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PICTORIAL ESSAY

Multimodality Imaging of Breast Augmentations: A Pictorial Essay

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INTRODUCTION

Breast augmentation is a procedure that has been performed for over a century. The first breast augmentation was performed in 1895 by Austrian-German surgeon Vincent Czerny, who used autologous fat implantation for breast reconstruction after partial mastectomy.[1] Since then, numerous techniques have been developed, whether used for cosmetic purpose, reconstruction after mastectomy, or correction of congenital malformations.

Breast augmentation can be divided into implant and injection types, which involve different materials and anatomical locations. Depending on the material used and the different methodologies, the corresponding complications are also specific.

It is crucial for radiologists to be familiar with the normal and abnormal appearance of breast augmentation in different imaging modalities including mammography (MG), ultrasonography (USG), and magnetic resonance imaging (MRI). This pictorial essay illustrates the imaging features of patients with breast augmentation in our institution from 2010 to 2022, highlighting the normal and abnormal radiological appearances.

IMPLANT AUGMENTATION

Implant Materials

Silicone and saline implants are the two most commonly used materials. Silicone implants are typically preferred for their natural texture and appearance. Saline implants are filled with sterile saline that, in case of implant rupture, is absorbed by the body. Silicon is a semi-metallic element, while silicone is an organic silicon polymer product with a main chain of alternating silicon and oxygen atoms.[2] On MG, silicone appears denser than saline. Figure 1 demonstrates the difference on MG, which is easily identifiable.

Distinguishing between silicone and saline breast implants on USG can be challenging. One potential differentiating factor is the appearance of the chest wall, which may appear 'deeper' than the expected position deep to the silicone implant due to the slower transmission speed of ultrasound waves through silicone.[3] This can result in a 'stepped' appearance at the edge of the implant compared to the smooth chest wall appearance seen with saline implants on USG (Figure 2). It is often difficult to detect such subtle differences in clinical practice.

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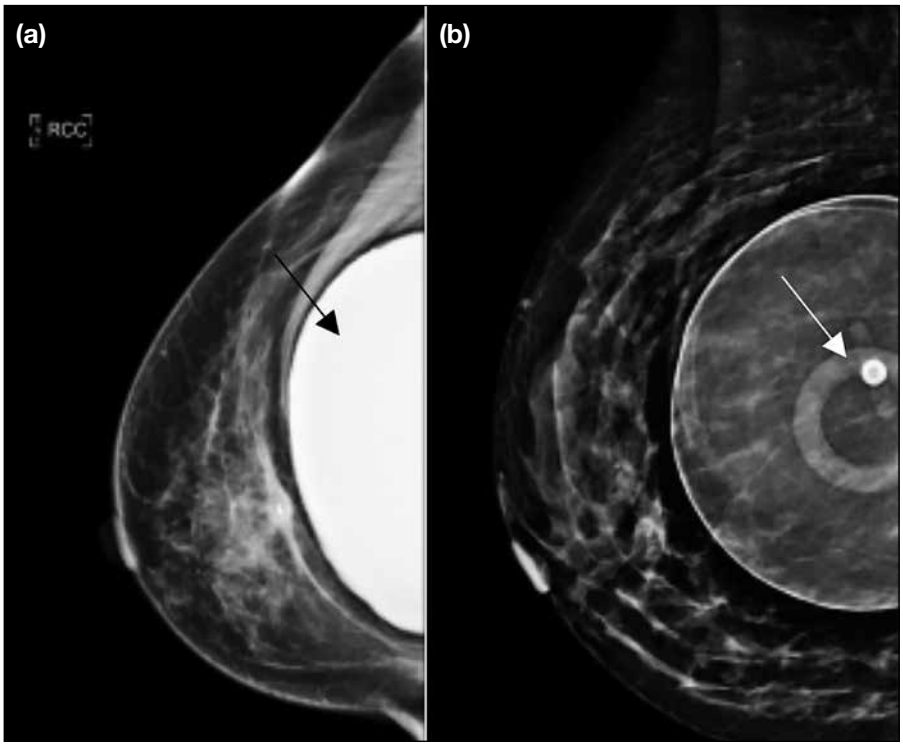

Figure 1. Mammography of a silicone implant (a) and a saline implant (b). Note the silicone implant (black arrow in [a]) is denser than the saline implant, which contains a valve seen as a small round hyperdensity with lucent centre (white arrow in [b]).

