Multimodality Imaging-based Evaluation of Single-Lumen Silicone Breast Implants for Rupture[1]

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Abbreviations: FSE = fast spin-echo, MLO = mediolateral oblique, STIR = short inversion time inversion-recovery

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Describe the strengths and limitations of mammography, US, and MR imaging for evaluation of implant rupture.
- Recognize the signs of intracapsular rupture of silicone implants at US and MR imaging.
- Identify US and MR imaging findings that may mimic findings of intracapsular rupture.

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Breast implants are frequently encountered on breast imaging studies, and it is essential for any radiologist interpreting these studies to be able to correctly assess implant integrity. Ruptures of silicone gel–filled implants often occur without becoming clinically obvious and are incidentally detected at imaging. Early diagnosis of implant rupture is important because surgical removal of extracapsular silicone in the breast parenchyma and lymphatics is difficult. Conversely, misdiagnosis of rupture may prompt a patient to undergo unnecessary additional surgery to remove the implant. Mammography is the most common breast imaging examination performed and can readily depict extracapsular free silicone, although it is insensitive for detection of intracapsular implant rupture. Ultrasonography (US) can be used to assess the internal structure of the implant and may provide an economical method for initial implant assessment. Common US signs of intracapsular rupture include the "keyhole" or "noose" sign, subcapsular line sign, and "stepladder" sign; extracapsular silicone has a distinctive "snowstorm" or echogenic noise appearance. Magnetic resonance (MR) imaging is the most accurate and reliable means for assessment of implant rupture and is highly sensitive for detection of both intracapsular and extracapsular rupture. MR imaging findings of intracapsular rupture include the keyhole or noose sign, subcapsular line sign, and "linguine" sign, and silicone-selective MR imaging sequences are highly sensitive to small amounts of extracapsular silicone.

Introduction

Breast augmentation is the most common cosmetic surgical procedure performed in the United States, with nearly 300 000 procedures performed annually (1). A majority of these procedures involve placement of silicone gel–filled implants, of which many variations exist in terms of available sizes, contouring, degree of shell texturing, and other components to appropriately tailor the implant to the individual woman's body habitus or personal preference (2).

The first silicone gel implants were developed in the early 1960s to replace direct injection of silicone gel or paraffin (3). Early generations of silicone implants suffered from high failure rates, and suspicion was raised about a possible link to connective tissue disorders. Recognizing these adverse events, the U.S. Food and Drug Administration banned the use of silicone implants in 1992 but reversed this decision in 2006, after manufacturers made improvements in implant design and when no association was found with connective tissue or autoimmune disorders (2,4,5). Fourth- and fifth-generation implants contain a more highly cohesive or semisolid filler gel encapsulated by a stronger and denser elastomer shell. Both types have the advantage of improved shape retention and a possibly lower incidence of rupture.

TEACHING POINTS

- With gel bleed, evidence of silicone in the lymph nodes will become apparent at imaging, even though the implant remains intact.
- Mammography is a reliable, cost-effective, readily available imaging technique that easily demonstrates free or residual silicone in the breast parenchyma, which is the hallmark of extracapsular rupture. Because of the limited sensitivity of mammography for assessment of intracapsular rupture, supplemental imaging with US and/or breast MR imaging is often required.
- Classic US signs of intracapsular rupture of a silicone implant include the "keyhole" or "noose" sign, the subcapsular line sign, and the "stepladder" sign.
- MR imaging is the most accurate imaging modality for noninvasive evaluation of implant integrity.
- When cohesive implants rupture, the traditional mechanisms of rupture may not occur, and the common imaging signs of rupture may not be present. Cohesive implants may fracture owing to the semisolid nature of the silicone gel.

Rupture has long been recognized as an important and common complication of silicone breast implantation. In general, the prevalence of rupture increases with implant age. The mean lifespan of an implant is approximately 13 years, with deterioration usually caused by weakening of the elastomer shell (6–8). Unlike rupture of a saline implant, which most often occurs in a dramatic fashion and is clinically obvious, silicone implant rupture is frequently asymptomatic and incidentally identified at imaging (9–11). Clinical findings, when present, may include changes in breast size or shape, a palpable abnormality in the breast or axilla, pain, or skin tightening (9,12,13). Mammography has not been proven to cause rupture, although anecdotal cases have been reported (14).

A thin fibrous capsule normally forms around all breast implants, representing an attempt by the body to wall itself off from the foreign object. This fibrous band fully encapsulates the elastomer shell and its contents, creating a barrier that has important implications regarding the pathway of free silicone in the setting of rupture. Free silicone may extrude from a disruption in the elastomer shell but will be confined to the area immediately around the implant if the surrounding fibrous capsule remains intact. This type of rupture, termed *intracapsular rupture*, is by far the most common type, comprising 77%–89% of all ruptures (Fig 1b) (10). Unfortunately, intracapsular rupture is frequently not apparent to the patient or clinician, which often accounts for the low sensitivity for detection at clinical examination (9). Breakdown of the fibrous capsule permits free silicone to enter the surrounding breast parenchyma, a scenario termed *extracapsular rupture* (Fig 1c). Free silicone within the breast tissue may incite inflammatory changes to become clinically apparent.

Mammography, ultrasonography (US), and magnetic resonance (MR) imaging have been used to evaluate silicone implants, with a number of prior studies comparing the diagnostic ability to identify rupture with each modality. In this article, we describe the strengths and limitations of each modality for identification of rupture, discuss the various imaging features signifying rupture for each modality, and highlight important imaging findings that may mimic those of rupture.

Mammography

The most common breast imaging study interpreted by radiologists is the screening mammogram, and, consequently, mammography provides the most frequently encountered opportunity to evaluate implants. Mammography may also provide the first clue about a potential problem with a breast implant. Unfortunately, mammography has long been considered the least sensitive modality to detect rupture when compared with US and MR imaging. Studies comparing the various imaging methods report a mammographic sensitivity of 11%–69% for detection of rupture (10–12,15,16). This low sensitivity is principally derived from the fact that a silicone implant is extremely radiopaque. Silicone implants are normally oval, smooth, and uniformly dense at mammography, thereby preventing any internal substructural evaluation (17). With the limited ability to evaluate implants internally, intracapsular ruptures go unseen, and mammographic sensitivity declines.

Although internal evaluation of the implant is impeded at mammography, the contour of a silicone implant merits close inspection. Comparison with prior mammograms is useful to identify subtle contour changes over time, such as the appearance of undulations, which potentially indicate a problem with implant integrity (Fig 2). Frank bulges or herniations represent areas of weakening of the fibrous capsule and potential weak points of the elastomer shell (Fig 3a). Identification of any of these contour abnormalities, although unreliable in the prediction of rupture, should prompt further investigation (17). An implant that becomes more rounded in appearance may signify the presence of capsular contracture rather than implying a problem with implant integrity. Calcifications along the fibrous capsule, thought to arise as a consequence of a chronic inflammatory response, are more frequently encountered in older implants that have been in place for multiple years (18,19). As such, capsular calcifications correlate with implant age, but calcifications alone do not necessarily imply capsular contracture or implant rupture (18).

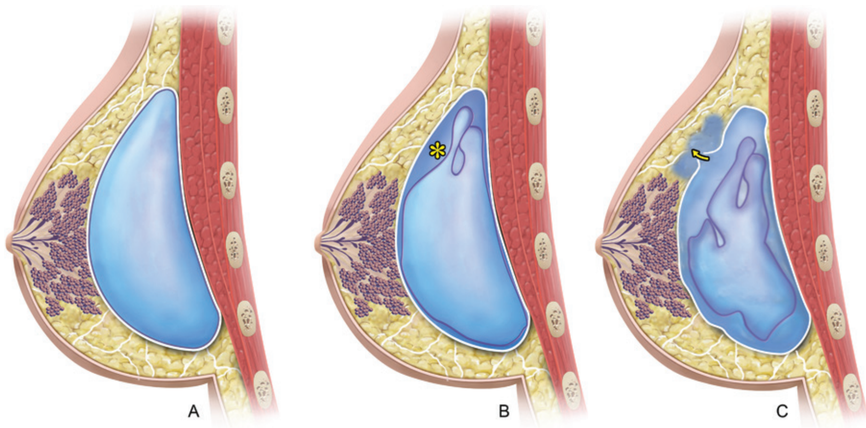


Figure 1. Anatomy of silicone implant rupture. *A,* The elastomer shell (purple outline) of an unruptured retroglandular single-lumen implant abuts and is entirely contained within the fibrous capsule (white outline). *B,* When intracapsular rupture occurs, silicone intercalates between the intact fibrous capsule and the elastomer shell (*). *C,* Disruption of the fibrous capsule allows silicone gel within the intracapsular space to escape into adjacent breast parenchyma (arrow) and is termed *extracapsular rupture.*

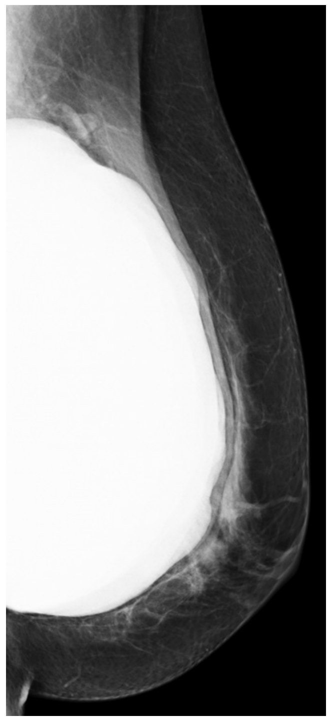


Figure 2. Left mediolateral oblique (MLO) mammogram shows the undulating contour of the anterior margin of a silicone implant, an appearance that may raise suspicion for an implant integrity issue. US images (not shown) confirmed intracapsular rupture.

