs; $P < .001$).

Conclusion: IV-MRL had potential as a noninvasive technique for comprehensive visualization of the lymphatics, including hepatic and mesenteric ones, which are often incompletely assessed by conventional lymphatic studies such as DCMRL.

Supplemental material is available for this article.

AQ4. We mean clinically significant. Please change "significantly" to "substantially" where appropriate.

Lymphatic imaging has advanced significantly since the introduction of pedal lymphangiography in the 1950s (1). The subsequent emergence of intranodal lymphangiography in the 2010s greatly improved accessibility to the lymphatic system (2). More recently, dynamic contrast-enhanced MR lymphangiography (DCMRL) has enabled three-dimensional imaging through the rapid propagation and high signal-to-noise ratio of MR contrast agents (3).

Despite these recent advances, current techniques remain limited in certain clinical settings. With inguinal intranodal injection, contrast agents predominantly enhance the retroperitoneal lymphatics, whereas the hepatic and mesenteric lymphatics—responsible for more than 70% of lymph production—are poorly visualized (4). This limitation has important clinical implications; for instance, in chylous ascites, failure to detect mesenteric lymphatic injury can significantly compromise treatment outcomes. [AQ6] Intranodal lymphangiography can identify leaks in only 55% of cases, with treatment success ranging from 76% in individuals with visible leaks to 21% in those without visible leaks (5), reflecting that the mesenteric lymphatics lie outside the inguinal-to-thoracic duct (TD) pathway (6). Moreover, intranodal injection for DCMRL is technically demanding and requires precise needle placement by an experienced interventional radiologist. Logistical hurdles, such as accessing lymph nodes under fluoroscopic or US guidance and transferring patients to the MR suite, may further limit its broader adoption.

To overcome these challenges, we propose intravenous contrast-enhanced MR lymphangiography (IV-MRL). The purpose of this study was to evaluate the feasibility of this technique in a swine model and a pilot patient group.

Materials and Methods

Three swine (27–39 kg; Orient Bio) were included in the animal study, which was approved by the Institutional Animal Care and Use Committee (see Appendix S1 for details). The subsequent pilot human study was exempt from institutional review board approval, as the data were fully anonymized and collected retrospectively. Patients were informed that IV-MRL was conducted as part of a preliminary study.

Fluid Sampling Experiment in Swine

Two animals were assigned to a body fluid sampling study and received gadolinium tetraazacyclododecane tetraacetic acid (Gd-DOTA; Dotarem, Guerbet) or gadolinium ethoxybenzyl diethylenetriamine pentaacetic acid (Gd-EOB-DTPA; Primovist, Bayer) ($n = 1$ each). Under general anesthesia, catheters were placed in the femoral vein, the portal vein, and TD for systemic venous, portal venous, and lymph sampling, respectively. The TD cannulation

Abbreviations

DCMRL = dynamic contrast-enhanced MR lymphangiography, Gd = gadolinium, Gd-DOTA = gadolinium tetraazacyclododecane tetraacetic acid, Gd-EOB-DTPA = gadolinium ethoxybenzyl diethylenetriamine pentaacetic acid, IV-MRL = intravenous contrast-enhanced MR lymphangiography, SI = signal intensity, TD = thoracic duct

Summary

[AQ5] Intravenous MR lymphangiography allowed for the noninvasive visualization of the lymphatic system, including the hepatic and mesenteric lymphatics.

Key Results

- Intravenous contrast-enhanced MR lymphangiography (IV-MRL) was a promising, noninvasive technique that enabled visualization of the retroperitoneal lymphatic system (cisterna chyli and thoracic duct).
- IV-MRL allowed visualization of the hepatic and mesenteric lymphatics, which were generally difficult to assess with intranodal lymphangiography or lymphoscintigraphy.
- Compared with ~~dynamic contrast-enhanced MR lymphangiography,~~ IV-MRL provided practical and logistical benefits, as intravenous administration occurred through a peripheral vein, avoiding the need for specialized personnel or complex procedural coordination.

method was described in Appendix S1. After TD cannulation, its distal part was occluded with microcoils to enable sampling of the lymph fluid with natural drainage. In separate animals, 7.5 mL of Gd-DOTA (0.10 mmol/kg) or 5 mL of Gd-EOB-DTPA (0.032 mmol/kg) was administered intravenously, which corresponded to 69% and 128% of the recommended doses (0.15 mmol/kg for Gd-DOTA and 0.025 mmol/kg for Gd-EOB-DTPA), respectively. Systemic and portal venous and lymph samples were collected at 5 minutes and every 10 minutes for 2 hours. Their gadolinium (Gd) concentrations were quantified by inductively coupled plasma-mass spectrometry (NexION 300; PerkinElmer) after nitric acid and hydrogen peroxide treatment and dilution to 50 mL with 1% HNO_3.