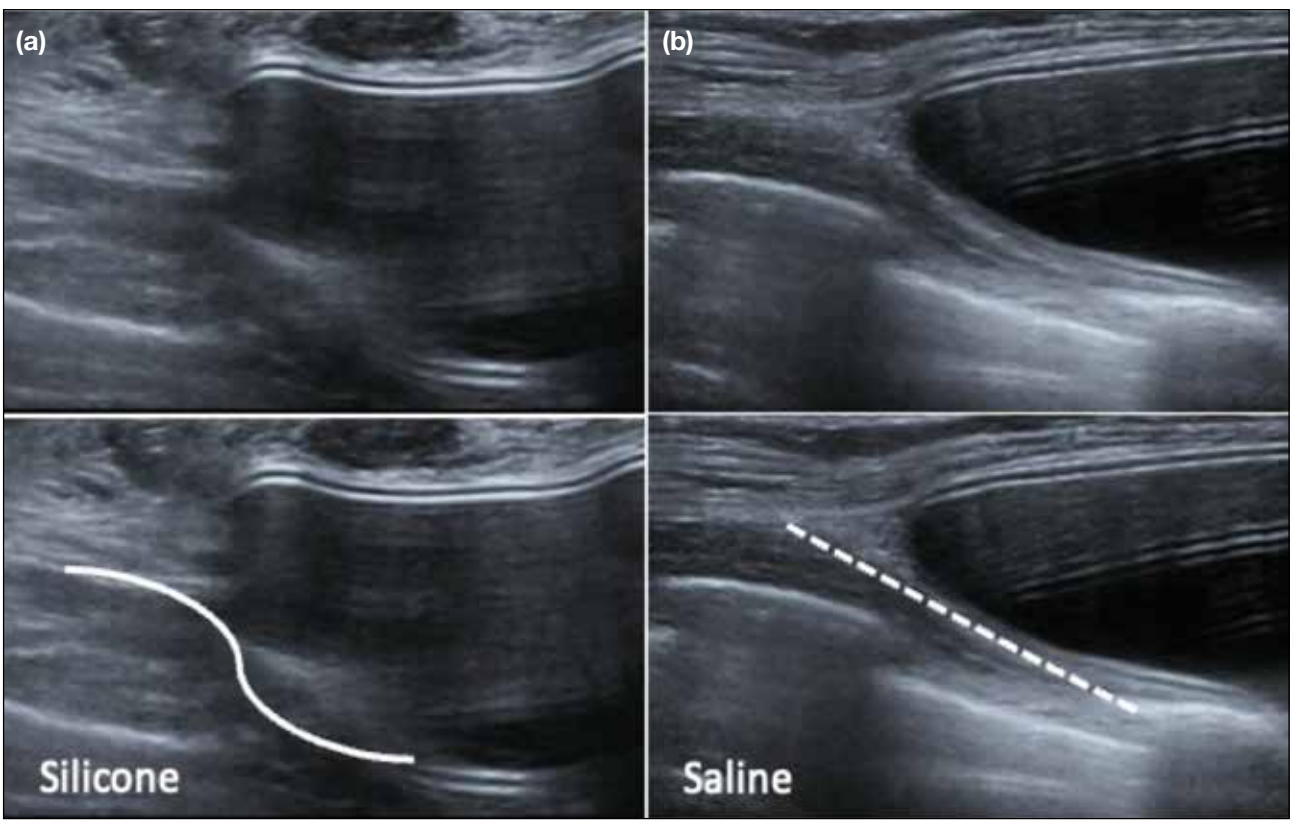

Figure 2. Ultrasonographic appearance of silicone and saline implants. (a) In the case of silicone implant, the chest wall behind the implant may appear 'deeper' due to the slower transmission speed of ultrasound waves through silicone compared to the expected location of the chest wall. This creates a 'stepped' appearance on the ultrasound image (solid line). (b) In contrast, saline implants typically appear as anechoic structures surrounded by a linear echogenic envelope, and the chest wall appears smooth on ultrasonography (dashed line).