Although insensitive for identifying intracapsular rupture, mammography is useful in detecting extracapsular silicone (15). When silicone escapes the confines of the fibrous capsule and enters the surrounding breast parenchyma, mammography can often reveal the high-density free silicone (Fig 4). In the absence of a history of implant rupture or revision, the presence of silicone outside the expected contour of the implant signifies extracapsular rupture and, by extension, intracapsular rupture (2). In this scenario, no supplemental imaging is usually required for diagnosis, although additional US or MR imaging may be requested to evaluate the integrity of the contralateral implant before surgical intervention.

The patient may present with a palpable area of concern at the site of silicone extrusion. Spot compression tangential imaging may be helpful to further assess the area, particularly if the implant is superimposed and obscures adequate visualization of the area on standard craniocaudal and mediolateral oblique (MLO) mammograms.

A small amount of free silicone in the breast may appear as a high-density focal asymmetry that can be deemed suspicious for malignancy, particularly when the ruptured implant has been removed. More confluent collections of silicone manifest as high-density granulomas, which can range in appearance from oval circumscribed masses to irregular masses with indistinct or potentially spiculated margins. A high level of suspicion for silicone is needed in these situations to avoid unnecessary biopsy (20).

Extracapsular silicone may dissect along fascial planes, extending along the pectoralis major muscle or subcutaneous tissues, and may greatly enlarge regional lymph nodes after filling the draining lymphatics (19). However, the mere presence of silicone within axillary lymph nodes is not sufficient to diagnose implant rupture because of the confounding effects of what is termed *gel bleed*. Silicone gel is usually secured within a complex polymer, but cross-linkages can break down over time, which allows small unpolymerized silicone molecules to permeate an intact elastomer shell. The lymphatics collect and transport these freed silicone molecules to regional lymph nodes. With gel bleed, evidence of silicone in the lymph nodes will become apparent at imaging, even though the implant remains intact. Nevertheless, mammographically depicted silicone-laden lymphadenopathy should warrant evaluation of the implant with US or MR imaging.

It should be emphasized that, in the setting of breast cancer screening, the primary purpose of

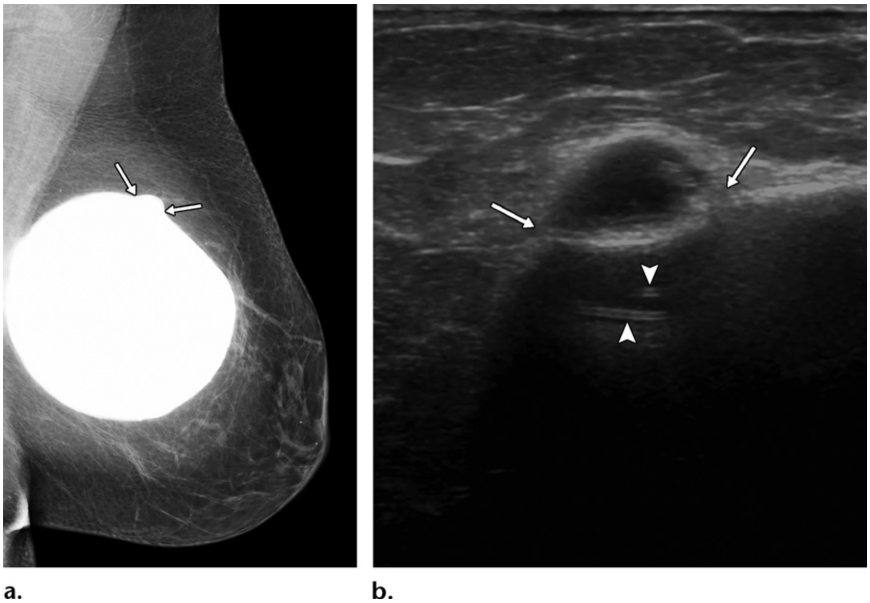


Figure 3. Silicone implant bulge. **(a)** Left MLO mammogram shows a focal bulge (arrows) along the superior aspect of a silicone implant, potentially exposing an implant integrity issue. **(b)** Targeted US image depicts not only the bulge (arrows) but also parallel echogenic lines in the interior of the implant (arrowheads) that correspond to an inwardly displaced elastomer shell, indicating intracapsular rupture. Note the absence of the usual trilaminar line.

Figure 4. Left MLO mammogram shows extensive high-density free silicone within the breast tissue of the axillary tail that extends along the pectoralis major muscle, a finding consistent with extracapsular rupture.

the examination remains the detection of breast cancer and not the evaluation of implant integrity. However, mammography is a reliable, cost-effective, readily available imaging technique that easily demonstrates free or residual silicone in the breast parenchyma, which is the hallmark of extracapsular rupture (6). Because of the limited sensitivity of mammography for assessment of intracapsular rupture, supplemental imaging with US and/or breast MR imaging is often required.

Ultrasonography

Several studies comparing US with mammography and MR imaging have found the sensitivity of US to be superior to that of mammography but inferior to that of MR imaging for detection of implant rupture, with the reported sensitivity of US ranging from 30% to 75% (15–17,21–24). The negative predictive value of US tends to be higher (in the 50%–90% range), which suggests that US may be useful in the initial evaluation of suspected rupture, given that US is usually faster, cheaper, easier for the patient to undergo, and more readily available than MR imaging (25). A recent economic cost-benefit analysis found the optimal implant rupture screening strategy for both asymptomatic and symptomatic women to be US followed by MR imaging as necessary (26).

Many patients with breast implants undergo US for reasons entirely unrelated to their implant, such as evaluating an area of concern noted on their screening mammogram. Detection of a rupture in this setting would be incidental. Given that breast US is a much more frequently performed examination than breast MR imaging, it is important for sonographers and radiologists to understand the normal appearance of implants and recognize features that suggest rupture.

Technical Considerations

A sonographic evaluation is operator dependent, and there is a learning curve involved in the proper US interrogation of breast implants. To begin, the US image should be optimized for evaluation of the implant rather than the breast parenchyma.

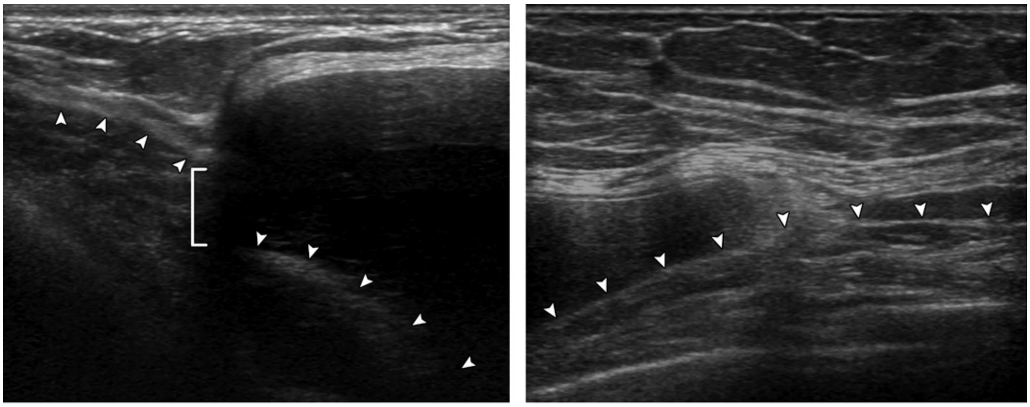


Figure 5. Determining implant type at US. **(a)** US image obtained at the periphery of a silicone implant shows the step-off phenomenon (bracket); the normal fascial plane (arrowheads) is disrupted at the implant edge because the slowing of sound through silicone within the implant causes normal soft tissue posterior to the implant to appear farther away. **(b)** US image of a saline implant in a different patient shows continuity of the fascial plane (arrowheads), without a step-off, at the interface of the implant and adjacent soft tissues.

The entire implant should be included in the field of view and the focal zones placed at an appropriate depth. A high-frequency (eg, 7–12-MHz) linear probe should be used to provide better delineation of the trilaminar fibrous capsule–elastomer shell complex, although a slightly lower–frequency (eg, 5.0–7.5-MHz) transducer may help with deep focusing, especially for larger breasts.

Extended field-of-view imaging may also be a useful assessment tool to globally assess the implant and its positioning within the breast. This panoramic technique should not be exclusively relied on for assessing implant integrity, as it lacks sufficient resolution and may obscure some of the classic signs of rupture more easily seen on single static images. Split-screen imaging can also be employed, using the contralateral side as a control, to evaluate questionable alterations in internal echogenicity (27). Mirror-image regions are jointly evaluated (eg, comparing the right 9-o'clock region to the left 3-o'clock region).

