Silicone-Suppressed 3D MRI of the Breast Using Rotating Delivery of Off-Resonance Excitation

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Objective: A new silicone-suppressed MR technique was developed, and its efficacy in identifying free silicone and differentiating it from other breast tissues was investigated.

Materials and Methods: Silicone-suppressed MRI was performed using the RODEO (rotating delivery of excitation off-resonance) pulse sequence, which selectively eliminated signal from the narrow range of $(CH_3)_4Si$ resonance. Ninety breasts in 61 patients were evaluated with both a fat-suppressed 3D MR sequence and a silicone-suppressed 3D MR sequence.

Results: Extracapsular free silicone and silicone injections demonstrated a unique appearance compared with normal breast tissue in all cases. Magnetic resonance identified free silicone in 26 breasts, 10 of which were confirmed pathologically or from a history of previous silicone injections. No free silicone was present on MR in 64 breasts; 8 of these were confirmed by biopsy or mastectomy as showing no evidence of free silicone. This technique was useful in evaluation of prosthesis integrity, free silicone, focal palpable or mammographic lesions, and the breast with silicone injections.

Conclusion: Silicone-suppressed RODEO MRI of the breast can accurately identify free and intracapsular silicone and can distinguish silicone from other tissues. This provides unique information about the breast in a number of specific applications.

Index Terms: Breasts, implants—Silicone—Magnetic resonance imaging, techniques.

The ~2 million breast augmentation procedures performed in the last few decades have resulted in many challenging clinical and diagnostic dilemmas. Evaluation of the augmented breast as well as the underlying prosthesis can be difficult for both the surgeon and the radiologist, and a number of unique diagnostic problems have arisen (1). These include the evaluation of (a) prosthesis integrity, (b) extracapsular free silicone, (c) a palpable lesion in an augmented breast, (d) a mammographic lesion in an augmented breast, and (e) breast parenchyma in a patient with a history of silicone injections.

Common to these problems is the identification and separation of silicone material from normal and abnormal breast tissues. The recently described RODEO (rotating delivery of excitation off-

resonance) sequence (2), a fat-suppressed, 3D volume acquisition, can be adapted to selectively suppress silicone instead of fat. This allows for silicone-specific MRI. As such, it is able to address these problem cases and provide unique information.

METHODS AND MATERIALS

All MRI was performed on a Signa imager (GE Medical Systems, Milwaukee, WI, U.S.A.) operating at 1.5 T with 4X software. Image reconstruction and maximum intensity projection were performed on an independent console (GE Medical Systems).

Patients were imaged in a prone position without breast compression. A prototype of either a linear (Medrad, Pittsburgh, PA, U.S.A.) or quadrature (MRI Devices, Waukesha, WI, U.S.A.) radiofrequency (RF) transmit–receive breast coil was utilized for all patients.

Ninety breasts in 61 patients were examined at our institution. Patients included in the study had one or more of the following: (a) clinical or conventional imaging findings suspicious for prosthesis rupture or free silicone; (b) mammographic or sonographic evidence of a discrete lesion in the presence of a silicone prosthesis; (c) a palpable lesion in the presence of a silicone prosthesis; or (d) a history of silicone injections into the breast. The patients' ages ranged from 30 to 73 years (mean 46 years).

The MRI was performed using the recently described RODEO technique. This 3D sequence allows voxel resolution of ~1.4 × 0.7 × 0.7 mm on a display matrix of 128 × 256 × 256 pixels for an 18 cm field of view. With this technique, protons in either fat or silicone can be selectively suppressed by applying an RF sine excitation on the resonant frequency of fat or silicone followed by a similar sine excitation 180° phase shifted. This sequence of pulses excites protons that are off-resonance but produces no net excitation to those that are on-resonance (2).

All studies included a fat-suppressed RODEO sequence and a silicone-suppressed RODEO sequence. In 32 patients (45 breasts) with clinical or mammographic findings suggesting possible malignancy, an additional fat-suppressed RODEO sequence was obtained following the intravenous administration of 0.1 mmol/kg (usually 8–16 ml) of gadolinium at 10 ml/min. The precontrast fat-suppressed images were obtained without RF spoiling, producing high signal intensity in fluid. Postcontrast fat-suppressed sequences were performed with RF spoiling, yielding low signal intensity in fluid and allowing it to be distinguished from contrast enhancement.

