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Thrombus-Mimicking Artifacts in Two-Point Dixon MRI: Prevalence, Appearance, and Severity

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Abstract

Purpose—To evaluate the incidence and severity of potentially thrombus mimicking, flow-induced misallocation artifacts in a clinical setting. Two-point “Dixon” fat–water separation methods, with bipolar readout gradients, may suffer from flow-induced fat–water misallocation artifacts. If these artifacts occur within blood vessels, they may mimic thrombus.

Materials and Methods—Two-point Dixon coronal and axial images acquired in 102 consecutive patients were retrospectively evaluated for the presence of flow-induced artifacts in arteries and veins. Artifacts were graded on a 3-point scale (none, mild, severe) by two independent readers. Interreader agreement was evaluated with kappa statistics.

Results—Reader 1 reported 63 artifacts in 46 (45%) of the cases (severe in 19 cases, 18.6%). Reader 2 reported 51 artifacts in 43 (42.2%) of the cases (severe in 18 cases, 17.6%). Misallocation of fat and water was apparent in all datasets with severe artifacts, whereas variable signal intensity changes in water and fat images were observed in mild artifacts. Interreader agreement was good for artifacts appearing in coronal images ($\kappa = 0.7$) and fair for artifact appearance in axial images ($\kappa = 0.24$).

Conclusion—Our study shows a high incidence of flow-induced mild and severe artifacts in a two-point Dixon method with bipolar readout gradients. This artifact should not be misinterpreted as intravascular thrombus.

Chemical shift-based two-point Dixon fat–water separation magnetic resonance imaging (MRI) techniques provide robust fat saturation and have recently been applied to MR

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angiography (MRA).^{1,2} The advantage of the Dixon fat–water separation in MRA is its ability to provide T_1 -weighted water-only images with arterial contrast enhancement. This improves the quality of maximum-intensity projection (MIP) images by suppressing background fat-signal without the need for subtraction from precontrast datasets. Apart from application in MRA, two-point fat–water separation methods are increasingly used for body MRI, as they not only provide robust fat saturation, but also include information about the fat content of tissue.^{3,4}

However, the acquisition of two separate echoes leads to an increase in scan time. Therefore, methods such as partial k -space acquisitions and parallel imaging are applied to reduce the scan time.^{5,6} The use of bipolar readout gradients acquired in the same relaxation time (TR) is another common method to reduce scan time⁷ and is routinely implemented in commercially available pulse sequences.

However, with a bipolar readout acquisition, the first moments of the two echoes are different, leading to phase differences between the two echoes described by the following equation:

$$\Delta\phi = \gamma \Delta M_1 v \quad (1)$$

where γ is the gyromagnetic ratio of ^1H , M_1 is the difference in the first moment of the readout gradient between echoes, and v is the velocity of a moving spin along the readout direction. Spins that are moving during the readout (eg, due to vascular flow) will accrue additional phase due to the bipolar acquisition. Because two-point fat–water imaging relies on the phase information, these additional flow-induced phase shifts confound the separation of the fat and water signals, and can lead to misallocation of the phase information of spins flowing in the readout direction. If the phase accrual between the two echoes equals 180° , complete misallocation occurs.⁷ In addition, velocity-induced phase dispersion within a voxel containing spins of varying velocity will result in magnitude signal dropout.

A recent study discovered the artifact and demonstrated that the different first moments of the readout gradient at the two echo times were the main cause of flow-induced misallocation of fat and water signals.⁷ Specifically, differences in first moments at the two echo times lead to potentially thrombus-mimicking artifacts in vessels aligned in the readout direction.⁷

However, the prevalence, severity, and potential clinical impact remains to be elucidated. It is critical that radiologists and MR scientists are aware of flow-induced artifacts in two-point Dixon techniques, including their frequency and appearance, as intravascular artifacts have the potential to be misdiagnosed as thrombus.^{8,9} The purpose of this work was to characterize the incidence, severity, and location of these artifacts in body MRI. We further investigated the causes and probable solutions that may help to avoid misallocation artifacts in two-point Dixon MRI.