Silicone and saline implants also show different signal intensities with the use of specific MRI sequences due to their inherent material differences (Figures 3 and 4). Our MRI protocol for post-augmentation breast imaging is summarised in the Table. The silicone-only MRI sequence is a protocol that has been specifically designed to visualise silicone gel–filled breast implants using a combination of pulse sequences and specialised software to improve the signal-to-noise ratio of silicone gel in the imaging data, allowing for more accurate visualisation of the implants.

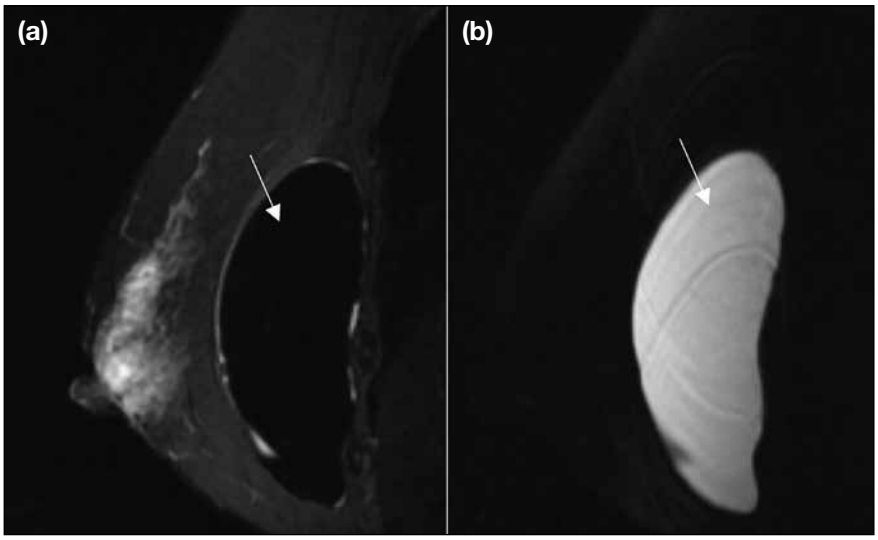

Figure 3. Subpectoral silicone breast implant with characteristic signals on specified magnetic resonance imaging sequences. (a) Silicone (arrow) is hypointense on the T2-weighted fat-suppressed, silicone-suppressed, saline-only sequence. (b) Silicone (arrow) is hyperintense on the T2-weighted short-tau inversion recovery silicone-only, water-saturated sequence. Note that this uncomplicated implant has a smooth border and is somewhat triangular in shape, with the vertical dimension more than twice the anteroposterior dimension.