When beginning an implant evaluation, it is useful to first know what type of implant is in place. The patient can generally provide this information when asked, but this answer may be unreliable, especially if one or several implant exchanges have occurred. The easiest way to determine the implant type is to consult the mammogram, although a prior or current mammogram may not be available, such as when imaging young patients. The implant type can be determined at US by examining the implant at its margin and witnessing the effect the implant has on surrounding normal tissue. Because the speed of sound through silicone (997 m/sec) is slower than that through soft tissues and saline (1540 m/sec), it will take longer for sound waves to travel through a silicone implant compared with through a saline-filled implant. Consequently, the tissues deep to a silicone implant appear to be farther away, and a step-off phenomenon is created at the edge of the implant (Fig 5). This artifactual shift is easier to detect as the thickness of the implant increases. Thus, light compression during scanning is recommended because it also helps to minimize reverberation echoes (27).

Normal Appearance

A single-lumen silicone implant is most often featureless and anechoic, which provides reliable US evidence that the implant remains intact and undamaged (28). A normal implant exhibits a smooth contour outlined by a trilaminar margin, which corresponds to the capsule-shell complex discussed in more detail in the next subsection.

Implants will often infold on themselves within the surgical pocket created by the plastic surgeon. These radial folds are a common feature of implants and should be recognized as a normal infolding of the elastomer shell rather than mistaken for evidence of intracapsular rupture.

Capsule-Shell Complex

Over time, a fibrous capsule forms around and closely approximates the implant elastomer shell. This fibrous capsule–elastomer shell complex appears at US most commonly as a trilaminar line at the periphery of the implant (Fig 6). The outer echogenic line corresponds to the outer surface of the capsule, the middle echogenic line represents a fusion of two echogenic lines corresponding to the inner surface of the capsule and the outer surface of the elastomer shell, and the inner echogenic line corresponds to the inner surface of the elastomer shell (27). The intervening isoechoic space between the

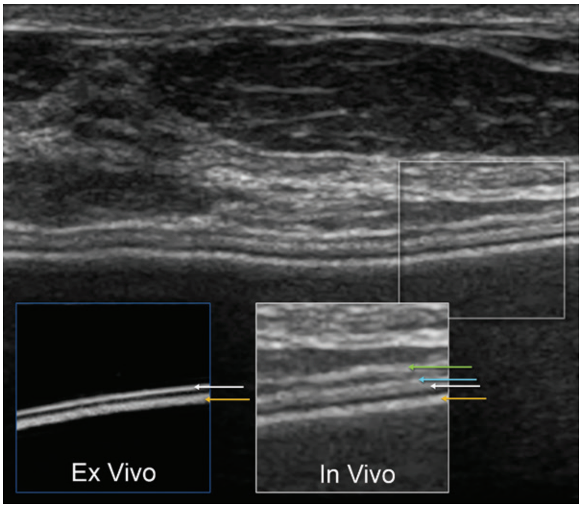
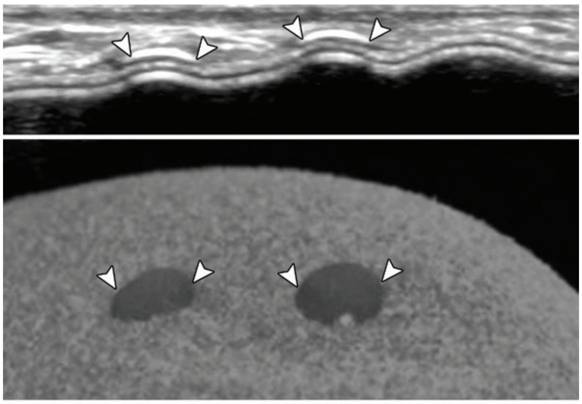


Figure 6. US images show the normal fibrous capsule–elastomer shell complex as a trilaminar line. In the top image and right inset *(In Vivo),* the most superficial hyperechoic line (green arrow) represents the outer aspect of the fibrous capsule, while the deepest hyperechoic line (yellow arrow) represents the inner aspect of the elastomer shell. The middle hyperechoic line is usually seen as a combination of two hyperechoic lines: the inner aspect of the fibrous capsule (blue arrow) and the outer aspect of the elastomer shell (white arrow). For comparison, the left inset US image *(Ex Vivo)* of a silicone implant submerged in a water bath reveals only two hyperechoic lines, which represent the outer (white arrow) and inner (yellow arrow) aspects of the elastomer shell.



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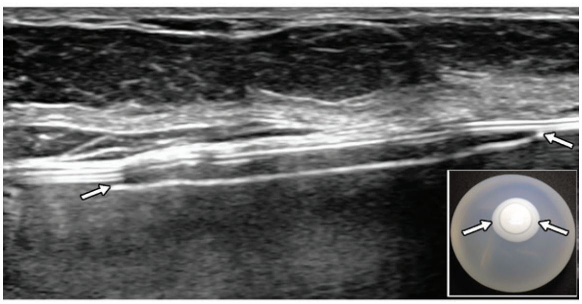


b.

Figure 7. Normal components of silicone implants. Silicone implants may vary in appearance depending on the manufacturer. **(a)** Alignment of a US image (top) and macrophotograph (bottom) demonstrates curved hyperechoic lines that correspond to orientation marks on a textured cohesive silicone implant (arrowheads). **(b)** US image and inset photograph of a silicone implant demonstrate a silicone patch (arrows) that results in localized expansion of a portion of the normal trilaminar line, mimicking the subcapsular line sign.

outer and middle echogenic lines reflects the thickness of the fibrous capsule, and the intervening anechoic space between the middle and inner echogenic lines reflects the thickness of the elastomer shell (27).

Demonstration of a normal trilaminar line during global assessment of an implant provides good evidence that the implant remains intact. Note that silicone orientation marks and patches are normal components of some types of silicone implants and will focally interrupt this normal trilaminar configuration (Fig 7) (12,29). Localized distortion or thickening or additional hyperechoic lines may relate to one of these normal components.

Bulges and herniations are protrusions of the elastomer shell outside the expected contour of the implant (Fig 3). These contour abnormalities occur in areas where the fibrous capsule is thinned or disrupted and often signal an implant integrity issue. Therefore, careful evaluation of the implant is required when these protrusions are noted.

Intracapsular Rupture

The spectrum of US findings seen with intracapsular rupture of a silicone implant is related to the location of the initial rupture, the amount of silicone extruded into the intracapsular space, and the degree of collapse of the elastomer shell. Classic US signs of intracapsular rupture of a silicone implant include the "keyhole" or "noose" sign, the subcapsular line sign, and the "stepladder" sign.

The apex of a radial fold can represent a weak point in the elastomer shell. Silicone may begin to collect within and expand a radial fold, giving the appearance of a keyhole or noose, which is considered one of the earliest signs of intracapsular rupture (Fig 8a). Silicone may also escape through a rent in the shell, distorting the configuration of the normal trilaminar line as the rupture develops. Extruded silicone wedges itself between the shell and the fibrous capsule, within the intracapsular space, causing a sheetlike separation. The shell is displaced inwardly, producing the subcapsular line sign (Fig 8b) (8). To differentiate the subcapsular

