Intravenous Line Phase-Wrap Artifact at Bilateral Axial 3-T Breast MRI: Identification, Analysis, and Solution

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Purpose: To understand and remove the source of a phase-wrap artifact produced by residual contrast agent in the intravenous line during acquisition of bilateral axial 3-T dynamic contrast material–enhanced (DCE) breast MRI.

Materials and Methods: A two-part study involved a phantom experiment, followed by an institutional review board approved clinical intervention, to evaluate the phase-wrap artifact at MRI. A phantom model evaluated artifact production by using an intravenous line filled with fluids with varying concentrations of gadolinium-based contrast agent (0, 0.4, 0.8, 1.2, 1.6, and 2 mmol/mL) and by positioning the simulated intravenous line within several fields of view (FOV) at 3-T MRI in breast coils. Next, a clinical assessment was performed with a total of 400 patients (control group: interventional group, 200:200) to determine the effect of taping the intravenous line to the patients’ backs. Breast MR images were assessed blindly for the presence of the artifact. Software was used for statistical analysis with a P value of less than .05 considered a significant difference.

Results: In the phantom model, the artifact was produced only with a 0.4 mmol/mL gadolinium concentration and when the tubing was either close to the edge or within a FOV of 350–450 mm. In the clinical experiment, the artifact was more prevalent in the retrospective control group than in the prospective intervention group (52.5% [105 of 200] vs 22% [44 of 200]; P < .005).

Conclusion: The presence of phase-wrap artifacts can be reduced by moving the contrast agent intravenous line out of the FOV during acquisition by taping it to a patient’s back during bilateral axial 3-T DCE breast MRI.

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Numerous studies have shown that dynamic contrast material–enhanced (DCE) MRI has a higher sensitivity in detecting breast lesions compared with mammography and breast US, and hence is recommended as an important modality in guidelines of breast imaging for screening and cancer diagnosis in specific subgroups of women (1–8), even despite limited positive predictive value (7). It is mandatory to optimize patient positioning and data acquisition of any system employed to maximize the resolution of the reconstructed images (8–10) and to decrease the risk of technique-associated artifacts (11). MRI artifacts as a potential cause of misinterpretation of pathologies have been reported rarely in the early days of 1.5-T MRI. Specifically, there were reports of inhomogeneous fat suppression mimicking pathologies in the orbits and the nasopharynx (12,13) and of chemical shift artifact simulating an aortic aneurysm (12–14).

In breast MRI, the axial orientation provides adequate depiction of the ductal organization of the breast glandular tissue and has the advantages of depicting concomitant bilateral contrast enhancement and facilitating accurate comparison of the breasts during interpretation. For axial slices, the phase-encoding direction should be right to left and left to right to prevent superposition of pulsation artifact from the heart on the breast tissue that could degrade the quality of the reconstructed images (11).

Although artifacts associated with breast MRI have been well described, little has been reported regarding the effect of patient positioning on the development of artifacts. Current guidelines for patient positioning during breast MRI maintain that it is important for the patient to be as comfortable as possible to minimize patient motion, and that long enough intravenous injection lines should extend from the manual or power injector to the injection site to enable contrast material administration without removing the gurney from the MRI tunnel (15–17). Furthermore, the patient’s arms should not be positioned alongside the body to help prevent phase-wrap artifact of the upper arms and shoulders superimposing the breasts (11). To our knowledge, only a few articles in the published literature address the optimal positioning of the arms during axial-oriented breast MRI and whether it is preferable to acquire the images with the patient in prone feet-first or head-first positioning (18).

Here, we described an artifact frequently encountered in our clinical practice during acquisition of simultaneous bilateral axial breast MRI with a 3-T magnet. We proposed that the artifact is a phase-wrap artifact generated by residual contrast material remaining in the intravenous injection tubing. We performed phantom experiments and clinical interventions to address the source of the artifact. We found that the artifact was the result of the contrast...
Intravenous Line Phase-Wrap Artifact

Abbreviations
DCE = dynamic contrast material enhanced, FOV = field of view, MIP = maximum intensity projection, VIBE = volumetric interpolated breath-hold examination

Summary
Phase-wrap artifacts could be produced by residual contrast material in the intravenous line during acquisition of bilateral axial 3-T dynamic contrast-enhanced breast MRI and may mimic an enhancing lesion; a simple intervention of preventing the intravenous line from falling within the field of view would prevent this artifact and eliminate a possible mimic of enhancing lesion.