Image analysis was performed with side-by-side comparison of fat- and silicone-suppressed images and multiplanar reformatted images from the 3D data set on an image-processing console (GE Medical Systems). Pre- and postcontrast fat-suppressed images were reviewed in a similar manner. Free silicone had low signal intensity on silicone-suppressed RODEO images and intermediate signal on fat-suppressed RODEO located outside the confines of the prosthetic capsule. Blood vessels and calcification were low in signal intensity on silicone-suppressed sequences but also low on fat-suppressed sequences.

Conventional imaging consisted of mammography supplemented by magnification mammography and sonography when appropriate. Standard mammograms were performed and interpreted in all patients by a single radiologist experienced in mammographic interpretation with all relevant clinical information available at the time of interpretation. Standard four view (MLO and CC views of both breasts) mammograms were obtained in all cases. In patients with silicone implants, the implant-

displaced or Eklund views were performed. All patients with evidence of a discrete mammographic lesion or a palpable mass in the presence of a silicone prosthesis were examined with sonography in addition to mammography. An Acoustics Imaging dedicated breast sonography device was employed with 7.5 and 10 MHz transducers. This combination of mammography, magnification mammography, and sonography is described elsewhere in this article as conventional imaging.

RESULTS

The MR results are summarized in Table 1. Of the 90 breasts studied, 26 (29%) had evidence of extracapsular free silicone on MR (positive cases). The remaining 64 breasts (71%) had no evidence of free silicone on MR (negative cases).

All patients with silicone implants and extracapsular free silicone collections also had intracapsular rupture. Because the implant shell and the gel are composed of silicone, both suppress with silicone-suppressed RODEO. The presence of intracapsular rupture is determined on the images without silicone suppression.

In 18 cases, confirmation of the MR findings was obtained. Confirmation was available in 10 of the 26 breasts (38%) with MR evidence of free silicone and in 8 of the 64 breasts (13%) without findings of extracapsular silicone. All negative cases and 4 of 10 positive cases were substantiated following surgery and pathologic analysis. The remaining six positive cases had a documented history of silicone injections. In none of the 18 confirmed cases was there a discrepancy with the MR findings. Of the confirmed cases, 10 of 18 (56%) were positive cases and 8 of 18 (44%) were negative cases.

In the patients with silicone injections, collections of free silicone were demonstrated as moderate intensity on fat-suppressed and hypointense on silicone-suppressed RODEO images. Fibrous tissue is typically hypointense on both fat- and silicone-suppressed precontrast images. The capsule around an implant consistently enhances with contrast agent, but no enhancing capsule could be demonstrated around the free silicone collections in the silicone injection breasts.

Pathologic information is available in eight cases in which no free silicone was found and in which a postgadolinium RODEO sequence demonstrated an

TABLE 1. *Summary of MR findings*

	Total	Confirmed
Total breasts examined	90	18
Evidence of free silicone	26 (29)	10 (56)
No evidence of free silicone	64 (71)	8 (44)

Values in parentheses are percents.

enhancing lesion. The histology of these lesions is listed in Table 2.

Conventional imaging of the confirmed cases yielded 13 cases with free silicone (9 true positives and 4 false positives) and 5 cases without free silicone (4 true negative and 1 false negative). The sensitivity and specificity of MR and conventional imaging are listed in Table 3.

DISCUSSION

Silicone-suppressed RODEO imaging was useful in a variety of clinical scenarios. Evaluation of silicone prosthesis integrity is performed by assessing for evidence of intracapsular or extracapsular rupture. RODEO, like other breast imaging techniques, can identify the "linguine" sign of intracapsular rupture (3) (Fig. 1). However, the 3D image-reformatting capabilities of RODEO are especially useful in distinguishing the many folds and undulations frequently seen in prostheses from true tears or extracapsular loculations.