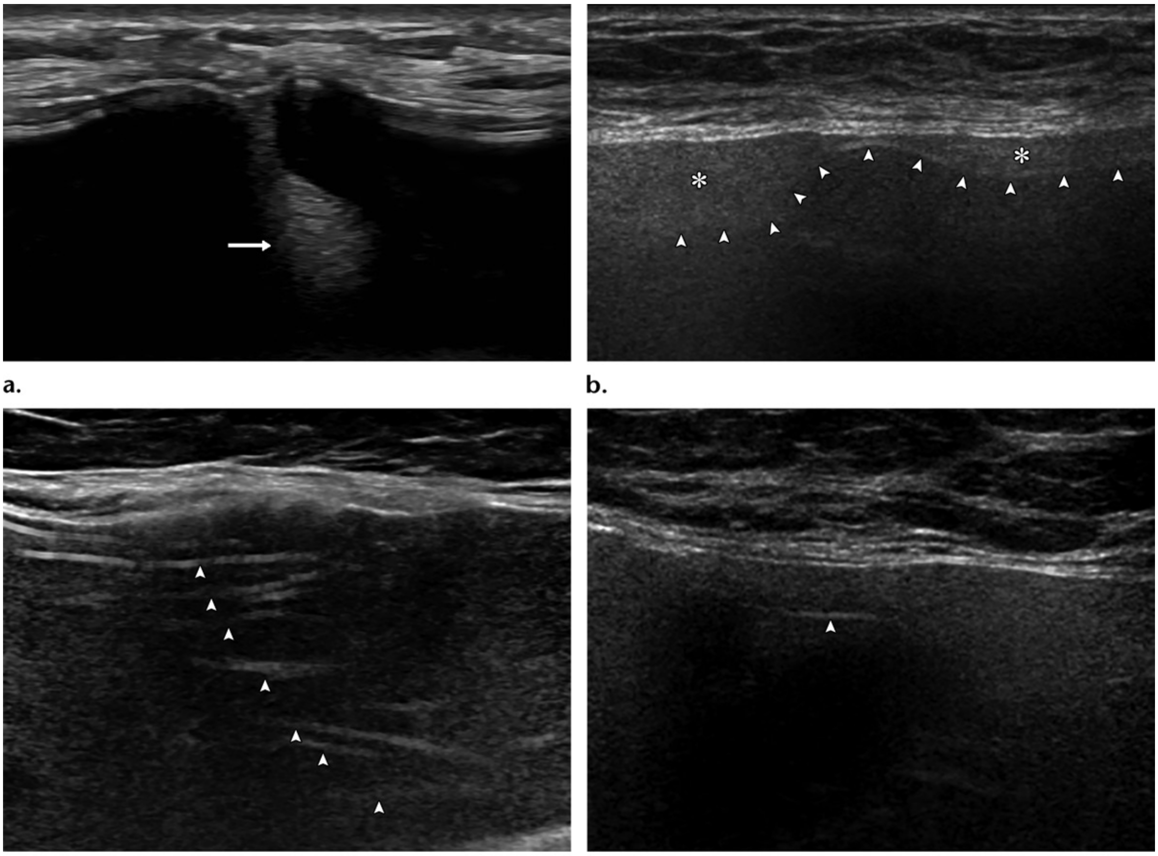


Figure 8. Signs of intracapsular implant rupture at US. **(a)** US image shows the keyhole or noose sign (arrow) resulting from the collection of intracapsular silicone within the apex of a radial fold. **(b)** US image depicts the subcapsular line sign (arrowheads), which represents the implant shell pushed inwardly by intracapsular silicone (*). **(c)** US image shows the stepladder sign. The thin echogenic lines (arrowheads) are parallel to the probe surface and represent the collapsed and highly infolded elastomer shell. **(d)** US image reveals complete loss of the normal trilaminar line due to extrusion of silicone into the intracapsular space. The internal echogenicity of the implant has increased, with diffuse low-level echoes corresponding to a large amount of silicone within the intracapsular space. A short subcapsular line sign (arrowhead) is also visible.

line sign from a normal radial fold, US interrogation of the region in two orthogonal planes should confirm that the internally displaced shell never extends to the margin of the implant

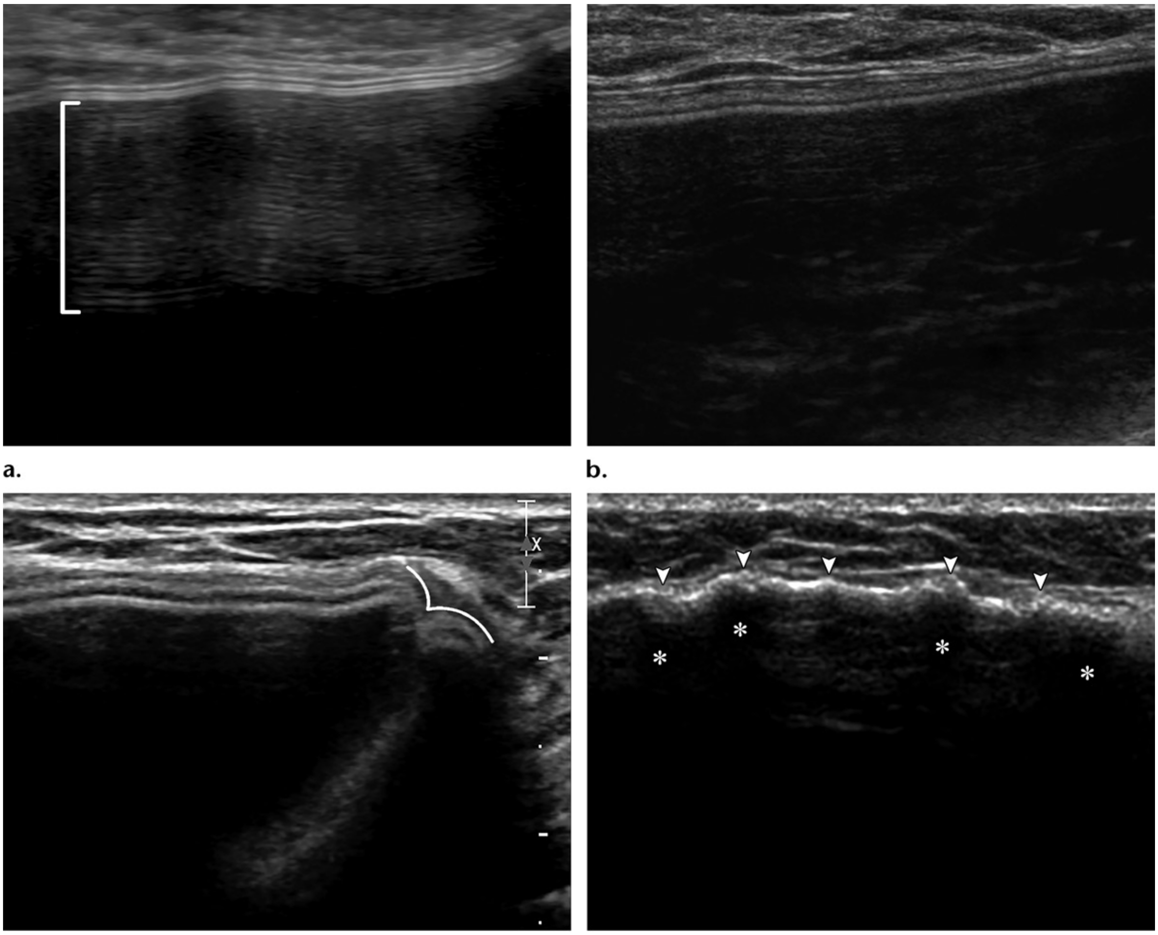
As silicone continues to escape, the elastomer shell progressively invaginates, producing a series of thin echogenic lines that course parallel to the probe surface, known as the stepladder sign (Fig 8c). Equivalent to the "linguine" sign at MR imaging, the stepladder sign is one of the most reliable US signs of intracapsular rupture (28). Over time, most of the silicone may be extruded into the intracapsular space, causing complete loss of the trilaminar line (Fig 8d).

Intracapsular Rupture Mimics

The diagnosis of intracapsular rupture at US can be confounded by a number of variables, which can either be mistaken for rupture or may hinder US evaluation of the implant. Reverberation artifact is commonly seen along the near field of the implant margin and manifests as a band of increased echogenicity that closely parallels the capsule-shell complex (Fig 9a). The artifact can be due to heavy compression, which flattens the shell, and may be minimized by using lighter compression or possibly harmonic imaging. Usually, simple recognition of this common artifact is sufficient, with no requirement to eliminate its presence. Importantly, echogenic lines within the implant that do not parallel the capsule-shell complex should raise suspicion for rupture.

Silicone implants may also contain impurities, or the silicone gel may begin to aggregate or solidify over time, creating spurious echoes within the implant (Fig 9b). Cohesive implants, also known as "gummy bear" implants, are composed of a semisolid silicone that may also produce internal echoes within the implant at US. In both instances, the anechoic interior is lost or findings may even mimic the stepladder sign to give a false impression of rupture.

Radial folds have the potential to be easily confused with findings of intracapsular rupture be-



a. b. c. d.

Figure 9. Mimics of intracapsular rupture at US. **(a)** US image shows a band of multiple, closely spaced, echogenic lines (bracket) in the near field parallel to the capsule-shell complex, a finding consistent with reverberation artifact. **(b)** US image reveals multiple low-level internal echoes scattered throughout the implant lumen. These spurious internal echoes mimic the stepladder sign and result from aggregation or solidification of silicone gel over time or may be seen in patients with cohesive implants composed of semisolid silicone. **(c)** US image shows typical infolding of the elastomer shell at the base of a radial fold, causing the trilaminar line to pucker inward (curved white line). **(d)** US image demonstrates heavy coarse calcification of the fibrous capsule, as evidenced by the roughened contour (arrowheads) and prominent distal acoustic shadowing (*) that obscure the normal trilaminar line.

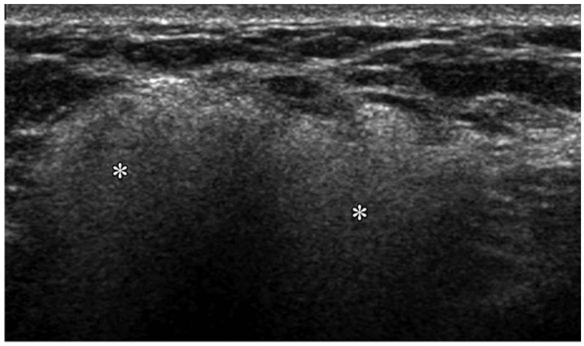
cause lines within the implant are created. A radial fold usually appears thick because it comprises two closely opposed elastomer shells rather than a single inwardly displaced shell related to rupture. Because radial folds are simply invaginations of the shell, it is helpful to trace these lines back to the margin of the implant. The base of the radial fold may cause subtle puckering of the trilaminar line where the invagination occurs (Fig 9c).

Capsular calcifications may develop along the fibrous capsule over time. Scattered punctate calcifications do not usually cause technical problems at imaging, but extensive coarse calcifications will create acoustic shadows and prevent adequate US evaluation of the implant (Fig 9d). The trilaminar line will be obscured by this acoustical shadowing, which may give the false impression of rupture. Recognition of a bumpy or jagged contour of the implant and associated distal acoustic shadowing should provide clues that the implant cannot be evaluated sonographically. Sometimes noncalcified acoustical windows can be found that permit limited internal evaluation.