Key Points
- Taping a contrast agent intravenous line to the back of a patient, instead of laying the intravenous line next to the patient, can reduce the incidence of phase-wrap artifacts at bilateral axial 3-T breast MRI (52.5% vs 22% patients; \(P < .005\)).
- Intervention of moving the intravenous line prior to bilateral axial 3-T breast MRI acquisition compared with placement of the intravenous line next to the patient reduced the number of images with artifacts overlying the breast tissue (13% vs 0.5%; \(P < .001\)).

Materials and Methods

Phantom Model Study Design
A commercial Siemens phantom model with two 1.5-L bottles containing a paramagnetic nickel-sulfate solution (3.75 g \(\text{NiSO}_4\cdot\text{H}_2\text{O}\)_6 and 5 g NaCl per each liter of distilled water) routinely used for breast coil calibration, was placed in the clinical breast coil. An identical injection line to the one used clinically for extension was taped at the edge of the breast coil on the right side (Fig 1). The tubing was filled with 5 mL of fluid containing varying concentrations of gadolinium-based contrast material (gadopentetate dimeglumine; Magnevist, Princeton, NJ) diluted with normal saline (0.9% NaCl). The phantoms were inserted into the 3-T clinical scanner routinely used for breast MRI, and an axial T1-weighted three-dimensional volumetric interpolated breath-hold examination (VIBE) sequence, with identical parameters to our clinical MRI protocol (see MRI and Data Acquisition), including the phase-encoding direction (right to left), was performed.

In the first experiment (series 1–7, Table 1), six different concentrations of gadolinium-based contrast material (0, 0.4, 0.8, 1.2, 1.6, and 2 mmol/mL concentrations; 0%, 20%, 40%, 60%, 80%, and 100% dilutions of gadolinium-based agent in saline, respectively) were evaluated with a constant FOV of 360 mm using an axial T1-weighted three-dimensional sequence. The first scan was a control and did not have tubing (series 1). Next, having determined the dilution in which the artifact was produced, the second phase of the phantom study (series 8–13, Table 2) was to determine the relation of the tubing to the FOV in producing the artifact. The concentration of gadolinium in the tubing was kept constant as defined in the first portion of the experiment (0.4 mmol/mL; 20% dilution), and the changing variable in this step of the experiment was the FOV, ranging from 300 mm to 500 mm at increments of 50 mm. Series 8 was used as a control scan with a FOV of 360 mm without the tubing line. To better delineate the artifact, the tubing was folded three times and taped together to a constant spot within the phantom at the edge of the breast coil, outside of a 360-mm but inside a 450-mm FOV.

Patient Groups and Study Design
This study was approved by our institutional review board. Analysis of the clinical portion of the study was retrospective and had no impact on clinical patient management; therefore, the need for informed consent was waived. There was no overlap in any study participants from previous studies. We reviewed 400 consecutive breast MRI examinations (mean age, 50.6 years \(\pm 1.25\) [standard deviation]) performed at our institution during the first half of 2016 for high-risk screening. Women with prior mastectomy or breast implants were excluded from the study. The examinations were divided into a retrospective control group which included 200 consecutive patients who underwent breast MRI just prior to our intervention and a similar prospective study group which included the first 200 consecutive patients meeting the inclusion criteria scanned after our intervention. The intervention examined in this study was a new standard fixation of the intravenous line to the patients’ backs during patient positioning. All patients were scanned with a single MRI scanner, using an identical scanning protocol.

Patient Positioning during Imaging
Patients were positioned prone with the breasts situated within the dedicated wells in the breast coil. The arms were raised above the head and placed on a pillow for comfort. The patient was placed in a head-first orientation. An intravenous injection line was inserted at the back of the palm and a long tubing attached, extending caudally through the MRI tunnel, ending at a power injector outside of the MRI machine located next to the patient’s legs. The injector was positioned at this location to enable visualization by the technicians who monitor the injection process from the command table outside of the room (Fig 2). In the retrospective control group, this long tubing was placed with no special control as to where exactly it fell within the FOV of the examination. In the prospective intervention group, the intravenous line tubing was routinely taped to the patient’s back in the region of the scapula on the ipsilateral side to the injection line insertion, so as to ascertain that the line would not fall anteriorly into the FOV of the breasts. The tubing length was identical in both groups, measuring approximately 240 cm and contained 13–15 mL of fluid.