Evaluation of IV-MRL in Swine

A separate animal underwent IV-MRL; after intramuscular sedation, 15 mL of Gd-DOTA and another with 10 mL of Gd-EOB-DTPA were used, corresponding to effective doses of 0.21 and 0.093 mmol/kg (143% and 370% of the recommended dose, respectively). MRI was performed on a 3.0-T MR scanner (3T TRIO-TIM, Siemens Medical) using precontrast T2-weighted turbo spin echo and T1-weighted turbo field-echo sequences, followed by the serial acquisition of postcontrast T1-weighted fat-suppressed images at 1 minute and every 5 minutes for 40 minutes after contrast material injection. MR signal intensity (SI) was measured at four anatomic landmarks: TD, cisternal chyli, hepatic lymph nodes, and infrarenal abdominal aorta (S.H.). The SI ratio was calculated by dividing SI at each anatomic landmark by that of the psoas muscle for standardization (7). For comparison, DCMRL and intraoperative mesenteric lymphangiography were conducted in the same animal (see Appendix S1 for procedure details) (3,6). Images were compared across modalities by side-by-side review, with anatomic levels matched using major aortic branches as reference landmarks. [AQ7]

AQ7. S.H. had more than 15 years of experience.
--> MR signal intensity (SI) was measured at four anatomic landmarks: TD, cisterna chyli, hepatic lymph nodes, and infrarenal abdominal aorta by S.H., who had more than 15 years of experience.

Pilot Human IV-MRL

Consecutive patients who underwent IV-MRL between September 2024 and August 2025 were retrospectively included (Fig 1). Clinical indication for IV-MRL was clinical suspicion of lymphatic leakage. Exclusion criteria included the surgical resection of the central lymphatic system, complete nonvisualization of the central lymphatic vessels due to severe lymphatic leakage, or poor image quality due to various factors. T1 turbo field-echo images were acquired before and at 1 minute after intravenous administration of Gd-DOTA (0.2 mmol/kg, corresponding to a double dose of the standard 0.1 mmol/kg) and subsequently at 5-minute intervals for 40 minutes (Table S1). The SI of TD and inferior vena cava was measured on 1- and 20-minute images, and their ratios (TD/inferior vena cava) were compared between the two time points.

Statistical Analysis

Normality was assessed using the Shapiro-Wilk test. Differences between time points were analyzed using a paired *t* test for within-subject comparisons. A two-sided *P* value of less than .05 was considered statistically significant. Given the exploratory nature of this pilot study, formal power or sample size calculations were not performed. Statistical analysis was conducted using SPSS software (version 30; IBM Corporation) by an author (L.M.K.).

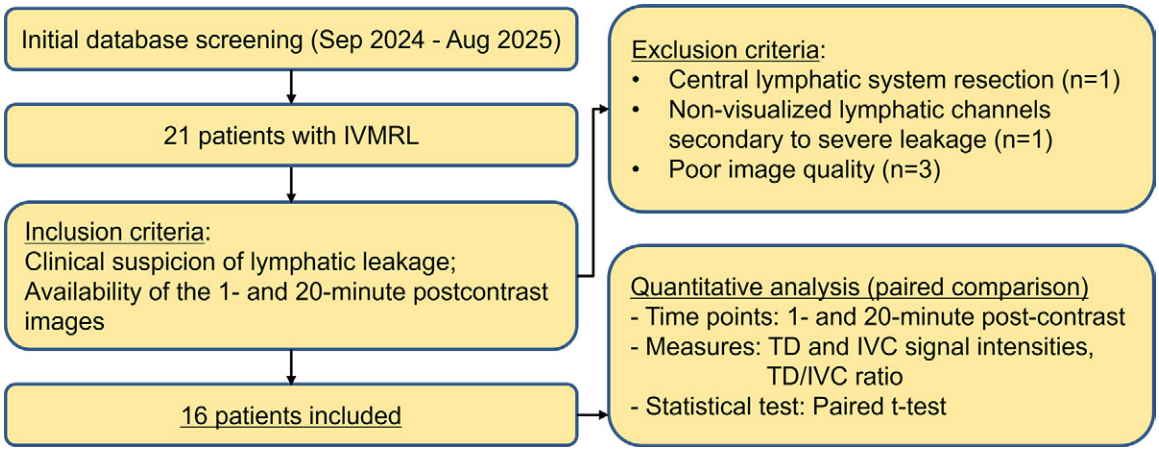

Figure 1: Study flowchart shows details of patient recruitment, including inclusion and exclusion criteria, and summarizes the quantitative analyses performed. IV-MRL = intravenous contrast-enhanced MR lymphangiography, IVC = inferior vena cava, TD = thoracic duct.