Materials and Methods

This retrospective study was approved by the local Institutional Review Board (IRB) and was Health Insurance Portability and Accountability Act (HIPAA) compliant. Given the retrospective nature of the study, the IRB granted a waiver of informed consent to perform this retrospective review.

In all, 102 consecutive patients (age range 18–83 years, mean age 41 years, 65 female) undergoing a body MRI scan including coronal and axial two-point Dixon MRI at our institution were evaluated. MR examinations comprised 72 chest exams, 11 exams of both the chest and abdomen, and 17 abdominal exams. Indications included: suspected pulmonary embolism ($n = 49$), vasculitis ($n = 10$ cases), follow-up of aortic aneurysm ($n = 9$ cases), aortic dissection ($n = 9$ cases), post-liver or renal transplant assessment ($n = 5$ cases), uncharacterized abdominal lesion ($n = 6$ cases), aortic valve assessment ($n = 3$ cases), gonadal vein insufficiency, pulmonary artery aneurysm, aortic coarctation repair follow-up, pretransplant assessment ($n = 2$ each), and jaundice ($n = 1$).

MRI Protocol

MR data were acquired using 1.5T clinical scanners (Optima 450w and Signa HDxt, GE Healthcare, Waukesha, WI) in 73 cases and 3.0T clinical scanners (Discovery 750 and Discovery 750w, GE Healthcare) in 29 cases.

Imaging parameters at 1.5T included: coronal slab excitation, field of view (FOV) = 26 cm (S/I) $\times$ 23.4 cm (R/L) $\times$ 16.8 cm (A/P), with $288 \times 192 \times 84$ matrix size for an acquired spatial resolution of 0.9 mm (R/L) $\times$ 1.2 mm (S/I) $\times$ 2.0 mm (A/P) interpolated to $0.5 \times 0.5 \times 2.0$ mm through zero-filling. Other parameters included TR/TE1/TE2 = 6.6/2.1/4.2 msec, flip angle = 15° , bandwidth (BW) = ± 83.3 kHz. Parameters for the axial excitation included: FOV = 26 cm (R/L) $\times$ 19.2 cm (S/I) $\times$ 21 cm (A/P), with $288 \times 192 \times 64$ matrix size for an acquired spatial resolution of 0.9 mm (R/L) $\times$ 1.1 mm (A/P) $\times$ 3.0 mm (S/I) interpolated to $0.4 \times 0.5 \times 1.5$ mm through zero-filling. Other parameters included TR/TE1/TE2 = 6.6/2.1/4.2 msec, flip angle = 15° , BW = ± 90.9 kHz.

Imaging parameters at 3.0T system included: coronal slab excitation, FOV = 48 cm (S/I) $\times$ 38 cm (R/L) $\times$ 32 cm (A/P), with $320 \times 192 \times 160$ matrix size for an acquired spatial resolution of 1.5 mm (S/I) $\times$ 2.0 mm (R/L) $\times$ 2.0 mm (A/P), interpolated to $0.8 \times 0.9 \times 1.5$ mm through zero-filling. Other parameters included TR/TE1/TE2 = 4.1/1.2/2.4 msec, flip angle = 12° , BW = ± 142.86 kHz. The parameters for the axial excitation included: FOV: 34 cm (R/L) $\times$ 30 cm (A/P) $\times$ 30 cm (S/I), with $320 \times 224 \times 100$ matrix size for an acquired spatial resolution of 1.0 mm (R/L) $\times$ 1.3 mm (A/P) $\times$ 3.0 mm (S/I) interpolated to $0.7 \times 0.6 \times 1.5$ mm through zero-filling. Other parameters included TR/TE1/TE2 = 4.1/1.2/2.4 msec, flip angle = 12° , BW = ± 142.86 kHz.

