Magnetic Resonance Imaging of Breast Implants

Mala Shah, MD, Neil Tanna, MD, MBA,† and Laurie Margolies, MD**

Abstract: Silicone breast implants have significantly evolved since their introduction half a century ago, yet implant rupture remains a common and expected complication, especially in patients with earlier-generation implants. Magnetic resonance imaging is the primary modality for assessing the integrity of silicone implants and has excellent sensitivity and specificity, and the Food and Drug Administration currently recommends periodic magnetic resonance imaging screening for silent silicone breast implant rupture. Familiarity with the types of silicone implants and potential complications is essential for the radiologist. Signs of intracapsular rupture include the noose, droplet, subcapsular line, and linguine signs. Signs of extracapsular rupture include herniation of silicone with a capsular defect and extruded silicone material. Specific sequences including water and silicone suppression are essential for distinguishing rupture from other pathologies and artifacts. Magnetic resonance imaging provides valuable information about the integrity of silicone implants and associated complications.

Key Words: breast, implants, MRI, silicone, rupture

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Five to ten million women are estimated to have breast implants globally.[1] Breast augmentation is the most common cosmetic procedure performed in the United States. Each year since 2000, approximately 200,000 to 300,000 cosmetic breast augmentation procedures are performed in the United States annually, with approximately 210,000 silicone implant procedures in 2013. In addition to the silicone implants placed for cosmetic purposes, approximately 69,000 of 96,000 postmastectomy breast reconstruction procedures in 2013 were silicone implants.[1,2] In sum, approximately 80% of silicone implants placed in the United States are for augmentation and 20% are for reconstruction.

Silicone breast implants were introduced in 1962, replacing risky procedures including the direct injection of industrial silicone gel and paraffin into the breasts. Direct injection, although a common practice for decades, was fraught with complications including silicone granuloma formation and embolization. With the advance of breast implants, the silicone gel was encased in a silicone elastomer shell. The first implants, however, suffered from high rates of failure years after surgery and were suspected of being associated with connective tissue disorders. The US Food and Drug Administration (FDA) restricted the use of silicone implants in 1992 but reapproved their use in breast reconstruction surgery in 1998 and cosmetic surgery in 2006 after improvements in design and after the implants were found to have no association with connective tissue disease.[3–5]

Rupture usually occurs spontaneously and is often asymptomatic unless there is accompanying breast deformity or distant migration of silicone gel. Magnetic resonance imaging (MRI) provides excellent spatial resolution and contrast between the prosthesis and normal breast tissue; with an array of sequences, it provides excellent sensitivity and specificity in the detection of common complications. Magnetic resonance imaging is the optimal tool for detecting silicone implant rupture. Clinical examination alone can miss up to half of ruptures.[6] Implant rupture is most common 10 to 15 years after surgery and increases with age; the average incidence is approximately 2 ruptures per 100 implant-years, either intracapsular or extracapsular, with intact rates of 98% at 5 years and 83% to 85% at 10 years.[6] Thus, in 2006, the FDA issued specific guidelines advocating the use of breast MRI as a screening tool for implant failure.[3]

TYPES OF IMPLANTS

A wide variety of breast implants are used today, including single-lumen silicone implants (Fig. 1) and saline implants, textured implants, double-lumen and reversed double-lumen implants, tissue expanders, and stacked implants. Implants can be placed superficial to the pectoralis muscle (subglandular or retromammary) or deep to the pectoralis muscle (retropectoral, subpectoral, submuscular). Recently, combined implants (eg, dual-plane mammoplasty) have been used with varying degrees of success, in which the upper part of the implant lies deep to the pectoralis muscle while the lower part lies superficial. Familiarity with the patient's implant is essential before MRI interpretation. Rupture of saline implants is readily apparent by clinical examination and requires no imaging. Tissue expanders are generally considered a contraindication to MRI. Many injection ports are not MRI compatible, and studies have raised concerns about dislodgement; in addition, they can produce significant artifact.[7]

The outer silicone shell of breast implants is composed of silicone rubber. Upon placement within breast tissue, in a process termed *encapsulation*, the shell elicits a foreign body reaction resulting in the formation of a fibrous capsule.[3] The primary complications of silicone implants include capsular contractures, silicone granuloma formation, gel bleed, and rupture. Risk of implant rupture is proportional to its age and inversely proportional to the thickness of the shell. The median implant lifespan is 10.8 years.[8] Over time, different implant modifications and types have been introduced to reduce these complications. Double-lumen implants, in which an inner silicone component is usually surrounded by an expandable saline component (although some double-lumen implants are silicone/silicone); reversed double-lumen implants; and stacked implants may carry some surgical and safety advantages. Subpectoral implants result in a lower incidence of fibrous contracture but a higher incidence of rupture.[3]

First-generation implants from the 1960s and 1970s are rarely encountered in clinical practice. Second- and third-generation implants carry high risks of rupture and continue to be seen in practice. Fourth- and fifth-generation implants were introduced in the 1990s to reduce implant complications mostly based on modifications in the gel composition and structure of the shell. These are summarized in Table 1.[3,4,9–11]

INDICATIONS FOR MRI

The primary role of MRI of silicone breast implants is to evaluate the integrity of the implant. The FDA recommends that patients with silicone breast implants undergo screening for "silent rupture" 3 years after implantation and every 2 years after that.[12,13]

From the *Ichan School of Medicine at Mount Sinai, New York; and †North Shore-LIJ Health System, Manhasset, NY.
Reprints: Mala Shah, MD, Ichan School of Medicine at Mount Sinai (e-mail: malatanna@gmail.com).
The authors declare no conflict of interest.