Extracapsular Rupture

Evidence of intracapsular rupture should prompt a careful search for extracapsular silicone, which can occur even in the early stages of intracapsular rupture. At US, silicone within the breast parenchyma creates a distinctive “snowstorm” or echogenic noise artifact (Fig 10a) (30,31). Identification of this artifact confirms the presence of free silicone while also hindering further US evaluation within the region by interrupting acoustical transmission. Silicone granulomas represent focal silicone aggregates that may vary in their US appearance, ranging from anechoic cystlike collections to isoechoic solid nodules to the

Figure 10. Signs of extracapsular rupture at US. **(a)** US image shows a large area of echogenic noise (snowstorm artifact) (*) in the breast parenchyma due to extruded free silicone. **(b)** US image shows a hyperechoic mass (arrows) with distal acoustic shadowing (*). Corresponding mammogram (inset) reveals a high-density mass (arrow), a finding compatible with a silicone granuloma. **(c)** Axillary US image shows an axillary lymph node mostly obscured by echogenic noise. Portions of normal cortex remain visible (arrows). This finding can be seen with extracapsular rupture and migration of free silicone or gel bleed.



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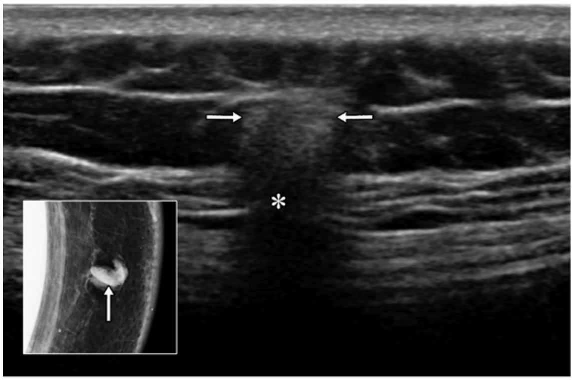

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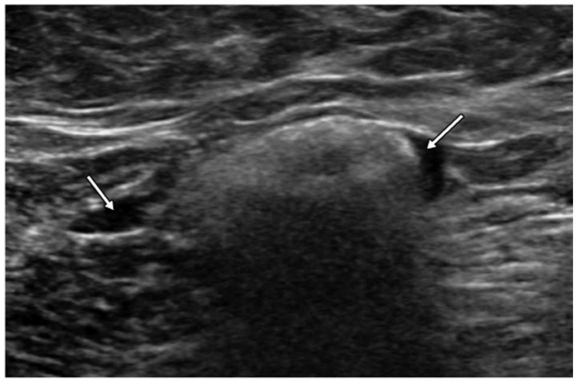


c.

classic snowstorm artifact (20). It is important to recognize the varying appearance of silicone granulomas, as some may appear suspicious and prompt biopsy, particularly if associated with posterior acoustical shadowing (Fig 10b).

Intracapsular rupture almost always occurs before the appearance of extracapsular silicone, although this may not always hold true, particularly if the patient has undergone prior implant revision or exchange of an implant because of prior silicone implant rupture. Silicone granulomas or free silicone from a prior rupture may compromise the ability to assess the integrity of the current implant.

Silicone may also travel through the lymphatics to collect in regional lymph nodes, manifesting as silicone-laden lymphadenopathy (Fig 10c) (32). Extensive rupture overwhelms the lymphatic system, and silicone will extend along the paths of least resistance, such as just beneath the skin surface or along the pectoralis major muscle. Extracapsular silicone commonly migrates toward the axilla but may also travel to distant regions such as the brachial plexus, upper extremity, anterior abdominal wall, or mediastinum (17,20). Note that echogenic noise artifact within lymph nodes is not, by itself, sufficient evidence to suggest implant rupture, because of the possibility of ongoing gel bleed (Fig 11).

When there is clinical concern for rupture, the evaluation may initially consist of mammography and US. Understanding the spectrum of possible imaging findings during intra- and extracapsular silicone rupture will aid in the detection and appropriate classification of implant rupture. If diagnostic uncertainty concerning implant integrity remains, the implants should be further assessed with MR imaging.

MR Imaging

MR imaging is the most accurate imaging modality for noninvasive evaluation of implant integrity. Multiple studies indicate sensitivity of 72%–94% and specificity of 85%–100% for detection of silicone implant rupture at MR imaging (15,16,22,33–35). The U.S. Food and Drug Administration supports the use of periodic MR imaging to detect asymptomatic ruptures of silicone implants, recommending that MR imaging be performed 3 years after implantation and every 2 years thereafter (36). There is ongoing debate about this screening approach because there is no conclusive evidence that such a strategy reduces patient morbidity. Ultimately, the choice to undergo surveillance MR imaging should be a shared decision between the patient and her surgeon (37).

Technical Considerations

Before imaging any breast implant, the MR imaging technologist should preliminarily screen for examination appropriateness. Saline

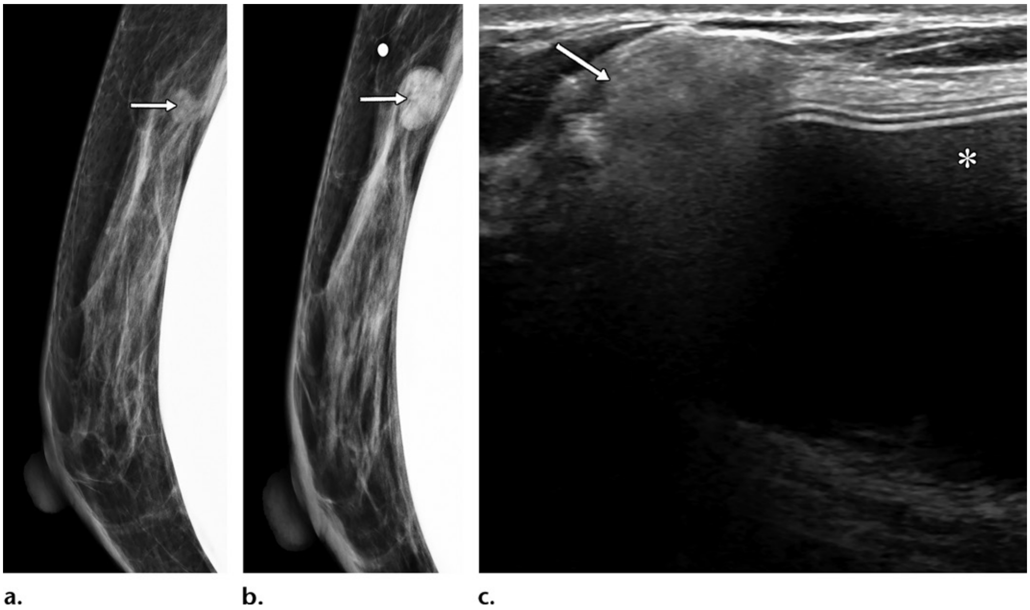


Figure 11. Gel bleed in an intact silicone implant. **(a)** Right MLO mammogram demonstrates an oval isodense mass (arrow) in the breast parenchyma adjacent to the silicone implant. **(b)** Right MLO mammogram obtained 3 years later demonstrates enlargement and increased density of the mass (arrow), which was now palpable. **(c)** Targeted US image of the mass reveals snowstorm artifact within an intramammary lymph node (arrow) due to extracapsular silicone. The implant remains anechoic, except for reverberation artifact (*), and maintains a normal configuration of the shell-capsular complex, indicating an intact silicone implant. The presence of extracapsular silicone was due to gel bleed.

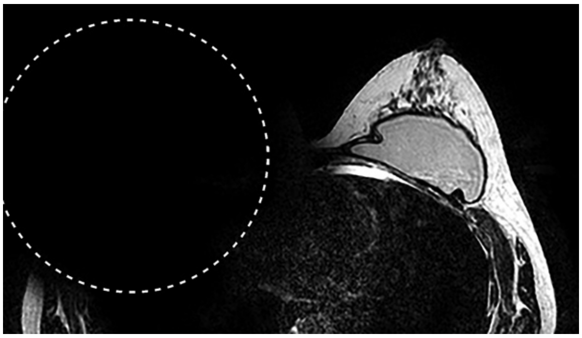


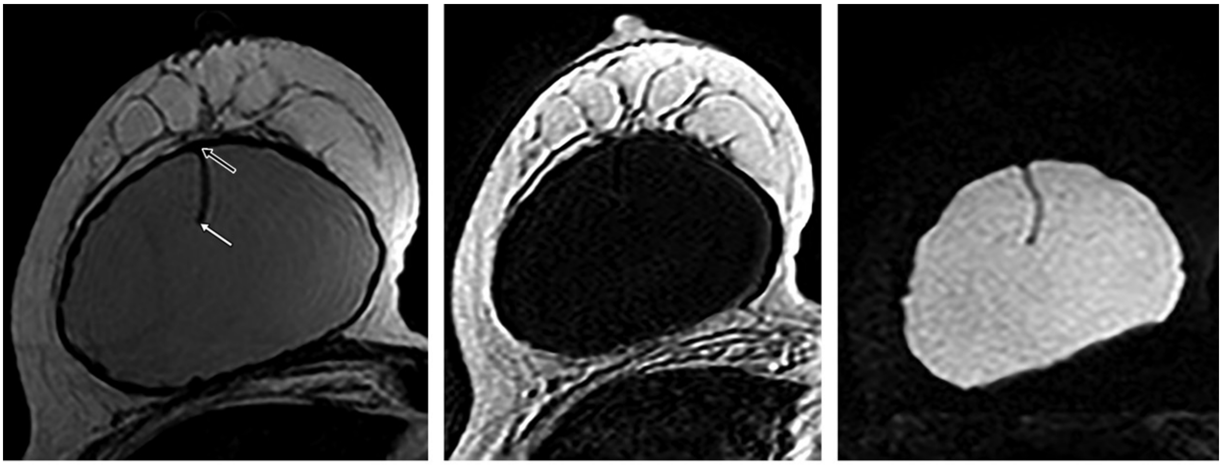
Figure 12. Axial T2-weighted MR image of the breasts shows a large susceptibility artifact (dashed circle) caused by a magnetic localization device within an implant tissue expander, which resulted in complete nonvisualization of the right breast and chest wall.

implants do not usually require imaging confirmation after deflation, and tissue expanders are generally considered a contraindication to MR imaging because most now contain magnetic localization devices to define the fill port (Fig 12). Therefore, only implants filled with silicone gel should typically undergo further MR imaging evaluation.