MRI was performed after injection of gadobenate dimeglumine (MultiHance, Bracco Diagnostics, Princeton, NJ) at a dose of 0.1 mmol/kg with an injection rate of 2 ml/s. Two-point datasets were acquired ~2–5 minutes after injection of contrast in the steady-state

equilibrium phase. All two-point Dixon fat–water image datasets were acquired in a single breath-hold at end-expiration.

Fat–water separated images were reconstructed online using the product implementation of the two-point Dixon fat–water separation technique.

T_1 -weighted, single echo spoiled gradient recall (SGRE) imaging postcontrast were reviewed in order to verify absence of thrombus. Sequence parameters included: TR/TE = 4.54/1.40 msec, BW = ± 127 kHz, FOV = $400 \times 360 \times 320$ mm³, $224 \times 160 \times 160$ matrix, for true spatial resolution interpolated to $0.8 \times 0.7 \times 1.1$ mm³ through zero-filling.

Qualitative Image Analysis

Two radiologists with 10 years (S.K.) and 7 years (T.S.) of body MR experience independently evaluated the contrast-enhanced coronal and axial water and fat images. Both radiologists were blinded to the other's assessment. Based on the appearance in the water and/or fat images, the severity of intravascular artifacts was recorded and graded on a 3-point scale (no visible artifact = no visually detectable intravascular signal changes in water and/or fat image; mild = visually detectable intravascular mild-moderate decrease in water and/or signal increase in fat image; severe = clear intravascular signal dropoff in water image with corresponding fat signal at same location on the fat-only image). Single-echo conventional postcontrast T_1 sequences acquired either in the arterial and venous phase or only in venous phase served as the standard of reference and were reviewed to exclude thrombus in cases when intravascular signal misallocation artifacts were present.

The following thoracic vessels were evaluated: 1) arteries: ascending and descending aorta, brachiocephalic artery, proximal left and right subclavian arteries, and proximal left and right common carotid arteries, 2) veins: superior vena cava, subclavian veins, jugular veins, and azygos vein. The following abdominal vessels were evaluated: 1) arteries: descending aorta, common and external iliac arteries, renal arteries, splenic artery, hepatic artery, superior mesenteric artery, 2) veins: inferior vena cava (IVC), left and right renal veins, splenic vein, right, middle and left hepatic veins, and main portal vein.

Quantitative Analysis

The IVC luminal change between the suprarenal segment to the smallest lumen of the hepatic segment of the IVC was evaluated in order to determine whether a potential correlation between flow induced misallocation and flow acceleration due to diameter change was present (Fig. 1). In order to quantify the change of the inner lumen of the IVC, the luminal area of the IVC was measured using an oval-shaped region of interest (ROI) at both levels. The percentage of cross-sectional area reduction of the IVC from the suprarenal to hepatic segment was calculated as follows:

$$\frac{(\text{IVC}_{\text{supraren}} - \text{IVC}_{\text{hep}})}{\text{IVC}_{\text{supraren}}} \times 100 \quad (2)$$

where *IVC suparen* refers to the cross-sectional area of the suprarenal segment of the IVC and *IVC hep* refers to the cross-sectional area of the hepatic IVC.

Statistical Analysis

Interreader agreement of artifact rating was assessed using Cohen's kappa statistics. A κ -value of 0.10–0.20 indicated slight 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.¹⁰

To test for a relationship between artifact appearance and IVC cross-sectional area change, a Spearman-Rank correlation analysis was performed for artifact severity in the IVC in the coronal plane and IVC cross-sectional area change.

To test for a relationship between artifact appearance and magnetic field strength, a chi-square test with artifact severity (none/mild/severe) and magnetic field strength (1.5T/3.0T) was performed. This analysis was performed for both readers.

P-values less than 0.05 were considered statistically significant.