The specificity of RODEO for silicone is particularly valuable in evaluating for extracapsular silicone. In some cases, mammography in concert with sonography is adequate for identifying free silicone. In these cases, the MR findings are characteristic, but add only supporting information (Fig. 2). In many cases, however, the mammographic findings are nonspecific and, in fact, may be highly suspicious for malignancy or other lesion. The RODEO technique is ideally suited for these cases, allowing definite determination of whether the lesion is composed of silicone. If not silicone, a gadolinium-enhanced sequence can further evaluate the lesion to determine its significance (Fig. 3). In our study, free silicone was discovered in 29% of all cases, and in those with confirmation available no false positives were found. This contrasts with mammography, which in this study had a false-positive rate of 31%. No false-negative MR results occurred. Mammographic false-negative values for free silicone were 20% in our study. Unfortunately, less pathologic or surgical confirmation is available in those cases in which the prosthesis was felt to be intact, as fewer of these proceeded to surgery (38 vs. 13%).

TABLE 2. *Pathological evaluation of enhancing lesions discovered*

Histology	No. cases
Infiltrating lobular carcinoma	2
Fibroadenoma	2
Infiltrating ductal carcinoma	1
Lobular carcinoma-in-situ	1
Apocrine cyst	1
Fibrosis	1
Total	8

TABLE 3. *Confirmed cases*

	MR (%)	Conventional imaging (%)
Sensitivity	100	90
Specificity	100	50

However, the number of confirmed cases was nearly equally divided between positive and negative cases (10 vs. 8). In addition, in those cases in which a focal lesion was shown not to be composed of silicone, pathologic evaluation revealed a number of benign and malignant entities (Table 2).

The RODEO imaging was also valuable in patients with prior silicone injections. Although infrequent, this situation can be a mammographic nightmare, and identifying a coexistent cancer is difficult or impossible. In this scenario, the silicone-specific capabilities of RODEO are important not in evaluating free silicone per se, as free silicone is certainly present in abundance, but as a comparison for post-gadolinium exams to exclude the presence of an enhancing lesion. In five cases we were able to evaluate breasts that could not be examined well with mammography, and in one case an enhancing lesion was discovered. Pathologic evaluation of that lesion is not available at this time.

Another benefit of RODEO MRI is the increased amount of the breast and adjacent tissues seen as compared with conventional or modified mammographic views. Breast prostheses frequently obscure lesions on conventional projections and may even lead to a delay in the diagnosis of breast cancer (4,5). The RODEO sequence not only shows the entire breast as well as the adjacent chest wall, but the 3D capabilities allow multiplanar reformatting

FIG. 1. Fat-suppressed (**left**) and silicone-suppressed (**right**) RODEO sagittal images show curvilinear markings within the prosthesis on the fat-suppressed image, representing intracapsular rupture ("linguine sign"). Since both the implant shell and the gel are composed of silicone, both materials are isointense on the silicone-suppressed image.

FIG. 2. a: Mediolateral mammogram reveals lobular collection of high density material in the upper aspect of the breast with an appearance similar to the silicone prosthesis. This was felt to represent extracapsular silicone. b: Fat-suppressed (left) and silicone-suppressed (right) sagittal RODEO images in same location demonstrate a lesion with signal characteristics following the silicone prosthesis on both sequences.

2a,b
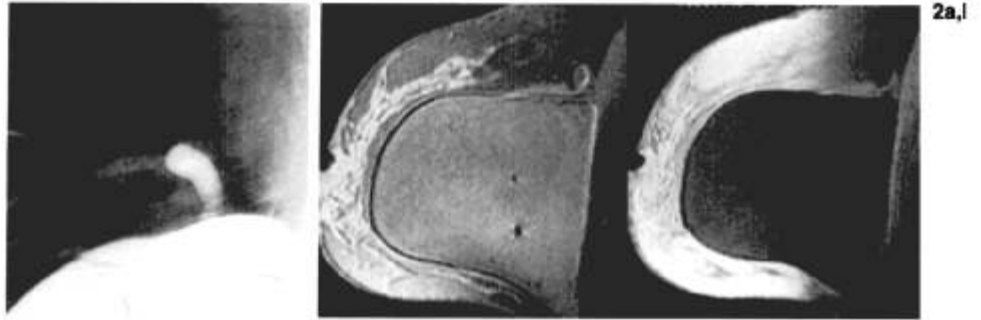
and better evaluation of the periprosthetic breast tissue (Fig. 1).