Results

Fluid Sampling Experiment in Swine

For both Gd agents, the concentration in TD exhibited a delayed peak. The concentration of Gd-DOTA reached a maximum of 70,803 ppb at 30 minutes, whereas that of Gd-EOB-DTPA peaked at 33,002 ppb at 20 minutes. Notably, the Gd concentrations in TD were greater than those in the femoral and main portal veins after 20–30 minutes, indicating the presence of a distinct and sustained "lymphatic phase." In comparison, the Gd concentrations in the femoral and main portal veins peaked earlier, both before 5 minutes. The femoral vein concentrations reached 401,175 ppb for Gd-DOTA and 60,724 ppb for Gd-EOB-DTPA, and the main portal vein concentrations peaked at 93,247 ppb for Gd-DOTA and 46,376 ppb for Gd-EOB-DTPA; in both veins, the Gd levels declined rapidly thereafter due to renal excretion. These findings suggest that intravenous administration of both contrast agents is preferentially distributed in the lymphatic system, supporting their potential utility in IV-MRL (Fig 2).

Evaluation of IV-MRL in Swine

The administration of both Gd-DOTA and Gd-EOB-DTPA produced characteristic enhancement profiles in lymphatic and vascular structures (Fig 3). For the cisterna chyli, both agents resulted in a rapid increase in the SI ratio, which reached approximately 5.5 by 10–15 minutes after injection. This was followed by sustained enhancement within an SI range of 4.0–5.5 for 40 minutes thereafter, indicating prolonged contrast agent retention. TD also showed progressive enhancement, reaching an

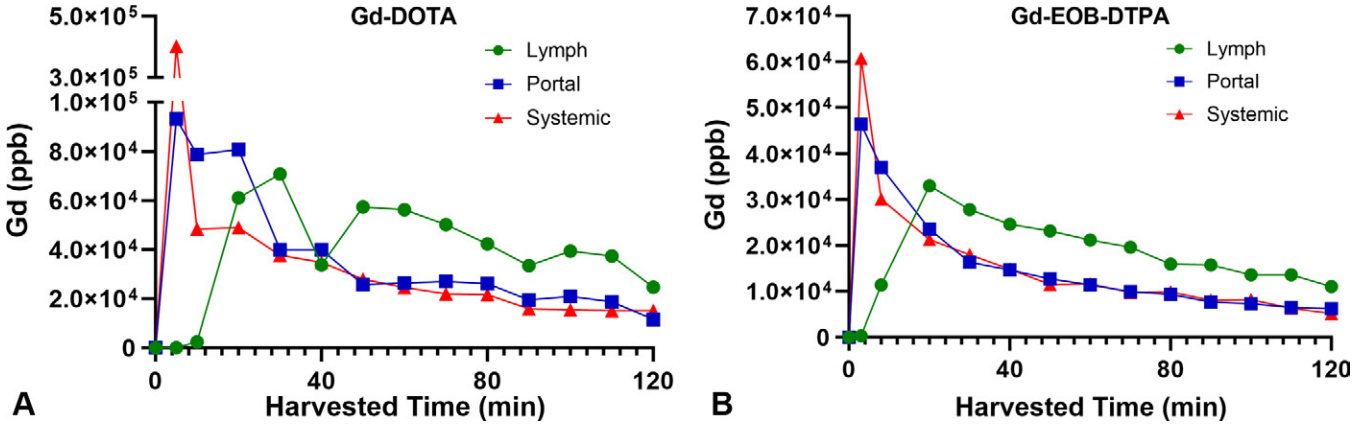

Figure 2: Line graph shows changes in the gadolinium (Gd) concentration within the systemic circulation, portal vein, and lymphatic compartment over 120 minutes after intravenous contrast agent administration. **(A)** Following Gd tetraazacyclododecane tetraacetic acid (Gd-DOTA) administration, systemic Gd concentration peaked at 5 minutes at 401,175 ppb and then declined rapidly. Portal venous Gd concentration also peaked at 5 minutes, reaching 93,247 ppb, and then decreased gradually. In contrast, the concentration of lymphatic Gd showed a delayed peak at 30 minutes, reaching 70,803 ppb, followed by a steady decrease. **(B)** Following Gd ethoxybenzyl diethylenetriamine pentaacetic acid (Gd-EOB-DTPA) administration, systemic and portal venous Gd concentrations peaked at 5 minutes, with values of 60,724 ppb and 46,376 ppb, respectively, and declined thereafter. The lymphatic Gd concentration peaked at 20 minutes, reaching 33,002 ppb, and subsequently decreased. On the x-axis, the zero and two coordinates represent the time of before intravenous injection and the time of immediate after injection measurements, respectively.