All statistical analyses were performed using commercially available software (SPSS, v. 23.0; SPSS, Chicago, IL)

Results

Figure 2 shows examples of two-point Dixon images with absent, mild, and severe water–fat signal misallocation artifacts in the IVC. Separated water and fat images demonstrate how misallocation of intravascular signal from the water-only into the fat-only image mimics thrombus on the water-only image. T_1 -weighted spoiled gradient recall (SGRE) imaging (not shown) verified the absence of IVC thrombus in all cases.

Figure 3 shows a similar example of water–fat misallocation artifact mimicking thrombus in the renal arteries. Increased signal on the fat-only image is visualized, and conventional T_1 -weighted SGRE imaging verifies the absence of intra-arterial clot.

Figures 4 and 5 show cases where misallocation artifacts were present in coronal and axial images at the same location. In both cases, T_1 -weighted SGRE images proved absence of thrombus.

Figure 6 shows a patient with a large tumor thrombus extending from the right renal vein into the inferior vena cava. Although the thrombus partly obstructs the IVC, no flow-induced artifact was present.

Reader 1 reported 63 (35 mild, 28 severe) artifacts in 46 (45%) of the cases (severe in 19 cases, 18.6%). Reader 2 reported 51 artifacts (28 mild, 23 severe) in 43 (42.2%) of the cases (severe in 18 cases, 17.6%).

In two patients, intravascular thrombus was detected (inferior vena cava, left hepatic vein). However, in none of these two cases were flow-induced artifacts present.

Artifacts in Coronal Imaging

Mild intravascular fat–water misallocation artifacts were reported in 25 cases (24.5%) by Reader 1 and in 23 cases by Reader 2 (22.5%). Severe intravascular fat–water misallocation artifacts were reported in 18 cases (17.6%) by Reader 1 and in 17 cases by Reader 2 (16.7%). Interreader agreement was good in the coronal plane ($\kappa = 0.7$).

Artifact in Axial Imaging

Mild intravascular fat–water misallocation artifacts were reported in 10 cases (10.2%) by Reader 1 and in five cases by Reader 2 (4.9%). Severe intravascular fat–water misallocation artifacts were reported in seven cases (6.7%) by Reader 1 and in three cases by Reader 2 (2.9%). Interreader agreement was fair in the axial plane ($\kappa = 0.24$). Location and severity of artifacts are summarized in Table 1.

IVC cross-sectional area change from the suprarenal to the hepatic segment showed a mean decrease of 32% ($\pm 35\%$ SD), ranging from 91% decrease to an increase of 29%. Spearman-Rank correlation analysis revealed a significant correlation between IVC luminal area change and IVC artifact frequency in the coronal plane (correlation coefficient = 0.254 / $P = 0.021$, Fig. 7), indicating a higher incidence of flow-induced misallocation artifacts at a greater reduction in IVC cross-sectional area.

Reader 1 reported artifacts in 37/73 patients (20 with mild, 17 with severe artifacts) scanned at a magnetic field strength of 1.5T (49% of patients scanned at 1.5T; 27% mild, 23% severe) and in nine (seven mild with mild, two with severe artifacts) out of 29 (31% of patients scanned at 3.0T; 24% mild, 7% severe) patients scanned at 3.0T. The chi-square test revealed no significant difference in artifact incidence at 1.5T and 3.0T ($P = 0.06$).

Reader 2 reported artifacts in 35/73 patients (22 with mild, 13 with severe artifacts) scanned at a magnetic field strength of 1.5T and in eight (three with mild, five with severe artifacts) out of 29 patients scanned at 3.0T. The chi-square test revealed no significant difference in artifact incidence at 1.5T and 3.0T ($P = 0.1$).

Discussion

In this study we investigated the prevalence, severity, and location of potentially thrombus-mimicking, flow-related fat–water misallocations in two-point Dixon images acquired with bipolar readout gradients. Our study revealed that misallocation artifacts appear in almost half of patients with two-point Dixon MR exams. The artifacts were observed particularly in the coronal slice orientation, and in vessels with flow in the same direction as the readout gradient. Misallocation artifacts appeared more frequently in the venous system with a predilection to occur in the intrahepatic IVC.