Several other MR techniques have been employed to evaluate silicone in the breast (3,6). One of these methods is not tissue specific for silicone (3). Another method requires five repetitions to obtain separate water, fat, and silicone images, but

has been implemented as a two image method (silicone and combined fat and water) with three repetitions (6). Inversion recovery prepared water-suppressed scans have been used to distinguish silicone based upon the T1 of fat and the chemical shift of water. This method is time consuming and susceptible to motion artifacts (7). The inversion
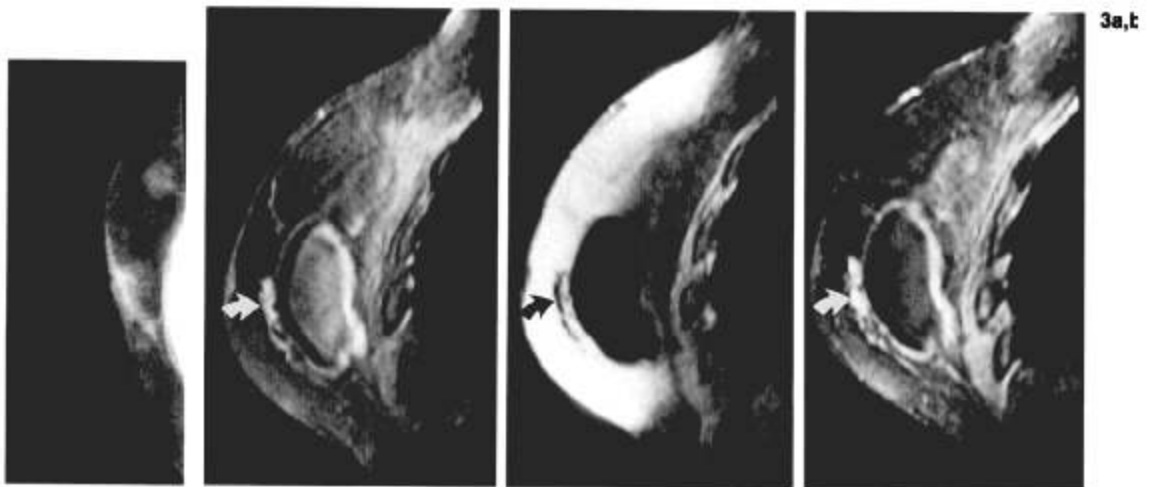

3a,b

3c

FIG. 3. a: Craniocaudal mammogram (Eklund view) reveals a poorly defined, irregular lesion in the upper outer quadrant. This appearance is nonspecific but is worrisome for a malignant lesion. b: Fat-suppressed, silicone-suppressed, and postcontrast fat-suppressed (left to right) sagittal RODEO images reveal a crescentic signal (arrows) anterior to the prosthesis with signal characteristics of free silicone. The appearance of free silicone on pre- and postcontrast fat-suppressed imaging alone could be confused with tumor. c: Precontrast fat-suppressed, postcontrast fat-suppressed, and silicone-suppressed (left to right) sagittal RODEO images of a palpable mass in the inferior aspect of the breast (arrows) demonstrate contrast enhancement without evidence of silicone. Biopsy revealed fibroadenoma.
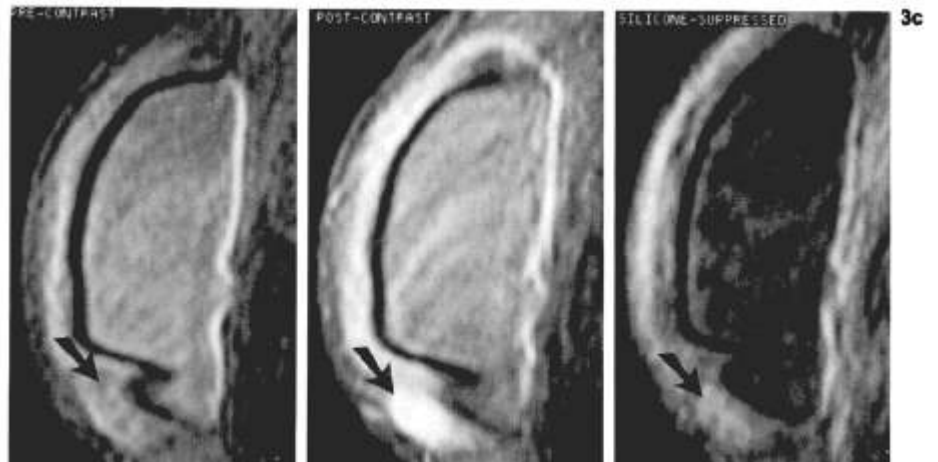
recovery preparation can be used with fast scans, but results in image blurring due to the filling of k-space with data off the T1 null. Water-saturated fast SE can separate silicone based upon the T2 of silicone and the chemical shift of water (8). All of these sequences have been implemented with 2D acquisition methods. When these sequences are designed to make silicone bright, this is done at the expense of a lower signal-to-noise ratio (SNR). The RODEO technique offers the combination of high SNR, fast scanning, and high resolution of 3D imaging.