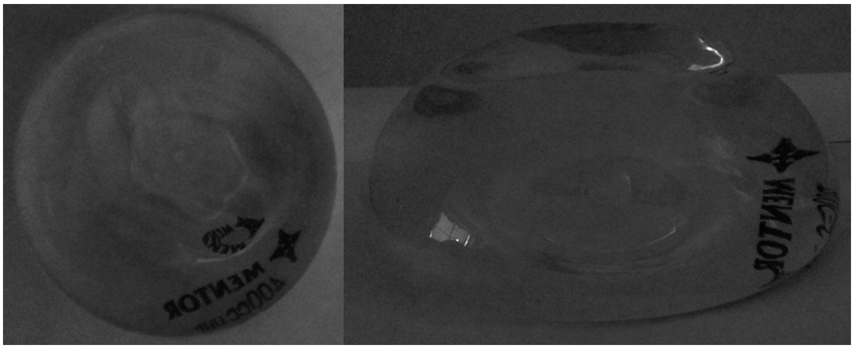

FIGURE 1. Single-lumen silicone implant.

Reporting of MRIs in patients with breast implants must include composition (saline or silicone) and number of lumens. In addition, if MRI is performed to assess for implant rupture, a statement that the breasts have not been assessed for cancer should be included in the report, given the absence of contrast.[14]

Accuracy of MRI detection of silicone implant rupture is purported to be high, ranging from 77% to 95% sensitivity and 85% to 100% specificity in various studies, depending on the techniques used.[6,15] By comparison, ultrasound detection of rupture has reported sensitivities of 47% to 74% and specificities of 55% to 96%.[16] Conventional mammography is not useful in the evaluation of silicone implant integrity. However, a recent meta-analysis of studies that evaluated the diagnostic accuracy of ultrasound and/or MRI for silicone breast implant rupture, while calculating a pooled sensitivity of 87% and pooled specificity of 90% for MRI, found that most of these studies only evaluated symptomatic patients; asymptomatic patients were rarely included.[17] Furthermore, the diagnostic performance for MRI as measured by odds ratio was 14 times better for symptomatic patients versus asymptomatic patients and 2 times better for symptomatic patients versus screened samples. A recent economic cost-benefit analysis suggested the optimal screening strategy is to screen asymptomatic women with silicone breast implants by ultrasound followed by MRI as necessary and to screen symptomatic women with ultrasound.[18]

The question of whether MRI should be used as a cancer screening tool in patients with implants is unsettled. Patients with implants demonstrate no significant differences in the incidence of breast cancer or survival rates.[19–22] However, one recent study found a slightly decreased overall incidence of breast cancer.[23] In addition, an association with primary breast lymphoma, specifically anaplastic large cell lymphoma, developing within the fibrous capsule has been suggested; it can appear as a mass or fluid collection.[24,25] Some have recommended using contrast-enhanced MRI to supplement screening mammography for patients with implants, as suboptimal visualization of the breast parenchyma limits the ability to detect cancers by mammography, particularly in subglandular implants. There is up to 40% decrease in visualized parenchyma, with 55% of cancers missed on mammogram in patients with implants, versus 33% missed in patients without implants, as per some estimates.[26,27] In a 2007 survey, 21% of breast imaging practices used MRI as a cancer screening tool in patients with implants.[28]

MRI TECHNIQUES

Excellent high-resolution and high-contrast images of breast tissue and the implant interface can be achieved using dedicated breast coils using phase-array technology. On standard T2-weighted MR images, water and silicone are bright, with water appearing more hyperintense, and fat is of moderate signal intensity. Dedicated water, fat, and silicone suppression parameters aid in accurately assessing the presence of rupture and avoiding common pitfalls. Note that silicone-suppressed sequences should be performed in 2 planes, sagittal and axial, to further distinguish normal folds from intracapsular rupture.

NORMAL APPEARANCE ON MRI

On MRI, the fibrous capsule of a silicone implant normally appears as a T2-hypointense line surrounding the implant. Capsular

TABLE 1. Chronological Classification of Silicone Implants

Generation	Timeline	Shell	Filler Gel	Advantages	Disadvantages
First	1960s–1970s	Thick elastomer	Thick	Reduced leakage	High rates of contracture and calcification
Second	1970s–1980s	Thinner	Fluid consistency	Improved comfort	High rates of rupture
Third	Late 1980s	Barrier coated	Thicker, more cohesive	Reduced rate of rupture early*	High rates of rupture with age
Fourth	Post-1993	Stronger	Highly cohesive†	Shape retention, prevention of gel migration‡	Capsular contractions
Fifth "gummy bear" "form-stable"	Post-1993	Extremely dense	Semisolid	Shape retention, low rupture	Very few, some report excessive firmness

*Rate of rupture still 15% at 10 years.

†The interpretation on "highly cohesive" varies greatly by manufacturer.

‡Silicone lymphadenopathy still reported. Rates of rupture of less than 3% at 5 to 8 years.