The augmented breast is composed primarily of water, fat, and silicone, each of which have their own distinctive hydrogen signal that can be selectively suppressed to more confidently assess implant integrity (38). Silicone-selective sequences take advantage of these different resonance frequencies to create specific silicone-only and silicone-suppressed images. Sequences that null fat signal and suppress water signal are capable of creating images where silicone alone appears bright against the dark background of the breast parenchyma (Fig 13c). Likewise, a sequence that suppresses silicone signal provides a useful supplemental means to confirm that extracapsular silicone is present. High-resolution T2-weighted imaging with water suppression may be used to help differentiate extruded intracapsular silicone from peri-implant fluid within the intracapsular space.

With use of dedicated breast coils, both 1.5-T and 3.0-T MR imaging systems can produce high-quality images for implant assessment. A common implant protocol combines axial silicone-selective sequences with axial and sagittal fast spin-echo (FSE) T2-weighted imaging. The internal structure of a silicone implant is excellently depicted on these FSE T2-weighted images, which translates to high sensitivity in accurately identifying rupture (15,21).

Image acquisition in at least two orthogonal planes helps to differentiate early intracapsular ruptures from complex radial folds, particularly along the superior and inferior aspects of the implant. To minimize artifacts related to chest and heart motion, the phase-encoding direction should not be defined in the anteroposterior plane. A sample MR imaging protocol for implants is provided in Table 1, bearing in mind that



a. b. c.

Figure 13. Normal single-lumen silicone implant at MR imaging. **(a)** Axial T2-weighted MR image shows a single-lumen implant with silicone gel producing homogeneous intermediate signal intensity. A normal radial fold emanates from the anterior aspect of the implant. Black arrow = base of radial fold, white arrow = apex of radial fold. **(b)** Axial T1-weighted MR image with silicone suppression shows that silicone gel displays homogeneous hypointense signal intensity. **(c)** Axial inversion-recovery MR image obtained with both fat and water suppression shows that silicone gel demonstrates the only bright signal intensity within the breast.

Table 1: Sample MR Imaging Protocol for Breast Implants*

Imaging Parameter	Axial T2-weighted	Sagittal T2-weighted	Axial STIR	Axial STIR with Water Saturation	Axial STIR with Silicone Suppression
Sequence	2D FSE	FSE	2D FSE	2D FSE	2D FSE
TE (msec)	68	68	42	42	32
TR (msec)	5000	5000	5000	5000	5000
TI (msec)	…	…	150	150	400
Flip angle (°)	160	160	160	160	160
Section thickness (mm)	6	6	5	5	5
Field of view (cm)	34	20	34	34	34
No. of phase-encoding steps	256	256	224	224	224
No. of frequency-encoding steps	352	256	320	320	384
Frequency direction	AP	AP	AP	AP	RL

*Examinations performed at our institution use a 1.5-T imager (Optima MR450w GEM; GE Healthcare, Waukesha, Wis) and a 16-channel breast MR imaging table (Sentinelle Vanguard; GE Healthcare). All axial imaging is bilateral, and sagittal imaging is unilateral. Parallel imaging is used for axial images. AP = anteroposterior, RL = right to left, STIR = short inversion time inversion-recovery, TE = echo time, TI = inversion time, TR = repetition time, 2D = two-dimensional.

intravenous administration of gadolinium-based contrast agent is not required when evaluating solely for implant integrity.

Determining Implant Type

Most breast implants are single-lumen varieties composed entirely of saline or silicone. Distinction between fill material can usually be made with a T2-weighted sequence (12), which causes fat, silicone, and saline to appear with increasing signal intensities respective to one another. A saline implant appears very bright relative to fat on T2-weighted images, whereas silicone exhibits intermediate signal intensity. Saline appears darker in signal intensity than silicone on standard T1-weighted images. Saline implants have fill valves (also known as injection ports) that are readily identified along the margin of the elastomer shell, frequently in a subareolar location. Small localization marks or larger patches characteristic of some silicone implants should not be mistaken for saline fill valves (29). MR imaging technologists should be capable of characterizing implant types and should use the appropriate implant-specific sequences when necessary. If a patient has a history of prior silicone implants replaced with saline implants, silicone-selective sequences will be useful to determine if free silicone is present within the breast tissue or lymphatics.

Figure 14. Implant contour abnormalities at MR imaging. **(a)** Axial T2-weighted MR image of the right breast demonstrates herniation along the posterolateral aspect of the silicone implant. Herniations typically extend further outside the expected contour of the implant and often create acute angles (arrow) at the neck of the protrusion. **(b)** Axial T2-weighted MR image of the left breast shows a posteromedial bulge (*) and a posterolateral herniation (arrow). The linguine sign indicating intracapsular rupture (arrowhead) is also seen.

Normal Appearance

A normal single-lumen silicone implant is most frequently oval with a smooth, sometimes undulating contour. A rounded implant may indicate the presence of capsular contracture. The silicone gel within the implant usually has homogeneously intermediate signal intensity on T2-weighted images and low signal intensity on T1-weighted images. The fibrous capsule appears as a T2-hypointense line along the periphery of the implant. Nearly all implants exhibit at least one or several radial folds, appearing as perpendicular internal extensions of the hypointense elastomer shell. It is uncommon to encounter an implant with no radial folds whatsoever.

A trace peri-implant effusion, more commonly seen with textured implants, can also be present normally, as the implant can elicit a foreign body–type inflammatory reaction. Water droplets floating within the silicone gel may be a consequence of the plastic surgeon injecting steroids, betadine, and/or antibiotics at the time of implant placement (4).

Contour Abnormalities

MR imaging permits an easy global assessment of implant contour, particularly the posterior aspect of the implant that may go unevaluated at either mammography or US. Small protrusions, including bulges and herniations, can be readily identified with MR imaging. In general, herniations protrude farther outside of the expected contour of the implant than bulges and often create acute angles at the neck of the protrusion (Fig 14).

The presence of these protrusions does not imply implant rupture, but they often occur concurrently. The fibrous capsule has been thinned or disrupted, possibly by a traumatic event that predisposes to rupture. Undulations of the implant shell occur frequently, a consequence of filling a confined space with a pliable gel-filled sack, and should not be misinterpreted as a contour abnormality.

Intracapsular Rupture

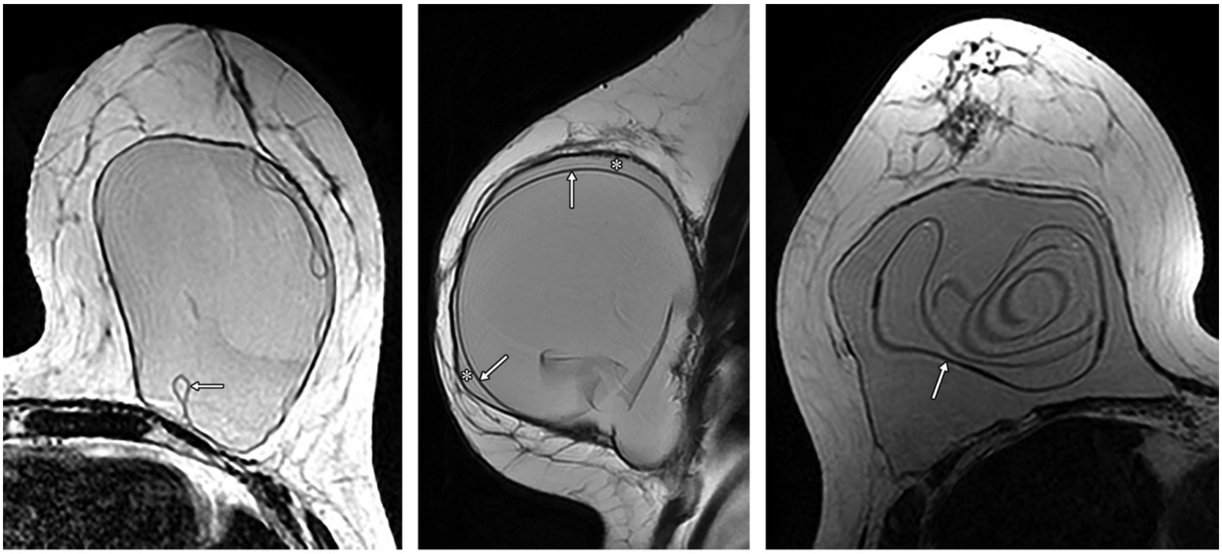
MR imaging more easily detects intracapsular ruptures compared with mammography and US, which largely accounts for its high sensitivity in direct comparisons of the various imaging modalities. There are several important signs that describe the degree of collapse of the implant shell, which help delineate the presence of intracapsular rupture and its extent (Table 2) (39).