While the results of our study are encouraging and suggest several areas in which silicone-specific imaging can provide unique and valuable information, there are some limitations. The greatest limitation is the lack of more pathological confirmation. None of the patients who were determined to have intact prostheses chose to undergo surgery unless another lesion was discovered in the breast. While this course lends itself to less documentation, especially in negative cases, it does help validate the utility of our study in that the presence of free silicone in the breast is clearly the finding that determines whether surgery or other intervention is performed. Whether free silicone should play this role is beyond the scope of this article and relates to the ongoing questions regarding the significance of free silicone and the variety of clinical problems alleged to be related to it (9–11).

In addition, postinfusion sequences were performed only in those patients with palpable or mammographic lesions. Additional lesions might have been discovered if postinfusion studies had been performed in all patients, but such was not the intent of the study. Work regarding the use of pre- and postinfusion RODEO has been presented previously (2).

Another limitation regards the size of detectable extracapsular collections of silicone. Despite the high resolution of our technique, collections of free silicone could be identified only if they were at least 2–3 mm in size. Pathologic literature actually suggests that microscopic free silicone is present in all breasts, and therefore the identification of larger collections of silicone may or may not prove to be a useful tool (12,13). A negative MR examination cannot exclude the presence of free silicone.

Since only patients with clinical or mammographic findings were studied, our data should not be extrapolated directly to a screening, asymptomatic population.

We have developed an MRI technique that provides accurate tissue-specific evaluation of silicone in the breast. This specificity for silicone has proven to be valuable in a variety of clinical scenarios in our limited but ongoing study, both as a unique tool to evaluate the augmented breast and as a complement to pre- and postcontrast enhanced

MRI in the evaluation of discrete palpable or mammographic lesions. The potential benefits may increase as more is learned about the significance of free silicone in the breast.

CONCLUSION

In the augmented breast, RODEO permits the assessment of the integrity of the prosthesis itself, identification of free silicone outside the prosthesis, and evaluation of the breast parenchyma. The integrity of the prosthesis can be studied with multiplanar reformatted projections to differentiate folds in the prosthesis from focal areas of distortion of the prosthesis shape and from the "linguine" sign of intracapsular rupture. Free silicone within the breast is well demonstrated with RODEO, and direct comparison between fat-suppressed and silicone-suppressed sequences permits specific identification of silicone. This specificity of the silicone-suppressed images is of value when evaluating the breast with a palpable lump or a focal mammographic finding in the presence of prostheses. While the medical significance of intra- or extracapsular rupture is controversial, the risk of breast cancer is not, and the difficulties that prostheses present to mammography are well recognized. If no free silicone is found in these patients, further assessment can be performed with a postgadolinium fat-suppressed RODEO MR sequence to identify and characterize mass lesions.

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