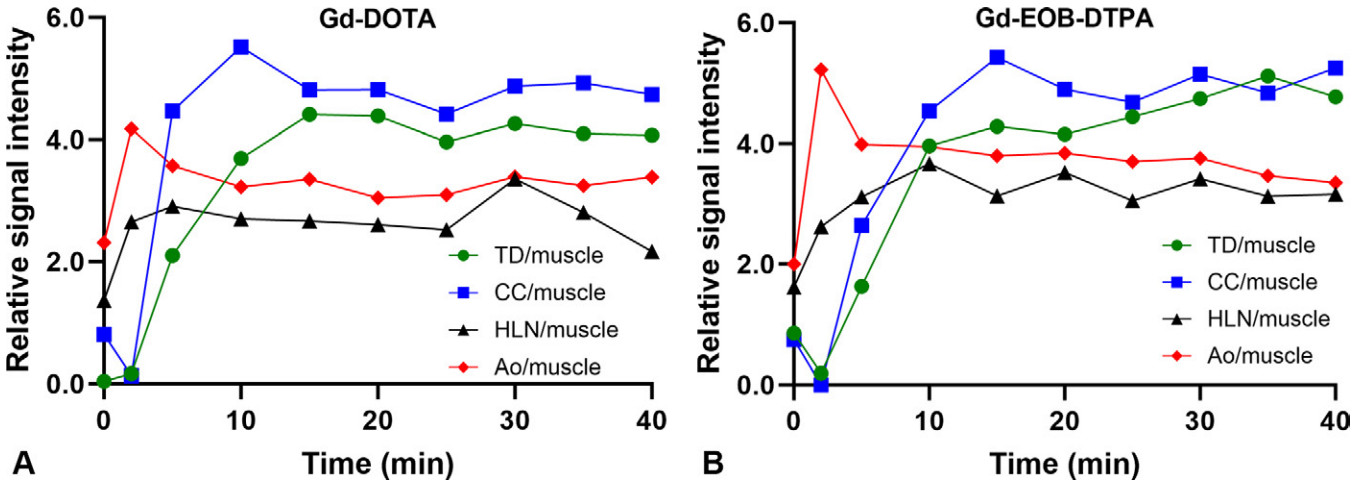

Figure 3: Line graph shows changes in MR signal intensity over time in the thoracic duct (TD), hepatic lymph node (HLN), aorta (Ao), and cisterna chyli (CC). All signal intensities are expressed as ratios relative to the muscle signal intensity on the same axial image. **(A)** Following gadolinium tetraazacyclododecane tetraacetic acid (Gd-DOTA) administration, the signal intensity ratio of the CC markedly increased between 2 and 15 minutes, peaking at 5.5, and remained elevated throughout the observation period. The TD also increased significantly, reaching 4.4 at 10 minutes. HLNs showed sustained enhancement at 5 and 30 minutes, with a peak of 3.4. The Ao peaked at 2 minutes with a ratio of 4.2 and then decreased and stabilized. **(B)** With gadolinium ethoxybenzyl diethylenetriamine pentaacetic acid (Gd-EOB-DTPA), the CC ratio similarly increased to 5.4 between 2 and 15 minutes and remained high. The TD ratio rapidly increased to 4.2 by 10 minutes, followed by a slower increase. The HLN ratio also increased between 5 and 30 minutes, peaking at 3.6. The Ao ratio showed an early peak at 2 minutes, with a ratio of 5.2, and then gradually decreased.

SI of 4.4 with Gd-DOTA at 15 minutes and slightly declining, whereas with Gd-EOB-DTPA, the SI continued to increase, peaking at 5.1 by 35 minutes. The hepatic lymph node SI ratio initially increased until 5 minutes, followed by steady enhancement from 5 to 30 minutes, reaching an SI of 3.3 with Gd-DOTA at 30 minutes and of 3.6 with Gd-EOB-DTPA at 10 minutes. The abdominal aorta SI ratio peaked rapidly at 2 minutes, reaching 4.2 with Gd-DOTA and 5.2 with Gd-EOB-DTPA, and decreased thereafter, which is consistent with rapid vascular washout. These findings suggest that IV-MRL allows visualization of prolonged lymphatic enhancement, supporting the previously suggested concept of a lymphatic phase and its feasibility for effective visualization.