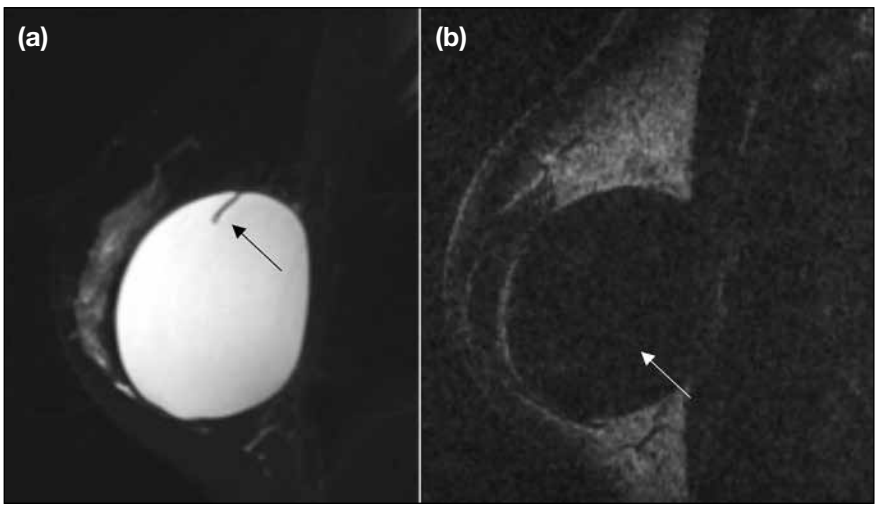

Figure 4. Saline breast implant. These are the characteristic signals of saline on silicone-suppressed, saline-only (a) and silicone-only, water-saturated (b) magnetic resonance imaging sequences, with hyperintense saline on the T2-weighted fat-suppressed, silicone-suppressed, saline-only sequence and hypointense saline (white arrow in [b]) on the T2-weighted short-tau inversion recovery silicone-only, water-saturated sequence. Also note the 'radial fold', a curved hypointense line running from the periphery and perpendicular to the implant shell (black arrow in [a]), which is a normal finding and should not be misinterpreted as rupture.

Table. Magnetic resonance imaging protocol for augmented breast with silicone or saline implants.

Sequence	TR, m/s	TE, m/s	FOV	Section thickness, mm
Axial STIR	9000	60	512 × 512	3
Axial T1W	100	2	512 × 512	7
Axial DWI b800	3000	70	256 × 256	3.6
Axial ADC	3000	70	256 × 256	3.6
Sagittal T2W STIR silicone-only, water-suppressed	12000	34	512 × 512	3
Sagittal T2W FS silicone-suppressed, saline-only	4000	100	256 × 256	3
Axial VIBRANT	7	3	512 × 512	1

Abbreviations: ADC = apparent diffusion coefficient; DWI = diffusion-weighted imaging; FOV = field of view; FS = fat-suppressed; STIR = short-tau inversion recovery; TE = echo time; TR = repetition time; T1W = T1-weighted; T2W = T2-weighted; VIBRANT = volume imaging for breast assessment.

Location of Implant

Subpectoral and subglandular are two different placement options for breast implants. Subpectoral placement refers to placing the breast implant posterior to the pectoral muscles, which can supply added support and stability to the implant, therefore decreasing the chance of implant exposure, skin necrosis, and capsular contracture.[4,5] It is the standard technique of breast implant reconstruction.[6] However, it may cause animation deformities and relatively unnatural state.[7] Animation deformities occur when the pectoral muscle's contraction causes the breast implant to move or appear distorted during physical activity. Unnatural state refers to the aesthetic outcome where the breasts may not exhibit natural movement, resulting in an appearance that can seem artificial or rigid.

Subglandular placement, also called prepectoral placement, refers to placing the breast implant anterior to the pectoral muscle and posterior to the glandular tissue of the breast, and is considered less invasive. There are several relative contraindications, including obesity, poorly controlled diabetes, and previous radiation treatment, which carry a higher risk of skin necrosis.[7] The different MG appearances of subglandular and subpectoral implants are demonstrated in Figure 5.

Type of Implant

A single-lumen implant is a shell filled with silicone gel or saline solution. A standard double-lumen implant is filled with silicone gel in the inner lumen and saline solution in the smaller outer lumen (Figure 6). An inverse double-lumen implant is filled with saline solution in the inner lumen, which can be expanded as necessary, and with silicone gel in the outer lumen (Figure 7).