MRI and Data Acquisition
Breast MRI was performed with a 3-T unit (Magnetom Trio; Siemens, Erlangen, Germany) with a dedicated eight-channel breast coil (Siemens, Erlangen, Germany). Following an ini-
FOV, 340 mm; slice thickness, 2 mm; number of slices, 80 in one slab; matrix, 512 × 512 pixels; phase encoding direction, right to left; number of acquisitions, one; acquisition time, 1:20 minutes) prior to and four times after injection of 0.1 mmol/kg of body weight of gadopentetate dimeglumine (Magnevist, Bayer, Princeton, NJ) or gadoterate meglumine (Dotarem; Guerbet, Roissy, France) at a 2 mL/sec rate, followed by a 20-mL normal saline flush, injected by a power injector. The first scan after contrast agent injection was initiated immediately at the end of the saline flush (20 seconds after the beginning of injection). Fat saturation was employed by automatic shimming with manual adjustment. Subtraction images were obtained by subtracting the precontrast scan from each of the postcontrast series. Axial, coronal, and sagittal maximum intensity projection (MIP) reconstructions were automatically derived. Additional sequences included a bilateral axial T2-weighted scan without fat saturation (TR, 5000 msec; TE, 82.6 msec; FOV, 340 mm; slice thickness, 3 mm; interslice gap, 0.6 mm; matrix, 512 × 512 pixels; number of acquisitions, one; acquisition time, 2:50 minutes) and sagittal T2-weighted turbo spin-echo (spectral attenuated inversion recovery) of each breast separately (TR, 4670 msec; TE, 80 msec; FOV, 260 mm; slice thickness, 4 mm; interslice gap, 0.4 mm; matrix, 384 × 288 pixels; number of acquisitions, one; acquisition time, 4:20 min). Total examination time was approximately 25 minutes.

**MR Image Assessment and Data Analysis**

Two readers, one fellowship-trained breast radiologist with 16 years of experience in interpreting breast MRI (T.S.) and one board-certified radiologist (Y.A.), a breast imaging fellow in-training with 6 months of experience, evaluated the source axial images of the first postcontrast scan and axial MIP reconstructions of all breast MRI examinations of both the control and study groups, for the presence or absence of the phase-wrap artifact. The readers were blinded to the assigned group of a specific study at the time of interpretation. Studies were anonymized prior to review.

The presence of the artifact was scored as “1” and the absence as “0.” If an artifact was present, it was further analyzed by location within the image as follows: the image was divided by the anterior chest wall into anterior, including mainly breast tissue, and posterior, including the heart, great vessels, and the lungs. When an artifact appeared in the anterior part of the image, its appearance including the heart, great vessels, and the lungs. When an artifact appeared in the anterior part of the image, its appearance was further described as either overlaying breast tissue or not.
Artifact shape was assessed on MIP images as round or tubular. The tubular artifacts were further scored as short when less than 1 cm, medium if measuring between 1 and 3 cm, or long if length was greater than 3 cm.

Statistical Analysis

Data were entered into an electronic spreadsheet using the Excel software program (Microsoft, Redmond, Wash). Categorical variables were described as frequencies and percentage. Comparison between the study and control groups was performed by using the χ² test for categorical variables. All tests were performed by using a commercial statistical software (SPSS statistics for Windows, version 22.0, IBM, Armonk, NY). A P value of less than .05 was considered to indicate a significant difference.

Agreement between observers was determined by using the Cohen κ statistic for categorical variables. Interclass correlation coefficients were interpreted as follows: 0–0.2 denotes poor agreement, 0.3–0.4 denotes fair agreement, 0.5–0.6 denotes moderate agreement, 0.7–0.8 denotes strong agreement, and greater than 0.8 denotes excellent agreement.

Results

Baseline Observations and Patient Case Example

A tubular artifact, which was not clinically significant and did not affect image interpretation, was commonly encountered at breast MRI in our clinical practice. Rarely, the shape and location of this intravenous line phase-wrap artifact mimicked a suspicious lesion and adversely influenced interpretation and recommendations. Such an example is presented in the following case: A 42-year-old woman with a BRCA mutation was referred for routine annual surveillance MRI of the breasts. A new 0.5-cm round and well-defined enhancing nodule was depicted in the right upper inner breast (Fig 3, A, B). Although the morphologic features appeared benign, the finding was new compared with findings from multiple previous examinations. MRI-guided biopsy was recommended for further evaluation because this was a new enhancing focus in a woman who was at very high risk. On the day of MRI-guided biopsy, the enhancing lesion was not depicted in the breast, and the biopsy was canceled. Review of the original study, which prompted the biopsy, revealed an identical finding in a similar location in the far-right anterior border of the image, just lateral to the anterior portion of the left breast, not overlaying the breast, which was overlooked at the time of initial interpretation (Fig 3, C). The identical appearance of the two artifacts and their perfectly aligned location within the image in this and similar cases led to the phase-wrap hypothesis related to the positioning of the contrast material injection line and the design of the experimental model testing this hypothesis.