Comparison of IV-MRL and DCMRL images revealed that both modalities successfully visualized TD and retroperitoneal lymphatics. IV-MRL, however, also depicted hepatic and mesenteric lymphatic structures and the anterior part of the cisterna chyli, which were not clearly visible at DCMRL (Fig 4). Intraoperative mesenteric lymphangiography revealed contrast agent accumulation in the same mesenteric lymphatic regions seen at IV-MRL, supporting the ability of the latter to depict these structures noninvasively (Fig S1).

Pilot Human IV-MRL

A total of 16 patients underwent IV-MRL and were included in the analysis (Table 1) (11 men and five women; mean age, 56.6 years ± 24.7; range, 10–91 years) (Figs 5 and S2). The mean TD/inferior vena cava ratios at 1 and 20 minutes were 0.49 ± 0.21 and 1.47 ± 0.32, respectively, and the data were normally distributed (Shapiro-Wilk $P = .493$ and .923, respectively). The paired *t* test revealed a significant difference in the ratios between the two time points ($P < .001$), indicating a relative increase in the SI of TD compared with that of the inferior vena cava at 20 minutes (Table 2). No adverse events were observed following IV-MRL.

Discussion

Our study introduces intravenous contrast-enhanced MR lymphangiography (IV-MRL) as a noninvasive method for visualizing the lymphatic system through the intravenous administration of gadolinium (Gd)-based contrast agents. During the lymphatic phase—when the Gd concentration in the lymph exceeds that in the blood—IV-MRL selectively highlights the lymphatic vessels. A pilot human study showed selective enhancement of the thoracic duct at 20 minutes with statistical significance ($P < .001$).

Current lymphatic imaging techniques, including intranodal lymphangiography and DCMRL, require nodal access, and thus, they primarily opacify retroperitoneal lymphatics and often fail to visualize hepatic and mesenteric structures (7). To address these limitations, more invasive techniques, such as retrograde mesenteric lymphangiography using balloon occlusion (balloon-occluded retrograde abdominal lymphangiography) or direct liver