Over time, the implant shell develops small defects that will permit silicone gel to seep into the intracapsular space. The apex of a radial fold expands as silicone gel trickles in, allowing separation of the two coapted shell walls to produce the keyhole sign (Fig 15a) (40–42). Also known as the "lasso," "noose" (21,43), "inverted teardrop" (41,42,44), or "dark open loop" (15) sign, this is an early manifestation of rupture contained solely within a radial fold. The remainder of the elastomer shell of the implant remains in proximity to the fibrous capsule, a state known as uncollapsed rupture.

A defect occurring outside a fold, along the margin of the implant, will push the elastomer shell inward as silicone extrudes into the intracapsular space. Likewise, as silicone continues to expand a radial fold and migrate toward the periphery, the shell separates from the fibrous

Table 2: MR Imaging Signs of Intracapsular Breast Implant Rupture

Degree of Collapse	Description of Rupture	Imaging Sign
Uncollapsed rupture	Silicone gel is contained within a radial fold	Keyhole sign (Fig 15a)
Minimal collapse	Extruded silicone separates the implant elastomer shell from the fibrous capsule	Subcapsular line sign (Fig 15b)
Partial to full collapse	Silicone gel has mostly to entirely escaped from the implant proper into the intracapsular space	Linguine sign (Fig 15c)



a. b. c.

Figure 15. Signs of intracapsular rupture at MR imaging. **(a)** Axial T2-weighted MR image of the breast shows the keyhole or noose sign (arrow) with silicone expanding the apex of the radial fold. **(b)** Sagittal T2-weighted MR image depicts the subcapsular line sign as a hypointense line that parallels the implant contour (arrows). Extruded intracapsular silicone (*) displaces the implant shell inwardly. **(c)** Axial T2-weighted MR image of the right breast shows multiple hypointense curvilinear lines floating within the silicone gel, producing the linguine sign (arrow) and indicating complete collapse of the implant shell upon itself.

capsule to signify minimal collapse. Inward displacement of the implant shell creates a hypointense wavy line parallel to the implant contour, termed the *subcapsular line sign* (Fig 15b) (2,41,42).

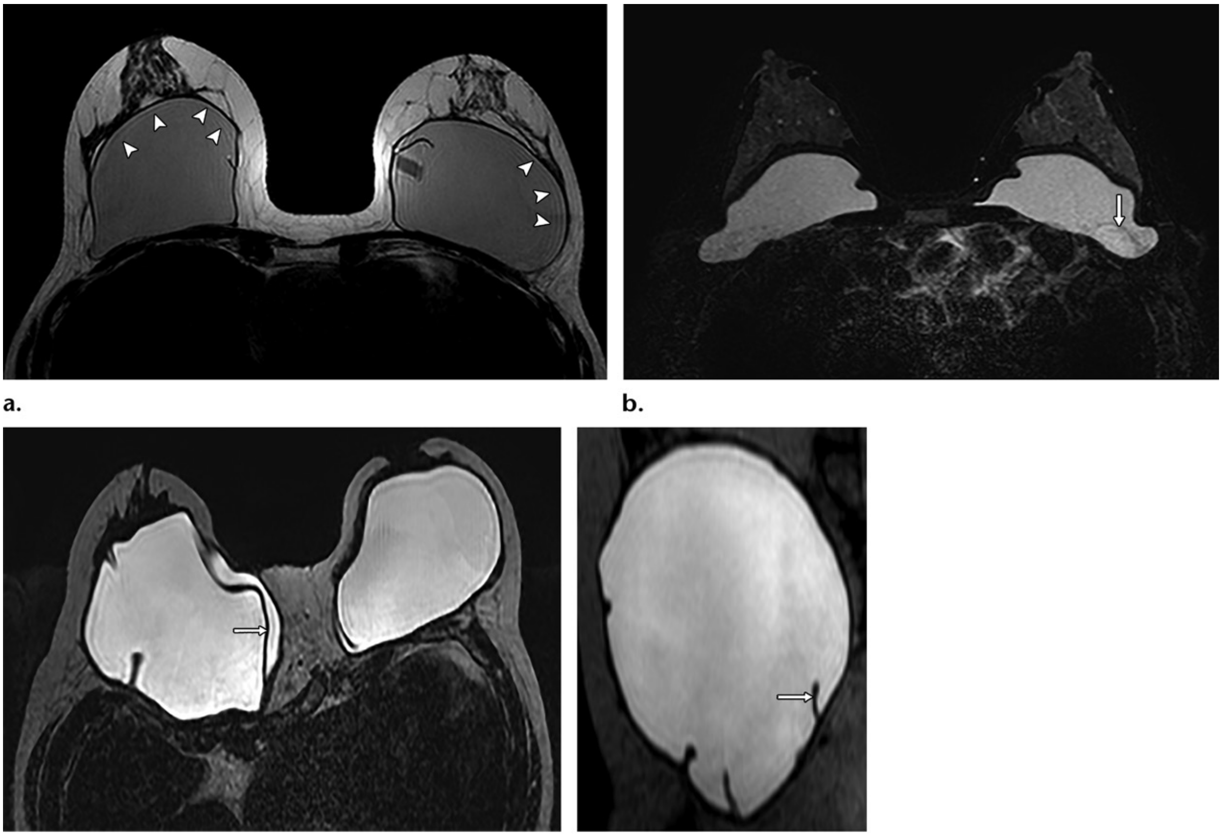
Further seepage of silicone into the intracapsular space causes the implant shell to partially and then fully collapse upon itself, producing the classic linguine sign or "wavy line" sign (40,44,45). The heavily infolded shell manifests as multiple low-signal-intensity curvilinear lines floating within the extruded silicone gel or pushed off to one side of the implant (Fig 15c). The linguine sign is the most recognizable and reliable finding of intracapsular rupture, as it represents its most advanced stage (45).

Intracapsular Rupture Mimics

Several artifacts inherent to MR imaging may be mistaken for an inwardly displaced elastomer shell and erroneously characterized as intracapsular rupture. A truncation (or Gibbs) artifact may be seen within an implant as one or more lines parallel to the implant shell (Fig 16a). The artifact is related to the abrupt interface changes at the implant boundary. Ghosting artifact from patient or cardiac motion may also cause spurious lines to appear within an implant in the phase-encoding direction (Fig 16b).

As discussed previously, a majority of silicone implants have normal invaginations of the elastomer shell, termed *radial folds*, which may be difficult to distinguish from an inwardly displaced shell related to intracapsular rupture. Radial folds appear as hypointense lines that are often perpendicular to the implant capsule, unlike subcapsular lines, which are oriented more parallel to the capsule. Radial folds also appear thicker than subcapsular lines because two layers of the elastomer shell are interposed. Suspected radial folds should be inspected in one or several imaging planes (Fig 16c, 16d). Simple folds can be easily followed to the periphery to confirm continuity with the remainder of

Figure 16. Mimics of intracapsular rupture at MR imaging. **(a)** Axial T2-weighted MR image demonstrates multiple hypointense lines (arrowheads) parallel to the implant shell. These artifactual lines, known as truncation (or Gibbs) artifact, result from abrupt interface changes at the implant border. **(b)** Axial silicone-selective MR image shows a curvilinear hypointense line (arrow) due to ghosting artifact in the phase-encoding direction, a finding related to cardiac motion. **(c, d)** Axial **(c)** and coronal **(d)** silicone-selective MR images in a 47-year-old woman with a pectus deformity show a normal radial fold (arrow). On the axial image, the curvilinear hypointense line (arrow on **c**) emanating from the medial aspect of the fibrous capsule mimics the subcapsular line sign. However, inspection of the orthogonal (coronal) image confirms a normal radial fold (arrow on **d**).



a. b. c. d.

the elastomer shell. Radial folds that have more complex folding patterns are more difficult to resolve and distinguish from intracapsular rupture (42). If the lines are always separated from the fibrous capsule by some amount of silicone gel, then intracapsular rupture may be present.

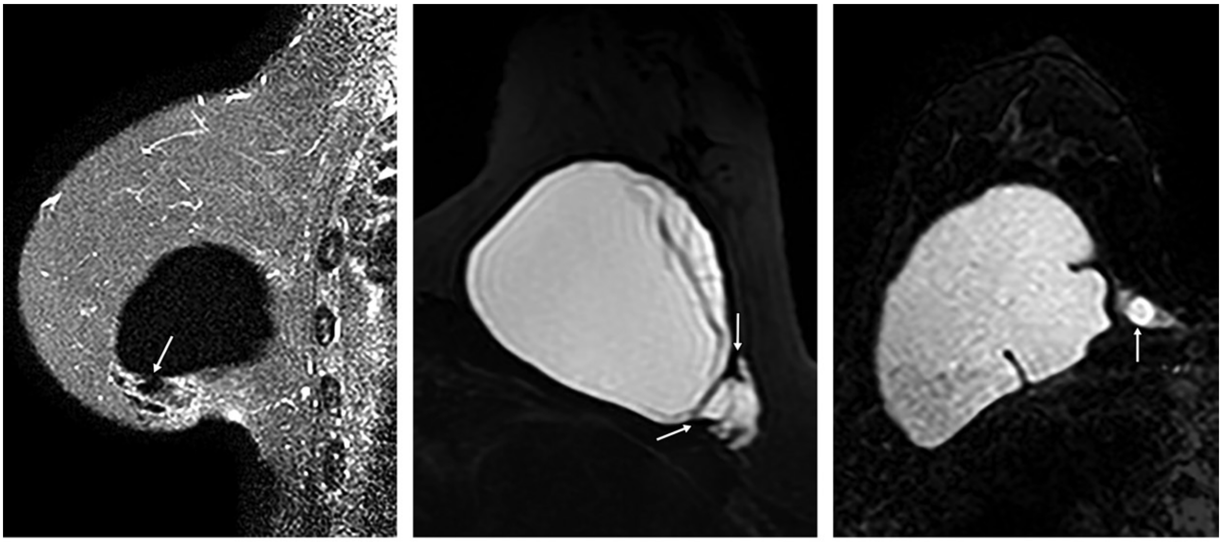
Peri-implant effusions may also cause confusion regarding implant integrity. A peri-implant effusion can usually be distinguished from intracapsular rupture at T2-weighted imaging with silicone-selective sequences. A peri-implant effusion follows the signal intensity of water rather than that of silicone. Scant effusions may mimic the keyhole sign within a radial fold; therefore, care should be taken to confirm that the signal intensity of the material within the keyhole matches that of silicone before diagnosing an uncollapsed rupture.