A double-lumen breast implant is designed to prevent massive deflation of the implant. In the event of inner shell rupture, the ruptured material will be contained by the outer chamber. Some designs allow volume adjustment of the chamber during surgery, so that the size and shape of the augmented breast can be adjusted accordingly with a more personalised result. However, it has been reported that there might be less natural result in some patients due to the difference in consistence of silicone and saline materials, and a potential complication due to the reaction between inner and outer layer implants.[8] The placement of a double-lumen implant requires special expertise due to their special structure.[8]

Complications

Capsular Contracture

Capsular contracture is the most common complication of breast augmentation, yet its reported rate is highly variable depending on surgical technique and diagnostic threshold, ranging from 0% to 45% in different cohorts.[9] It occurs when there is excessive foreign body reaction,

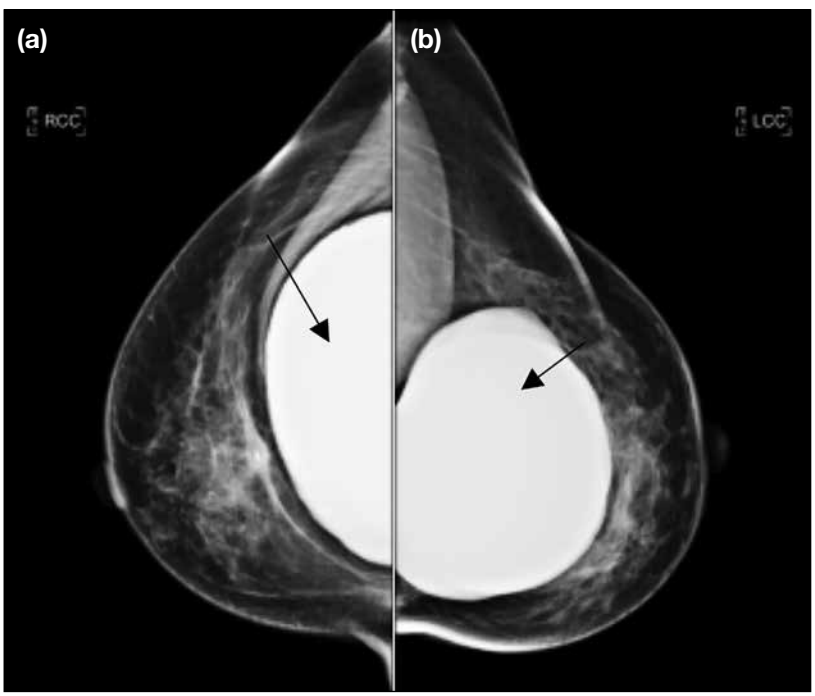

Figure 5. Mammography illustrating (a) a right subpectoral breast implant (arrow) and (b) a left subglandular breast implant (arrow) of the same patient. Both are single-lumen silicone implants.