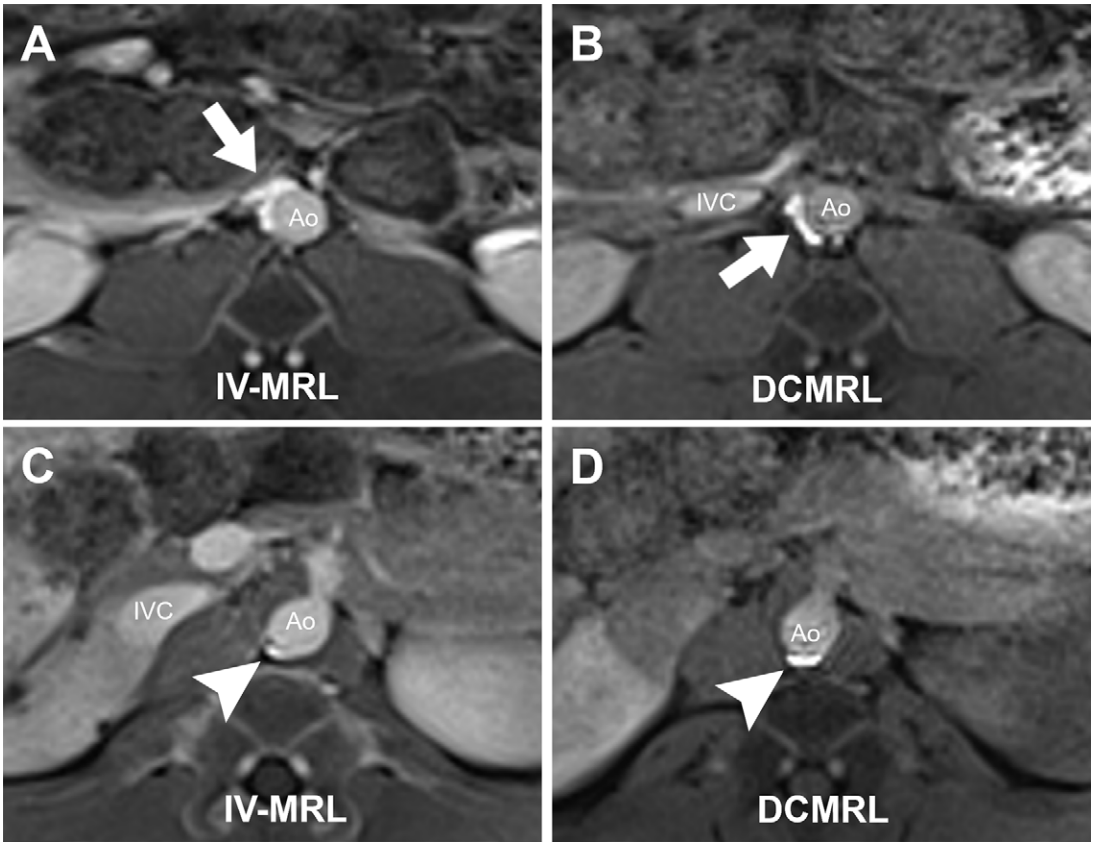

Figure 4: Representative swine intravenous contrast-enhanced MR lymphangiography (IV-MRL) images of the thoracic duct and cisterna chyli and comparisons with dynamic contrast-enhanced MR lymphangiography (DCMRL) images. On the **(A)** IV-MRL image, a τ-shaped enhancing structure (arrow) corresponding to the cisterna chyli is observed in the retroperitoneal space to the right of the aorta (Ao), whereas on the **(B)** DCMRL image, only the dorsal portion of the structure remains visible (arrow). **(C)** IV-MRL demonstrates a tubular enhancing structure, identified as the thoracic duct (arrowhead) behind the aorta, which appears more prominent on the **(D)** DCMRL image. IVC = inferior vena cava.

Table 1: Patient Demographic and Clinical Characteristics

Variable	Patients (n = 16)
Age (y)*	62.5 (10–91) [40.3–71.8]
Sex	
Female	5 (31.3)
Male	11 (68.7)
Underlying state	
Oncologic surgery	7[†]
Aortic surgery	3
Lymphatic malformation	3
Others	3[‡]
Symptoms	
Chylous ascites	9
Chylothorax	4[§]
Others	5[‖]
Duration (d)*	18.5 (3–7300) [8–93.75]
Amount of daily drainage (mL)[#]	916.5 ± 613.0 (15–2500)

[AQ9]

Note.—Except where indicated, data are numbers of patients, with percentages in parentheses.

* Data are medians, with ranges in parentheses and IQRs in brackets.

[†] Malignancy includes pancreatic cancer (n = 4), prostatic cancer (n = 1), thyroid cancer (n = 1), and lung cancer (n = 1)

[‡] This category includes cholecystitis (n = 1), thoracic outlet syndrome (n = 1), and renal vein thrombosis due to antithrombin-3 deficiency (n = 1).

[§] Two of the four patients developed both chylothorax and chylous ascites.

[‖] This category includes chylolymphatic cyst (n = 1), pelvic lymphocele (n = 1), skin lymphorrhea (n = 1), perirenal lymphorrhea (n = 1), and chyluria (n = 1).

AQ9. Please change "skin lymphorrhea" to "cutaneous lymphorrhea" for consistency.

[#] Data are means ± SDs, with ranges in parentheses. Leakage volume was not quantifiable in three patients (chylolymphatic cyst, cutaneous lymphorrhea, and chyluria), and therefore, these cases were excluded from the analysis.

or mesenteric lymphangiography, have been introduced (6,8–10). However, these methods remain technically challenging and invasive, limiting their feasibility for routine diagnostic application. In contrast, the intravenous approach of IV-MRL overcomes these limitations and provides a practical, noninvasive alternative for lymphatic imaging. Noncontrast T2-weighted MR lymphangiography can depict lymphatic channels as high-SI structures, providing basic anatomic information without contrast agent injection (11). However, this technique mainly reveals morphologic details and cannot be used to assess lymphatic flow or leakage dynamics over time. Moreover, lymphatic structures may be obscured by adjacent fluids such as pleural effusion or ascites. IV-MRL may provide complementary information by enabling temporal assessments of lymphatic enhancement.

A previous study by Verma et al (12) demonstrated enhancement of the cisterna chyli 3–5 minutes after intravenous administration of a Gd-based contrast agent. However, at this early phase, the relatively high vascular SI may reduce the contrast between lymphatic and vascular structures. In the present study, lymphatic enhancement peaked after 20 minutes, a time at which the vascular SI had diminished, potentially improving the delineation of lymphatic structures. These findings are built upon prior work and suggest intravenous administration as a feasible approach for lymphatic imaging.