The qualitative analysis of the presence of artifacts revealed a higher distinctiveness of misallocation artifacts in the coronal plane. This finding is reflected by a good interreader agreement versus a fair interreader agreement in the axial plane. Due to the smaller diameter of blood vessels coursing left–right in the axial plane (eg. renal arteries and veins) compared

to large vessels coursing in the craniocaudal direction (eg. aorta, IVC), artifacts in axial images tend to be much smaller than those seen in the coronal plane.

Matching our experience, the signal misallocation artifact was described in the intrahepatic inferior vena cava (IVC) in a small number of clinical cases in a previous study.⁷ Therefore, we performed a quantitative analysis of the cross-sectional area change of the IVC in order to evaluate a potential effect of cross-sectional area reduction on artifact incidence and severity. A larger cross-sectional area reduction results in a greater degree of physiologic stenosis of the IVC with a greater flow acceleration. However, this quantitative analysis revealed only a weak correlation between artifact appearance and apparent decrease in cross-sectional area. Therefore, based on our results, a physiological IVC-stenosis might not necessarily lead to a greater likelihood of flow-induced artifact appearance.

The reason for the difference in artifact incidence between arteries and veins cannot yet be fully explained. Arteries and veins (eg, hepatic veins) may have pulsatile flow. The flow in veins, unlike flow in arteries, may also vary with respiration. It remains unclear how these differences impact the incidence of the observed artifact. Further studies in phantoms may be helpful to elucidate the underlying mechanisms.

Flow-induced artifacts were previously reported to theoretically appear more frequently at 1.5T due to longer echo spacing and a greater first moment (M_1 , Eq. 1).⁷ Indeed, artifacts appeared more frequently at 1.5T compared to 3.0T in our study, albeit without reaching a statistically significant difference.

Our study has clinical implications, as two-point Dixon MRI is increasingly used in clinical imaging due to the robust fat suppression and high image quality.¹¹ Generally, imaging artifacts in MRI are known to have the potential to mimic thrombus.⁸ However, severe flow-induced misallocation artifacts in two-point Dixon MRI can be correctly diagnosed as artifacts. Due to the fact that the artifact is caused by signal misallocation of fat and water due to flow, artifacts always appear dark in the water-only and bright in the fat-only image. Therefore, the artifact can be identified with certainty if the fat images are reviewed together with the water images. Artifacts that were graded as mild in our study did not consistently show definite signal change in the fat-only image. However, these are unlikely to be misinterpreted as thrombus due to the mild intravascular signal drop in the water-only image. The artifact appeared only in either the coronal or axial plane in the large majority of cases in our study. Nevertheless, we experienced two cases with severe flow-induced artifacts in the same location in both the axial and coronal planes. This may be due to vortical blood flow patterns that contained velocity components in both the craniocaudal and left–right directions. In this study, contrast-enhanced non-Dixon T_1 -weighted spoiled gradient echo (SGRE) MRI acquired in either the arterial and venous phase or in the venous phase only. This is widely regarded as the reference standard for IVC clot.^{12,13} Therefore, we recommend that in addition to water and fat images, single-echo postcontrast T_1 sequences should be reviewed when a potential thrombus-mimicking artifact is detected. Other solutions include swapping the readout and phase-encoding directions as well as the application of dual pass, unipolar readout methods.^{7,14} However, unipolar readout methods lead to increased scan time, which may be challenging for breath-hold examinations in body

imaging. A further way to reduce these artifacts are optimized readout gradients in order to minimize $M1$ at the opposed-phase and in-phase echo times⁷ as well as readout gradients that are designed to be first-moment nulled.

Future prospective studies performing direct comparison of Dixon MRI to conventional fat-suppressed T_1 -weighted imaging may be helpful to determine the true clinical impact of the thrombus-mimicking artifact.