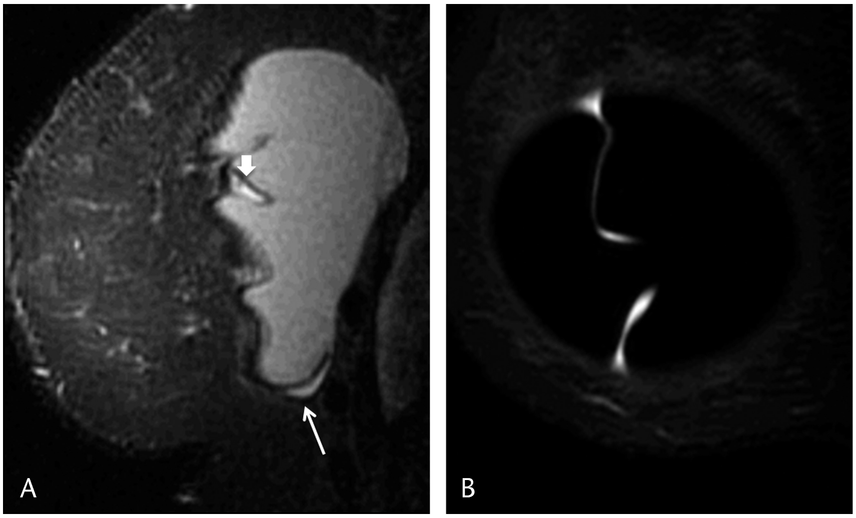

FIGURE 2. Retropectoral silicone breast implants. A, Sagittal T2-weighted short tau inversion recovery sequence demonstrating normal reactive fluid surrounding the capsule (arrow) and normal reactive fluid within a peripheral radial fold (solid arrow). Note the normal undulating contour of the implant at its margin. B, Silicone- and fat-suppressed sequence demonstrating normal reactive fluid signal within the peripheral radial folds.

contour can be slightly irregular secondary to differing pressures from surrounding tissues. The silicone gel itself appears as homogenous high signal on T2-weighted images and low signal on T1-weighted images. A potential space exists at the interface of the implant shell and fibrous capsule, which may contain a small amount of reactive fluid. This is more commonly seen with textured implants and more commonly seen at angled margins of the implant. In addition, the fibrous capsule can elicit a foreign body reaction and chronic inflammation, resulting in a small amount of fluid surrounding the capsule (Fig. 2A).[28,29] Peripheral radial folds are commonly seen at the shell-capsule interface. It is important to trace these folds back to the interface to distinguish normal folds from a potential intracapsular rupture (Fig. 3). Nonetheless, this can be a difficult distinction as even normal folds can have a complex appearance. A small amount of water signal can be seen at the vertex of the peripheral fold, sometime extending into the fold, termed a normal *noose* appearance (Fig. 2B). Free-floating water droplets may be visualized within the silicone gel cavity, usually reflecting injection of steroids, betadine, and/or antibiotics. *Gel bleed* represents microscopic diffusion of silicone through an intact shell and can result in migration of silicone to distant points including axillary and inguinal lymph nodes, abdominopelvic organs, and skin.[29]

Nonsilicone breast implants are commonly seen on breast MRI when performed for other indications. Saline implants appear as low signal on T1-weighted images and high-signal on T2-weighted images and are differentiated from silicone implants by virtue of low signal on silicone-sensitive sequences and slightly higher signal on normal T2-weighted sequences (Fig. 4). The saline component of double-lumen implants appears hyperintense compared with the silicone component on T2-weighted sequences. Free silicone injections appear as multiple nonenhancing T1-hypointense

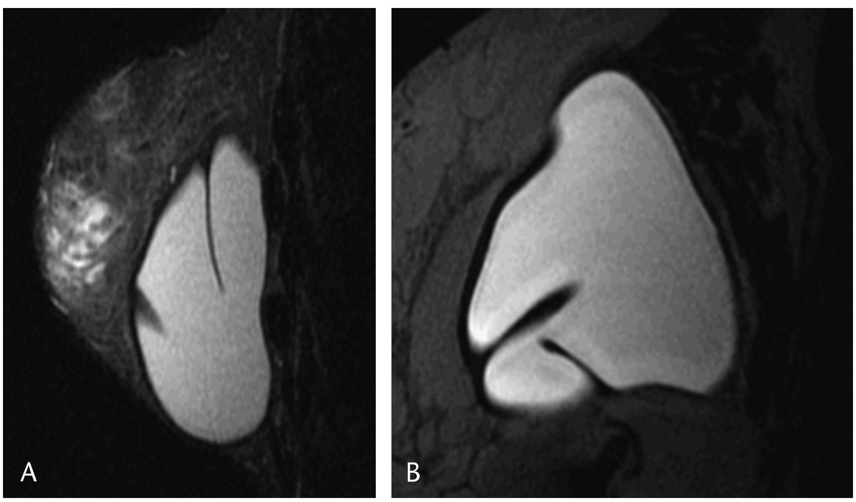

FIGURE 3. Retropectoral silicone breast implants. Sagittal T2-weighted short tau inversion recovery sequences demonstrating normal appearance of peripheral radial folds.