IV-MRL can comprehensively visualize the lymphatic system, including the hepatic and mesenteric regions and therefore offers significant diagnostic potential for conditions such as chylous ascites and protein-losing enteropathy. Moreover, IV-MRL may help detect lymphatic abnormalities not seen on conventional methods, such as DCMRL, demonstrating potential for guiding targeted interventions such as hepatic and mesenteric lymphatic embolization. Its noninvasive nature results in a simple procedure and relatively wide accessibility: unlike conventional intranodal techniques, IV-MRL does not require lymph node access

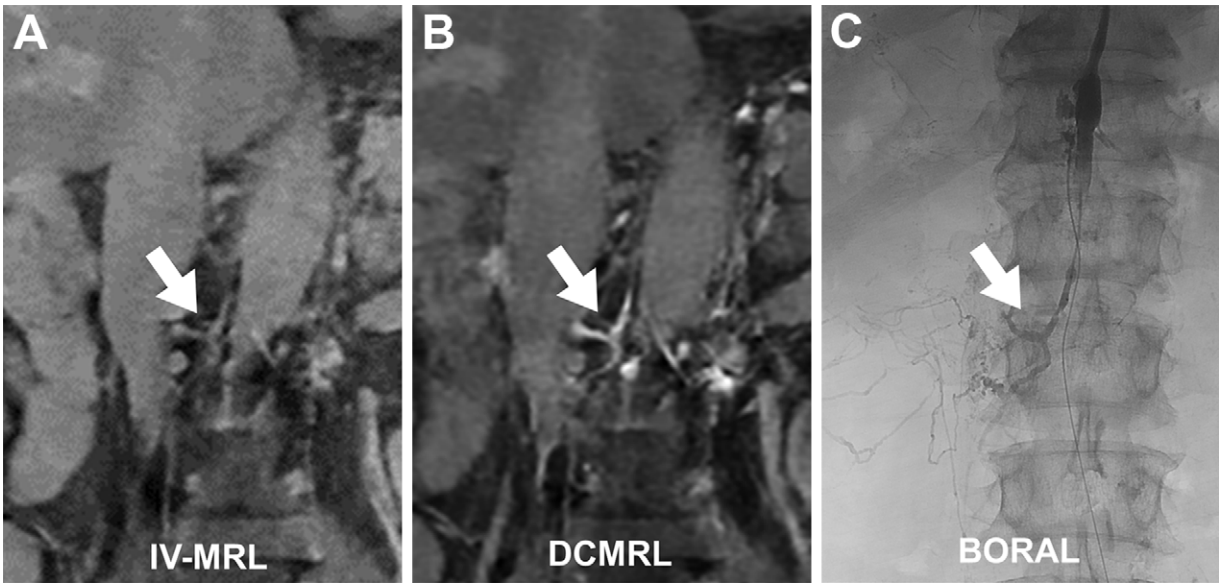

Figure 5: Intravenous contrast-enhanced MR lymphangiography (IV-MRL), dynamic contrast-enhanced MR lymphangiography (DCMRL), and balloon-occluded retrograde abdominal lymphangiography (BORAL) in a 65-year-old male with nontraumatic chyluria. On a coronal IV-MRL image acquired at **(A)** 25 minutes, an inverted Y-shaped linear structure (arrow) in the mesenteric area is enhanced; this structure appears more prominently on **(B)** DCMRL imaging, and the same configuration of mesenteric lymphatics is demonstrated on **(C)** BORAL imaging.

Table 2: Comparison of TD and IVC Signal Intensities and TD/IVC Ratios between 1 and 20 Minutes after Contrast Agent Administration

[AQ10]

Location~~/Time~~	1 Min	20 Min	*P* Value
TD	621.25 ± 269.43 (265–1144)	1461.44 ± 407.27 (680–2046)	<.001
IVC	1371.88 ± 495.92 (436–2407)	1048.63 ± 386.50 (383–1927)	<.001
TD/IVC ratio	0.49 ± 0.21 (0.21–0.95)	1.47 ± 0.32 (0.74–1.97)	<.001

Note.— Data are means ± SDs, with ranges in parentheses. The Shapiro-Wilk test confirmed the normality of the distribution for all variables (1-minute thoracic duct [TD], $P = .130$; 1-minute inferior vena cava [IVC], $P = .781$; 1-minute ratio, $P = .493$; 20-minute TD, $P = .553$; 20-minute IVC, $P = .448$; 20-minute ratio, $P = .923$); therefore, paired t tests were used for the 1-minute versus 20-minute comparisons. All comparisons were statistically significant (two-sided $P < .001$).

by an experienced interventional radiologist, and instead, contrast agents can be administered by a nurse through a peripheral vein, streamlining workflows and eliminating the need for patient transfer between procedural suites and imaging rooms.