Lastly, flow-induced misallocation artifacts should not be confounded with the well-known fat–water swaps caused by magnetic field inhomogeneities and the natural ambiguity that can occur when voxels contain primarily all water or all fat.^{15–17} These swaps represent a separate artifact that generally appear as nonanatomic geographic fat–water misallocations. Fat–water misallocations due to magnetic field inhomogeneities do not lead to the thrombus-mimicking artifact as described in this study. Further, magnetic field inhomogeneities do not exacerbate velocity-induced phase shifts, and therefore we do not expect such inhomogeneities to affect the thrombus-mimicking artifact in any way.

Limitations of our study include different sizes of the patient groups imaged at 1.5T and 3.0T and patient groups with thoracic and abdominal exams. Furthermore, in- and opposed-phase source images were not available for most datasets, as these are not typically stored.

In conclusion, this study has shown that flow-related fat–water misallocations occur in almost half of two-point Dixon exams acquired with bipolar readout gradients, and that these have the potential to be misinterpreted as thrombus. As Dixon algorithms continue to evolve, this may reduce the incidence rate of this artifact. However, it remains important for radiologists to be aware of the potential for these artifacts during the evaluation of 2-point Dixon fat–water separation methods.

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FIGURE 1.
Choice of imaging slices for IVC surface area calculation. White lines indicating the locations of IVC surface area measurements in the axial plane.

FIGURE 2.

None (**A**, scanned at 1.5T, 13.6% IVC cross-section area reduction), mild (**B**, 1.5T, 75% IVC cross-section area reduction), and severe (**C**, 1.5T, 64% IVC cross-section area reduction) misallocation artifact in the IVC (arrowheads) with the corresponding fat-only image (**D,E**) below each water image.

FIGURE 3.

Severe flow induced fat and water misallocation in bilateral renal arteries (arrows): **A**: water-only image, **B**: fat-only image. The corresponding MRA shows patent bilateral renal arteries (**C**).

FIGURE 4.

Severe misallocation artifact in the aorta and right common iliac artery in a patient with Takayashu's disease and multiple arterial stenoses. Artifacts are seen in coronal and axial fat- (B,E, arrows) and water-only (A,D, arrows) images in the same location. MRA (C) revealed patent but stenotic vessels.

FIGURE 5. Severe misallocation artifact in the proper and common hepatic artery (arrows) in axial and coronal planes in the same locations. **A,C:** Water-only images; **B,D:** Fat-only images.

FIGURE 6.

Case of a large, right-sided renal tumor (asterisk), scanned at 3T. A thrombus extends from the right renal vein into the IVC (arrows). No fat–water misallocation was detected in the water only images (coronal: **A**, axial: **D**) and the corresponding fat only images (coronal: **B**, axial: **E**). A single-echo, T_1 -weighted sequence postcontrast confirmed the presence of thrombus (**C**, arrow).

FIGURE 7.

Artifact severity (x-axis) plotted vs. % IVC cross-sectional area reduction (y-axis). A reduction in cross-sectional area correlates with the incidence of flow-induced artifacts.

TABLE 1

Total Numbers of Artifacts Within the Cohort of 102 Patients With Regard to Localization and Severity of Flow-Induced Artifacts Reported by Reader 1 and Reader 2 (Italics).

	Mild artifact		Severe artifact	
	Coronal	Axial	Coronal	Axial
IVC	17; <i>15</i>	3; <i>2</i>	17; <i>16</i>	—
Aorta	7; <i>5</i>	—	—	—
Liver veins	—	4; <i>3</i>	—	2; <i>1</i>
Azygos vein	—	3; <i>0</i>	—	2; <i>0</i>
Superior vena cava	1; <i>3</i>	—	—	—
Hepatic artery	—	—	1; <i>1</i>	1; <i>1</i>
Splenic artery	—	—	—	2; <i>1</i>
Common iliac artery	—	—	1; <i>1</i>	1; <i>1</i>
Renal artery	—	—	—	1; <i>1</i>