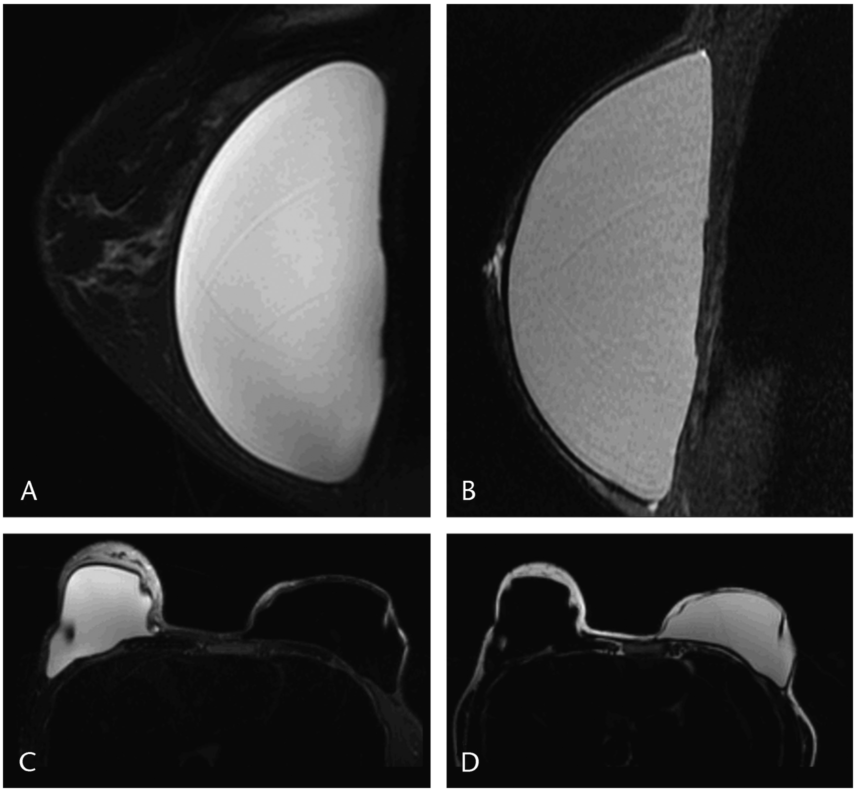

FIGURE 4. Sagittal T2-weighted sequences demonstrating saline (A) and silicone (B) breast implants. Axial silicone-suppressed image of a right-sided saline implant (C) and axial silicone-sensitive sequence of a left-sided silicone implant (D) in a single patient. Note the higher signal and smooth appearance of the saline implant.

and T2-hyperintense masses; the resultant masses and artifacts hinder the sensitivity of mammography and ultrasound. Autologous fat augmentation is high signal on T1- and T2-weighted sequences and suppresses on fat suppression sequences. Polyacrylamide gel injections appear as T1-hypointense and T2-heterogenous masses with variable enhancement and hypointensity on silicone-sensitive sequences.[28,30]

IMAGING OF COMPLICATIONS

Fibrous contractures are most common within months of surgery, when the fibrous capsule surrounding the shell can constrict, likely secondary to foreign body reaction.[4,28,31] Contracture is primarily a clinical diagnosis, marked by firmness and sphericity of the implant accompanied by breast pain, distortion, and inflammation. Contracture occurs more commonly with smooth-surfaced silicone implants and subglandular implants.[19] The polyurethane foam coating on textured implants reduces the incidence of contracture, but its use was discontinued in the United States because of carcinogenic risks, although it continues to be available in other countries.[3] Magnetic resonance imaging does not add significantly in assessing fibrous contractures. Nonetheless, contracture may appear as irregularity and thickening of the normally smooth capsular contour, a serrated appearance of the implant margins, an increased number of radial folds, or an increased AP diameter.[3,28] Note that enhancement of the capsule can be seen in asymptomatic patients and should not be interpreted as pathologic (Fig. 5).[3]

Most often, implants rupture because of mechanical forces resulting in a gradual weakening and thinning of the structure of the silicone shell. An accumulation of radial folds may portend rupture. Various other etiologies can cause implant rupture, including accidental trauma and closed capsulotomy surgeries. Ruptures are classified into intracapsular and extracapsular, dependent on the integrity of the fibrous capsule surrounding the silicone shell. Intracapsular ruptures comprise 77% to 89% of ruptures.[8] They are usually clinically silent. Intracapsular rupture reflects leakage of silicone outside of the shell but contained within the fibrous capsule. It encompasses a spectrum of rupture beginning with uncollapsed rupture progressing to tears and collapse of the shell. Up to 52% of ruptured implants demonstrate only an uncollapsed rupture or minimal collapse.[32]

Uncollapsed Rupture

Intracapsular rupture begins with diffusion of silicone gel across the shell over time. This migration of gel occurs through microscopic defects found in the shell, often along areas of weakening adjacent to radial folds. On imaging, gel can be seen in the potential space between the shell and fibrous capsule, manifesting as silicone signal instead of normally seen water signal. Silicone signal in this potential space has been variably termed the *noose, teardrop, lasso,* or *keyhole* sign (Figs. 6 and 9). Note that a single *noose* sign can be normal, and usually, multiple signs in which silicone is present both inside and outside of radial folds are diagnostic of rupture.

Minimal Collapse

Uncollapsed rupture progresses to minimal collapse—the implant wall retracts, and silicone accumulates beyond the shell.