Our study has several limitations. First, higher-than-recommended doses of contrast agent were used to maximize the enhancement of lymphatic structures, given the lack of prior information on the optimal dose for IV-MRL. In the human study, a double contrast agent dose was used (13). Second, only Gd-EOB-DTPA and Gd-DOTA were studied among various other MR contrast agents. Between the two, Gd-DOTA was selected for the human study because the hepatocyte uptake and biliary excretion of Gd-EOB-DTPA obscure periportal hepatic lymphatic structures. Further research to find out the ideal characteristics of a lymphatic contrast agent in IV-MRL is warranted. Third, the small, complex, and intertwined nature of hepatic and mesenteric lymphatics makes assessing continuity on single-plane images difficult, and IV-MRL currently lacks sufficient three-dimensional visualization. Advanced postprocessing tools, including automated segmentation, may improve anatomic interpretations. Finally, TD embolization was performed in the lymph sampling to allow passive external drainage, although this might have changed the pharmacokinetics of the contrast agent.

In conclusion, intravenous contrast-enhanced MR lymphangiography is a promising noninvasive technique for visualizing systemic lymphatics, including hepatic and mesenteric pathways, and may aid in localizing lymphatic leakage and guiding subsequent interventions; larger prospective studies are warranted to standardize the protocol and confirm clinical utility.

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Disclosures of conflicts of interest: Please see ICMJE form(s) for author conflicts of interest. These have been provided as supplemental materials.

[AQ8]

Reference

1. Hur S, Kim J, Ratnam L, Itkin M. Lymphatic Intervention, the Frontline of Modern Lymphatic Medicine: Part I. History, Anatomy, Physiology, and Diagnostic Imaging of the Lymphatic System. Korean J Radiol 2023;24(2):95–108.
2. Nadolski GJ, Itkin M. Feasibility of Ultrasound-guided Intranodal Lymphangiogram for Thoracic Duct Embolization. J Vasc Interv Radiol 2012; 23(5):613–616.
3. Krishnamurthy R, Hernandez A, Kavuk S, Annam A, Pimpalwar S. Imaging the central conducting lymphatics: initial experience with dynamic MR lymphangiography. Radiology 2015;274(3):871–878.
4. Hur S. Novel Interventional Radiology for the Treatment of Various Lymphatic Leakages: Lymphatic Intervention and Embolization. Vasc Spec Int 2023;39:42.
5. Nadolski GJ, Chauhan NR, Itkin M. Lymphangiography and lymphatic embolization for the treatment of refractory chylous ascites. Cardiovasc Intervent Radiol 2018;41(3):415–423.
6. Lim DY, Hur S, Kwon LM, Itkin M. Mesenteric Lymphangiography as a New Diagnostic and Therapeutic Tool for Refractory Chylous Lymphatic Leakages and Protein-Losing Enteropathy. J Vasc Interv Radiol 2025; 36(11):1667–1677.
7. Lee Y, Lee S, Hur S, et al. The spectrum of imaging manifestations of Gorham–Stout disease: a novel dynamic contrast-enhanced MR lymphangiography. Orphanet J Rare Dis 2023;18(1):96.
8. Itkin M, Rabinowitz D, Hur S. Liver Lymphatic Imaging and Interventions: Resurrection of the Forgotten Knowledge. Semin Intervent Radiol 2020;37(3):318–323.
9. Lee S, Hur S, Jeong YS. Balloon-Occluded Retrograde Transcatheter Magnetic Resonance Lymphangiography to Detect Leakage in Postoperative Chylous Ascites. J Vasc Interv Radiol 2021;32(4):617–619.

10. Dori Y, Smith CL, DeWitt AG, et al. Intramesenteric dynamic contrast pediatric MR lymphangiography: initial experience and comparison with intranodal and intrahepatic MR lymphangiography. Eur Radiol 2020;30(10):5777–5784.
11. Okuda I, Udagawa H, Hirata K, Nakajima Y. Depiction of the thoracic duct by magnetic resonance imaging: comparison between magnetic resonance imaging and the anatomical literature. Jpn J Radiol 2011;29(1):39–45.
12. Verma SK, Mitchell DG, Bergin D, Mehta R, Chopra S, Choi D. The cisterna chyli: enhancement on delayed phase MR images after intravenous administration of gadolinium chelate. Radiology 2007;244(3):791–796.
13. Chen W, Zhang W, Zhu W, Wang X, Zhang Y. Inner ear MRI enhancement based on 3D-real IR sequence: Comparison of standard, 1.5×, and double doses of gadolinium. Front Neurosci 2022;16:824837.

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