Extracapsular Rupture

Extracapsular rupture and extracapsular free silicone can be seen in association with all degrees of intracapsular rupture, ranging from uncollapsed to fully collapsed rupture. Therefore, a thorough assessment for free silicone should be performed whenever intracapsular rupture is detected. When silicone extends beyond the expected normal contour of the implant, it can often be detected mammographically. In this setting and for symptomatic patients in general, MR imaging can provide important information regarding the extent and location of silicone migration to better assist the surgeon tasked with removing the expelled silicone.

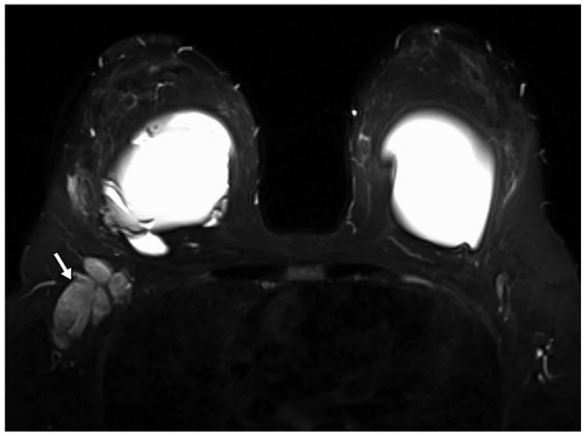
Once silicone gel escapes the fibrous capsule, it may diffusely infiltrate the surrounding breast parenchyma or aggregate into silicone granulomas. Occasionally, a focally traumatic incident will cause a direct discontinuity of the implant shell and fibrous capsule, with spillage of free silicone into the soft tissues immediately adjacent to the defect (Fig 17a).

Silicone-selective sequences are particularly useful and sensitive for identifying extracapsular free silicone gel (Fig 17b) (38). When fat and water signals are suppressed, even minimal amounts



a. b. c.

Figure 17. Signs of extracapsular rupture at MR imaging. **(a)** Sagittal STIR MR image shows a focal contour abnormality and direct discontinuity along the inferior aspect of the silicone implant (arrow), with extrusion of low-signal-intensity silicone into adjacent soft tissues. **(b)** Axial silicone-selective MR image of the left breast shows free silicone due to extracapsular rupture extruding into the axillary tail region (arrows). **(c)** Axial silicone-selective MR image of the right breast shows a mass (arrow) along the right parasternal region that exhibited the signal intensity of silicone on images obtained with all sequences (other images not shown), a finding consistent with a benign silicone granuloma. **(d)** Axial silicone-selective MR image of both breasts demonstrates bulky right silicone-laden lymphadenopathy (arrow) related to rupture of the right implant. The signal intensity of silicone within lymph nodes can be more heterogeneous than that of silicone contained within the implant.



d.

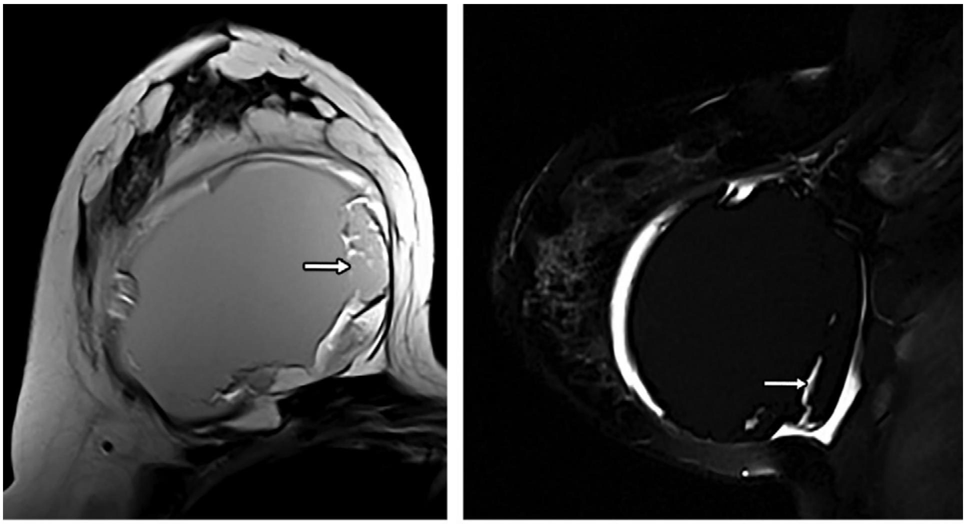
of silicone within the soft tissues can be detected (33). This is particularly true for silicone that has infiltrated the parenchyma, as this free silicone usually mirrors the signal intensity of silicone found within the implant. Inflammation and tissue ingrowth that can occur with silicone granulomas over time may alter the silicone signal, producing an inhomogeneous appearance on silicone-selective images (Fig 17c). Moreover, granulomas may display enhancement, further complicating the interpretation and mimicking suspicious masses. In cases of uncertainty, targeted US should be used to confirm the presence of extracapsular silicone by revealing a classic snowstorm artifact (4).

Free silicone particles may also collect in the lymphatics and be transported to regional lymph nodes, which may enlarge and become palpable over time (Fig 17d) (33). Silicone-laden lymph nodes usually but not always exhibit the signal intensity of silicone; they can also display an inhomogeneous appearance as silicone variably infiltrates the node. As previously discussed, detection of silicone in lymph nodes does not necessarily imply rupture because lymph nodes may exhibit silicone signal intensity as a consequence of gel bleed.

MR Imaging with Intravenous Contrast Agent

Examinations solely focused on evaluation for implant rupture do not require administration of intravenous gadolinium-based contrast agent, with an important caveat that a nonenhanced examination cannot be used for cancer detection. Therefore, MR imaging without intravenous contrast material and performed purely to assess breast implant integrity should not receive a Breast Imaging Reporting and Data System (BI-RADS) assessment score. Whenever intravenous contrast agent is administered as part of the MR imaging examination with the intention of detecting underlying occult malignancy, a BI-RADS assessment is required.

Likewise, patients with implants who require high-risk screening or extent of disease assessment should have implant-related imaging in addition to routine dynamic contrast-enhanced imaging as part of their MR imaging examination. Implant-related complications, such as spillage of silicone into the breast parenchyma, have the potential to mimic breast cancer and vice versa (12). It is



a. b.

Figure 18. Rupture of a cohesive silicone implant. Axial T2-weighted **(a)** and sagittal STIR **(b)** MR images of the right breast show fracturing (arrow) of the semisolid gel of a cohesive ("gummy bear") implant.

prudent to perform silicone-selective imaging in these patients to help differentiate a tumor from a silicone granuloma. It is also sensible to evaluate the current status of the implant in patients already planning breast-related surgery for a known malignancy, noting in particular the proximity of the cancer to the implant and whether the tumor involves the fibrous capsule.

Cohesive Implants

The newest generation of breast implants are composed of a semisolid silicone gel and are referred to as cohesive ("gummy bear") implants. This type of implant was developed in hopes of improving cosmesis, reducing the incidence of gel bleed, and decreasing complication and failure rates (2). The long-term integrity of these implants has not been established, but rupture is potentially less common.

When cohesive implants rupture, the traditional mechanisms of rupture may not occur, and the common imaging signs of rupture may not be present. Cohesive implants may fracture owing to the semisolid nature of the silicone gel (Fig 18). The fractured semisolid gel may not have the same propensity to migrate through defects in the fibrous capsule and spill into the surrounding breast parenchyma. Fewer extracapsular silicone extrusions diminish the ability to detect a possible rupture at mammography, and the semisolid gel may confound US evaluation. Thus, the overall imaging strategy to evaluate cohesive implants may rely more heavily on MR imaging to detect suspected fracturing. The purported improved resiliency of these newer implants may also obviate, or at least lessen the need for, implant rupture screening in the future.

Conclusion

Newer generations of silicone implants outperform older versions in terms of lasting integrity, although ruptures still occur and remain a long-term risk. Any radiologist who interprets breast imaging studies should be familiar with the normal and abnormal appearances of silicone breast implants, particularly the signs indicating intracapsular and extracapsular rupture for each of the most common imaging modalities.

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