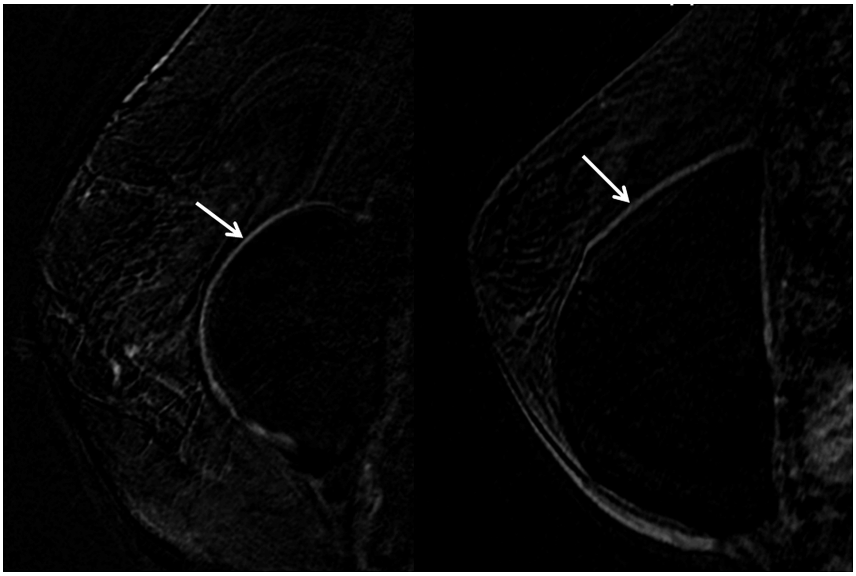

FIGURE 5. Sagittal fat-saturated contrast-enhanced subtraction images demonstrating normal capsular enhancement (arrows) in 2 different patients.

On MRI, this creates the *subcapsular line* sign, which is a dark wavy line following the implant contour (Figs. 7 and 9). The implant envelope has ruptured, but the fibrous capsule that was formed by the body's reaction to the implant remains intact. The fibrous capsule keeps the silicone from touching the breast or other tissue. The implant's envelope collapses into the space maintained intact by the fibrous capsule. Silicone is able to leak between the envelope and the capsule creating the subcapsular line.

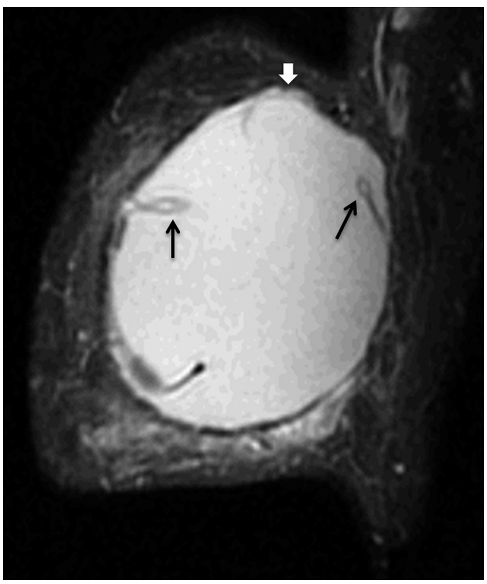

FIGURE 6. Sagittal T2-weighted water-suppressed sequence. *Noose* signs in a single-lumen silicone breast implant (arrows). Silicone signal is seen both within and outside the radial folds, distinguishing this from normal radial folds. Note the bulge in contour at the cephalad margin of the implant (solid arrow). This can be a sign of extracapsular rupture; however, here, the surrounding capsule is intact.

Gross Collapse

Progression to gross collapse is seen as the *linguine* sign (the MRI correlate of the *stepladder* sign on ultrasound). This appearance, marked by multiple low-signal curvilinear lines, represents the multiple layers of collapsed elastomer shell floating within the silicone gel (Figs. 8 and 9).[19,33]

The droplet sign, although not diagnostic of rupture when seen in isolation, can be seen in combination with any of the previously mentioned findings (Fig. 7). The sign reflects droplets of water suspended within the silicone gel.

With double lumen implants, the *salad oil* sign can be seen when the inner silicone component ruptures, leading to free mixing of saline with the silicone component.[19,33] This manifests as multiple T2-hyperintense foci (hypointense upon water suppression) within the envelope. When only the outer saline component ruptures, the saline eventually resorbs and disappears, leading to an appearance of a single-lumen silicone implant, sometimes surrounded by a small amount of remaining fluid. Such an appearance places added value on knowing what type of implant one is assessing (Fig. 10).

Extracapsular ruptures where the implant and the fibrous capsule rupture are identified when silicone leaks out of the ruptured fibrous capsule and into the surrounding tissue. They are usually managed with explantation to avoid complications such as silicone granuloma formation. Magnetic resonance imaging is an excellent modality for assessing extracapsular ruptures, which are much less common than intracapsular ruptures.[8,29] In one study, 22% of all ruptures detected on MRI were extracapsular.[8] On imaging, a bulge can be seen in the capsular contour, with loss of the normal hypointense capsular signal, suggesting a true leak rather than focal herniation given the presence of a capsular defect (Fig. 11).[3] Silicone lymphadenopathy can indicate extracapsular rupture when seen in the presence of other signs, although it can be also seen with *gel bleed* (Fig. 12). Coexisting granulomatous reaction within silicone granulomas can reduce the signal of silicone, making it difficult to distinguish from the normal intermediate signal of fat. In these cases, focal extracapsular signal just slightly hypointense to intracapsular silicone indicates