Phantom Studies to Generate the Intravenous Injection Tubing Phase-Wrap Artifact

The observed artifact was visible only following contrast material injection; therefore, it was necessarily related to signal produced by the gadolinium. However, it was not clear why gadolinium should produce signal in the injection line at all because in our clinical protocol we administer a rapid bolus injection using a power injector with a sufficient saline flush to remove the contrast material from the line prior to imaging. To further explore this issue, we designed a phantom model to determine the concentration and FOV parameters that were required to mimic the artifact.

Results from the phantom study are presented in Tables 1 and 2. The artifact was produced only in series 3 with the tubing filled with a 20% dilution of gadolinium resulting in a gadolinium concentration of 0.4 mmol/mL (Table 1). This concentration of gadolinium was selected for the second stage of the phantom experiment. In the second set of phantom experiments, the artifact was detected at FOVs of 350–450 mm (series 10–12) when the tubing was either close to the edge of the FOV or marginally within it (Table 2, Fig 4). The artifact was not detected when the tubing was well inside the FOV (series 13, FOV 500 mm) or well outside of it (series 9, FOV 300 mm).

Clinical Studies Confirming the Intravenous Injection Tubing Phase-Wrap Artifact Model

Patient characteristics.—MRI examination results in 400 women (mean age, 50.6 years ± 1.25; age range, 25–79 years) were evaluated. All women underwent clinical breast MRI for high-risk screening. No statistically significant difference was found in age between the control group (n = 200,
Intravenous line placement on the backs of patients reduced incidence of phase-wrap artifact.—Results are presented in Table 3. The artifact was more prevalent in the retrospective control group (52.5%, 105 of 200) compared with the prospective intervention group (22%, 44 of 200; \( P < .005 \)). Furthermore, when an artifact was present, it appeared in the anterior part of the image more often in the control group (47%, 49 of 105) compared with the intervention group (5%, two of 44; \( P < .001 \)). Overall, an artifact appearing overlying the breast tissue on the MR images was found in 13% (26 of 200) of examinations in the control group and only in 0.5% (one of 200) in the intervention group (\( P < .001 \)) (Fig 5).

The appearance of the artifact on MIP images was most commonly tubular in both the control (98%, 103 of 105) and the study group (100%, 44 of 44), with a round artifact present in only two patients in the control group. The length of the artifact was mostly long in the control group (78%, 82 of 105), and mostly of medium length (65%, 29 of 44) in the study group. Overall, 2% (two of 105) of artifacts in the preintervention control group were either round or short tubular and had the potential of simulating a suspicious lesion (Table 4).

Figure 3: MR images in a 42-year-old woman who is a carrier of the BRCA mutation for routine annual screening. A, First axial T1-weighted three-dimensional volumetric interpolated breath-hold examination image after contrast agent administration (cropped to right breast only) shows no abnormality. B, The same patient imaged at a routine surveillance examination 1 year later. A small well-defined, hyperintense nodule (solid white arrow) appears in the right upper inner breast which was erroneously interpreted as a suspicious focus of enhancement. C, Same image as B, however, uncropped image of both breasts, shows the suspicious focus (solid white arrow) and an identical finding lateral to the left breast (broken white arrow) revealing the true artifactual nature of the abnormality. The intravenous injection line was placed in the left hand, causing signal close to the edge of the field of view on the left (solid white arrow) which wrapped around to overlay the right breast (solid white arrow). A vague wrap-around of the left breast contour is also evident on the image to the right of the right breast (arrowhead).
Interobserver agreement between the two observers regarding the presence of the artifact was excellent with a Cohen $\kappa$ coefficient of 0.94 in the control group and 0.89 in the study group. Agreement was also very good regarding the location of the artifact in the control and study groups ($\kappa$ = 0.7 and 0.82, respectively).

**Discussion**

In this study, we presented a phase-wrap artifact that was caused by long intravenous line tubing falling into the FOV during bilateral axial 3-T DCE breast MRI. Patients were positioned with arms raised above the head so as to prevent phase-wrap artifact of the shoulders in a relatively small FOV in axial acquisition (11). The tubing extension ran alongside the body within the MRI tunnel, toward the automatic injector placed outside of the tunnel. If overlying the breast, the resulting artifact could potentially simulate a small enhancing lesion in the breast, causing unnecessary worry and potential work-up, as occurred in the case description above. Thus, understanding this common artifact and taking measures to eliminate it is clinically relevant.