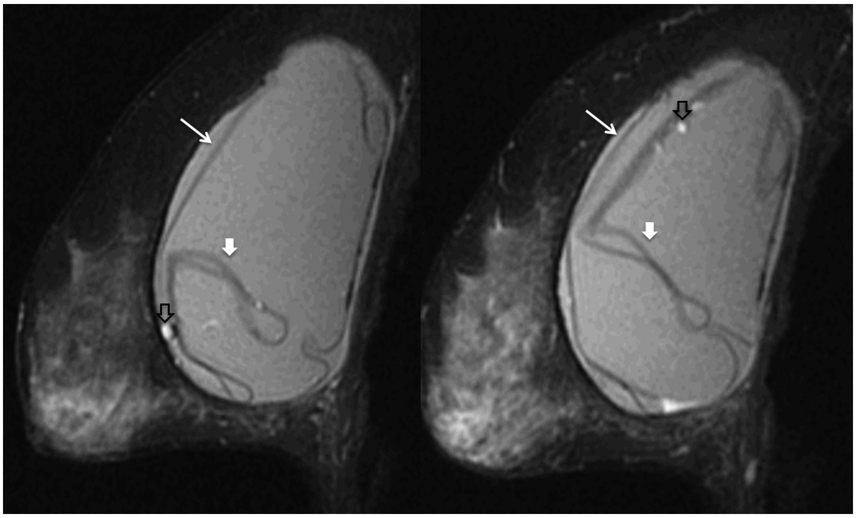

FIGURE 7. Sagittal T2-weighted water-suppressed sequence. Multiple T2-bright water droplets identified within the silicone envelope (open arrows) of a single-lumen silicone breast implant, likely indicating mixing of reactive subcapsular fluid with the silicone gel. When seen in isolation, this can be a normal finding. Here, they are consistent with intracapsular collapse in the presence of *subcapsular line* (arrows) and *linguine* (solid arrows) signs.

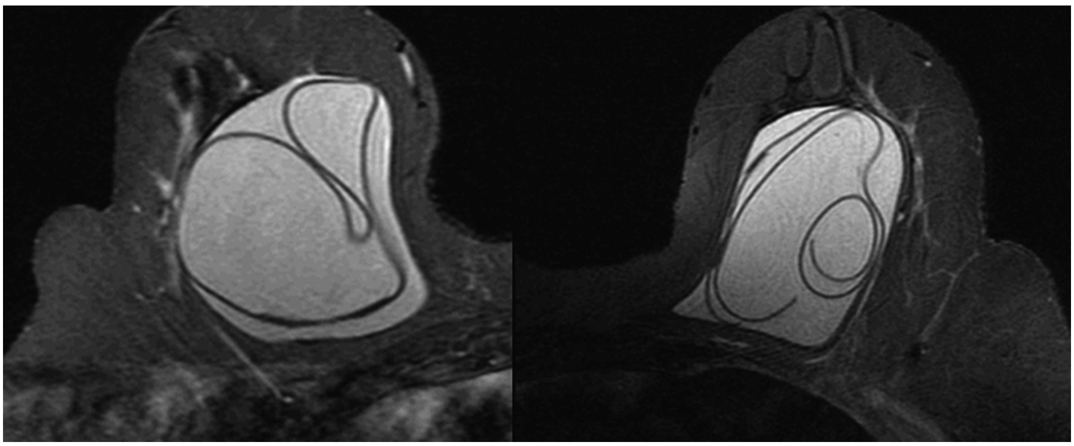

FIGURE 8. Silicone breast implants. Sagittal T2-weighted water-suppressed sequences demonstrating *linguine* sign. Curvilinear lines represent collapse of the implant shell with silicone inside and outside the implant lumen confined by the capsule, compatible with gross intracapsular collapse.

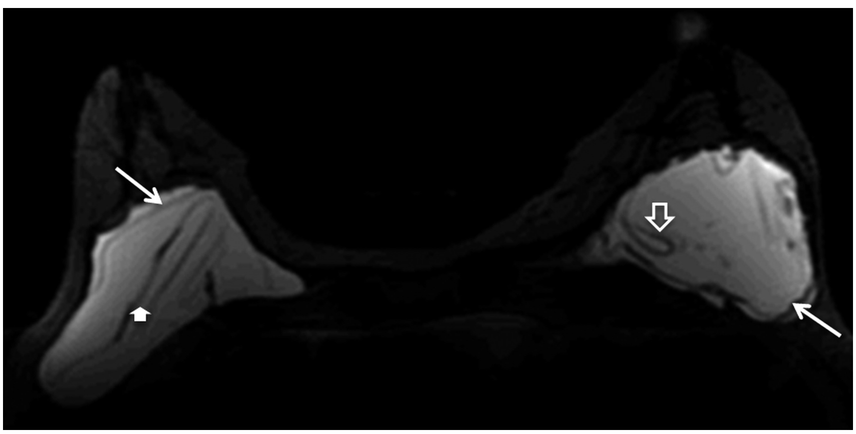

FIGURE 9. Axial silicone-sensitive sequence of a silicone breast implant. Summary of the signs of intracapsular rupture. Seen here are *noose/keyhole* (open arrow), *subcapsular line* (arrows), and *linguine* (solid arrow) signs.

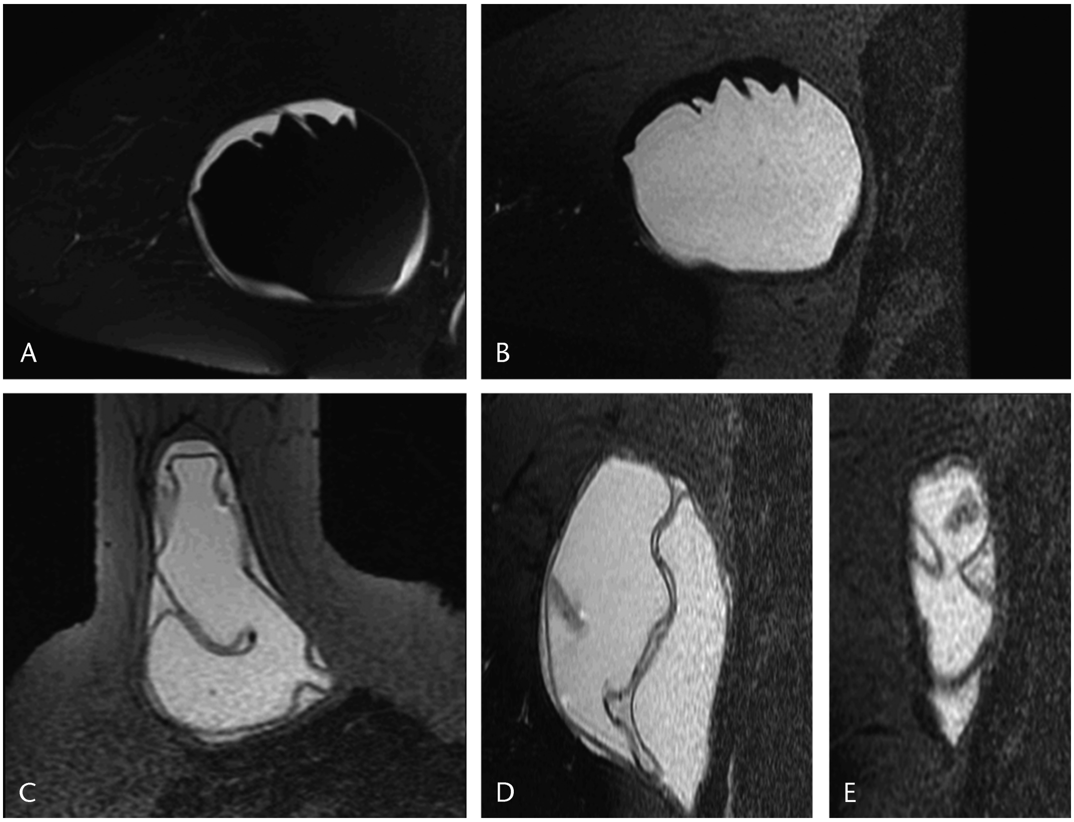

FIGURE 10. Bilateral double-lumen breast implants, with inner silicone component and outer saline component. Sagittal silicone-suppressed (A) and silicone-sensitive (B) sequences of the right breast. Although significant infolding of the silicone envelope is present, there is no evidence of silicone or saline component rupture. Axial (C) and sagittal (D) short tau inversion recovery sequences of the left breast. *Subcapsular line* and *linguine* signs indicate intracapsular rupture of the inner silicone component. No residual outer saline component is identified, also indicating saline component rupture. E, Sagittal short tau inversion recovery sequence of the left breast again demonstrating saline component rupture. Extracapsular rupture is also present.

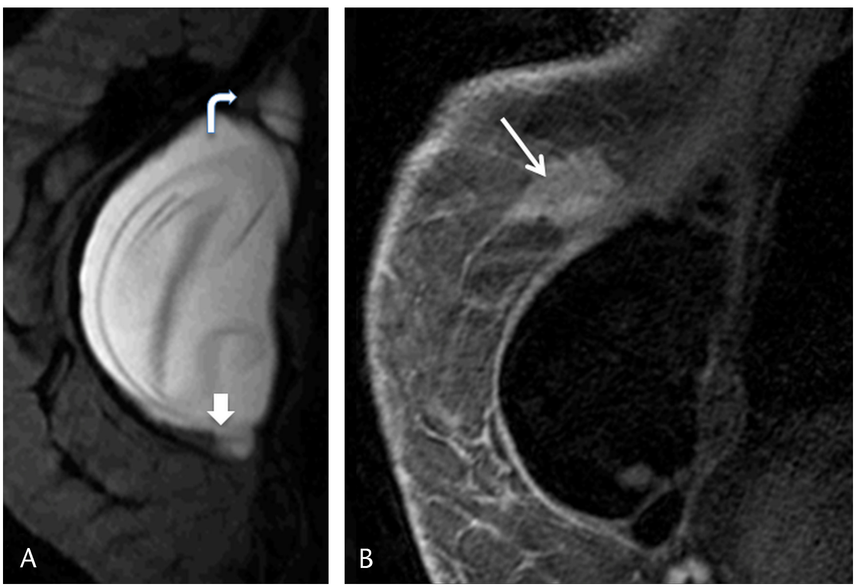

FIGURE 11. Subpectoral silicone breast implant demonstrating bilateral intracapsular and extracapsular rupture. A, Sagittal silicone-sensitive sequence demonstrating intracapsular rupture with *linguine* sign. Extracapsular rupture is seen at the superior margin of the implant with a contour bulge accompanied by capsular defects, with silicone present outside the hypointense capsular line (curved arrow). Inferiorly, a focal herniation is noted (solid arrow). The capsular line remains intact, with no extracapsular silicone signal. B, Sagittal silicone-suppressed contrast-enhanced sequence clearly depicting patient's malignancy (arrow) as well as extracapsular rupture at the superior and inferior margins.