Phase-wrap artifacts, also referred to as aliasing or wraparound artifacts, occur when signal-producing foreign elements are positioned at the far edge, or exceed beyond, the designated FOV in the phase-encoding direction. This results in signal generated from the foreign element at the edge or outside of the FOV, superimposed onto signals transmitted from pixels within the FOV on the opposite side (19). Prevention of a similar artifact in breast imaging, caused by heart motion, has been described by setting the phase-encoding direction in the right-left instead of anteroposterior direction (11). On the basis of our phantom study, we hypothesized that the cause of our observed clinical artifact was phase-wrap of residual gadolinium in the intravenous tubing at a specific concentration. To our knowledge, an artifact simulating a suspicious breast lesion because of phase-wrap has not been previously described. In general, prevention of wrap-around artifact can be achieved by either moving the foreign object further outside of the FOV or by changing the size of the FOV.

It is not certain why only a small part of the tubing in the clinical study showed increased signal following injection and resulted in appearance of the described artifact. We hypothesized that this was related to varying concentrations of residual gadolinium in different sections of the injection line, possibly caused by turbulent mixture at the meeting point of the contrast agent with the saline flush. Such a turbulent mixture may result in a small area of gadolinium that is dilute enough to shorten the T1-weighted relaxation time, with subsequent increased signal. High concentrations of paramagnetic contrast agents do not cause the substantial shortening in T1-weighted relaxation times needed to produce an elevated signal at MRI, nor does saline (20), as was

| Parameter                              | Retrospective Control ($n = 200$) | Prospective Intervention ($n = 200$) | P Value |
|----------------------------------------|-----------------------------------|--------------------------------------|---------|
| Artifact present                       | 105/200 (52.5)                    | 44/200 (22)                          | <.001   |
| Anterior location                      |                                   |                                      |         |
| Number                                 | 49                                | 2                                    | <.001   |
| Percentage among examinations with artifact | 49/105 (47)                       | 2/44 (4.5)                           | <.001   |
| Percentage among all examinations      | 49/200 (25)                       | 2/200 (1)                            | <.001   |
| Artifact overlies breast tissue        |                                   |                                      |         |
| Number                                 | 26                                | 1                                    | <.001   |
| Percentage among examinations with artifact | 26/105 (25)                       | 1/44 (2.3)                           | <.001   |
| Percentage among all examinations      | 26/200 (13)                       | 1/200 (0.5)                          | <.001   |

Note.—Numbers represent number of patients with percentages in parentheses.
confirmed in our phantom model. In the phantom experiment, a high signal intensity artifact appeared only at a 0.4 mmol/mL concentration (20% dilution) of gadolinium. Furthermore, the phantom model confirmed the relationship between the FOV and appearance of the artifact, strengthening our hypothesis that it was indeed a phase-wrap artifact. The significant reduction in the frequency of artifact production following a simple intervention to prevent the line from falling into the FOV further established this finding.

Agreement between both investigators regarding appearance and characterization of the artifact was very high, although the readers depicted two extremes in respect to their experience in breast MRI, indicating that this artifact is not a subtle finding. Taping the intravenous line to the back of the patient’s shoulder proved effective, reducing the artifact significantly from 52.5% (105 of 200) prior to intervention to 22% (44 of 200) following it, almost completely omitting superimposition of the artifact over the breast tissue (13%; 26 of 200 in control vs 0.5%; one of 200 in study group). Although taping the intravenous line to the patient’s back did not completely eliminate the artifact, when it appeared following the intervention, it was most commonly located in the posterior part of the image, overlaying the back and causing no interference with the evaluation of the breasts. Only one of the cases in the study group depicted the artifact overlaying the breast tissue. This case was one of the first cases performed after the new instructions to tape the intravenous tubing. We assumed that a technical misplacement of the tubing occurred and may have caused the artifact in this specific case.

Additional options for eliminating the described artifact include changing the phase-encoding plane, such as with imaging in sagittal orientation, or changing patient positioning to eliminate the possibility of the line falling into the FOV; for example, positioning the patient feet first with the hands above the head or positioning the patient head first with the hands alongside the body (not recommended because of shoulder wraparound).

The main limitation of our study was the application of a phantom model to understand a process causing a clinical observation. Although we designed the experimental model to simulate the clinical conditions as closely as possible, some factors were not identical. For example, it was extremely complex to simulate the actual resistance within the tubing of an intravenous injection in a phantom model; therefore, we used a fixed concentration of contrast material to best simulate the clinical scenario. Thus, we can only hypothesize what causes dilute contrast within the intravenous line in the clinical situation.

The current study demonstrated how to identify, evaluate, and eliminate a phase-wrap artifact, which in a certain situation can cause a clinical uncertainty. Changing the position of the intravenous line, as simple as it may be, eliminated the artifact.
overlying the breasts and enhanced the ability to produce more accurate, high-quality breast MRI.

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