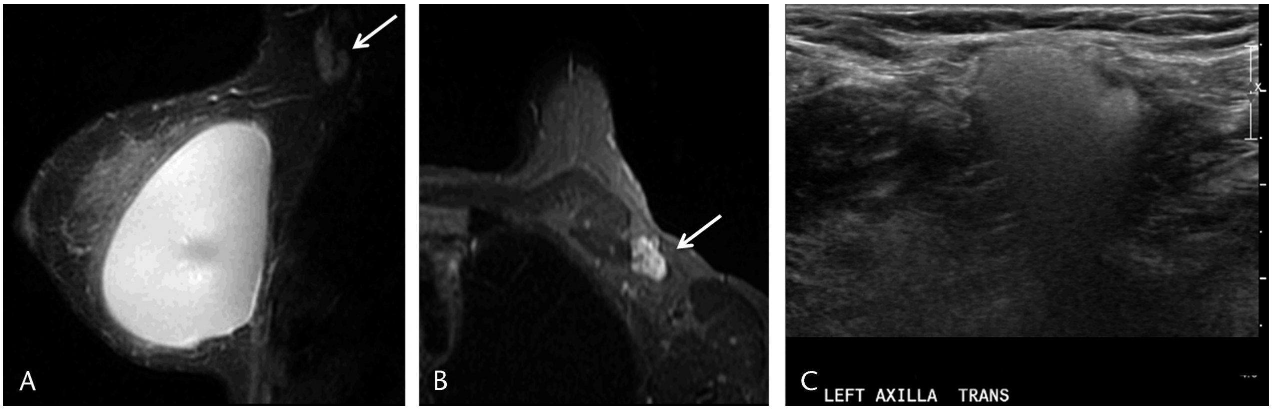

FIGURE 12. Silicone breast implant. Sagittal short tau inversion recovery sequence (A) and axial water-suppressed sequence (B) demonstrating bright signal within axillary lymph nodes, suggesting the presence of silicone (arrows). This can reflect *gel bleed* or extracapsular rupture. An intact implant is identified. C, Ultrasound image of the axilla depicts the classic *snowstorm* appearance of silicone within a lymph node.

extracapsular rupture.[32] A fat-suppressed or silicone-suppressed T2-weighted inversion recovery sequence will increase the signal of granulomatous reaction, but it still remains difficult to distinguish from normal fibroglandular tissue. In these cases, a water-suppressed (silicone-sensitive) sequence is useful because only silicone appears as bright signal. In borderline cases, correlation can be obtained with ultrasound, which demonstrates a *snowstorm* appearance in extracapsular rupture (Fig. 12).[34]

Additional MR interpretation pitfalls include the following:

- Silicone granulomas can display enhancement characteristics similar to those of breast cancer, making biopsy necessary in these cases.[19]
- A so-called *rat-tail* sign, which manifests as a wisp of silicone signal extending linearly from the implant, often results in false-positive readings. When thick, it likely reflects flattening of the implant between the chest wall and breast coil in a prone patient, and when thin, the appearance is nonspecific as an isolated finding.[35]
- Many complex and custom implants can be difficult to interpret if the implant type is not known; in some cases, their appearance can mimic *linguine* sign.[35]
- Ghosting artifact from movement can mimic *subcapsular line* sign.
- A double-lumen implant must be distinguished from a single-lumen silicone implant surrounded by reactive fluid. Similarly, a single-lumen silicone implant must be distinguished from a double-lumen implant in which there has been resorption of the outer saline component because of rupture.
- On occasion, incomplete water suppression on a silicone-sensitive sequence can cause cysts or even pleural effusions to mimic extracapsular silicone.[3]
- Chemical shift artifact at the silicone–soft tissue interface must be distinguished from encapsulation.
- In fifth-generation gummy bear implants, the normal MRI signs of extracapsular rupture may not be seen. The semisolid gel is unlikely to migrate through shell or capsular defects; “gel fracture” remains a rare complication in these implants.[3]

REPORTING OF IMPLANTS

The 2013 edition of Breast Imaging Reporting and Data System includes a detailed breast implant section and suggests 7 characteristics that might be included.[36] Of course, if implants are present, the report should so state.

1. The material that the implant is made of, the lumen type, and whether the implant is intact
2. Whether the implant is retroglandular or retropectoral
3. The presence of contour abnormality such as a focal bulge where the implant herniates through the fibrous capsule
4. If the implant is composed of silicone, one should include findings present within the capsule such as radial folds, subcapsular line, keyhole sign, or linguine sign
5. If there is extracapsular silicone in either the breast or the lymph node
6. The presence of water droplets
7. The presence of peri-implant fluid

CONCLUSIONS

Breast augmentation is the most common cosmetic procedure performed in the United States today. Approximately three quarters of implants are silicone, and therefore, it is important for the radiologist who interprets breast MRI to be familiar with their normal and abnormal appearance. Although newer generations of silicone implants feature significant advantages in integrity, rupture remains a continuing and somewhat expected chronic risk of implant placement. Magnetic resonance imaging has become an essential tool in assessing the integrity of silicone breast implants. There are a finite number of imaging appearances of implant rupture on MRI, allowing the diligent radiologist to quickly gain familiarity with the basic signs of intracapsular and extracapsular rupture. With the aid of specialized sequences, ruptures can be distinguished from artifacts and other pathologies. In addition, it is crucial that imaging is interpreted in the context of knowledge of the patient's surgery, implant type, and potential complications. Controversies surrounding MRI of breast implants, including cost, resource use, and cancer screening continue to be addressed. However, MRI provides excellent sensitivity and specificity in the detection of silicone breast implant rupture.

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