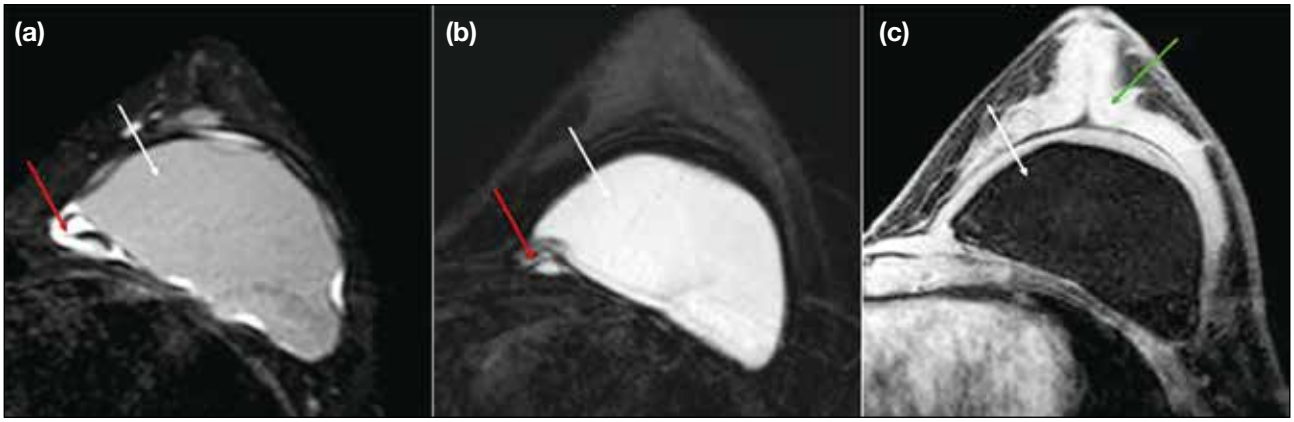

Figure 6. Double-lumen implant, with silicone gel in the inner lumen (white arrows) and saline solution (red arrows) in the smaller outer lumen. (a) Short-tau inversion recovery magnetic resonance imaging showing the hyperintense outer lumen containing saline solution (red arrow), and (b) a silicone-only sequence showing a hyperintense inner lumen containing silicone gel (white arrow). (c) The silicone gel signal is suppressed on the silicone-suppressed sequence (white arrow). The breast parenchymal tissue is indicated by the green arrow.

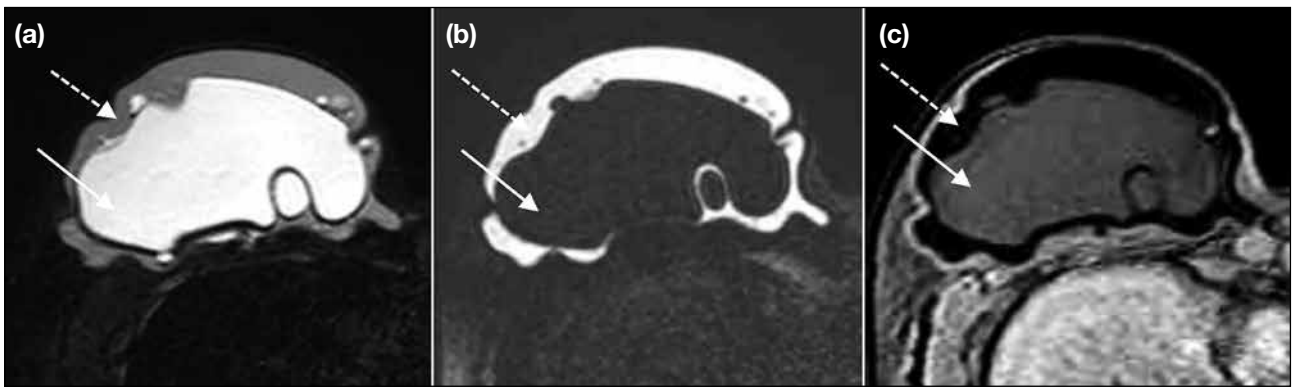

Figure 7. Inverse double-lumen implant, with saline gel in the inner lumen (solid arrows) and silicone solution (dashed arrows) in the outer lumen. (a) Short-tau inversion recovery magnetic resonance imaging showing the saline hyperintense inner lumen (solid arrow) and (b) silicone-only sequence showing the hyperintense silicone gel (dashed arrow) in the outer lumen. (c) In silicone-suppressed image, there is an exact reversal of the signal pattern, showing the saline inner lumen (solid arrow) with intermediate signal and the hypointense silicone gel (dashed arrow) in the outer lumen.

with collagen production contracting the capsule and distorting the implants. Patients commonly present with breast firmness, palpability of the implant, tenderness, or distortion. Capsular contracture is diagnosed with the Baker classification system, a subjective classification system that is based on clinical findings[9] to categorise the aesthetic outcomes and complications associated with breast implants, particularly focusing on capsular contracture.

Some radiological features can aid in the diagnosis of capsular contracture. Instead of the normal oval shape, the implants appear more rounded in shape, with an increase in anteroposterior diameter (Figure 8).[10] Also, visible capsular calcifications might develop due to local inflammation and fibrosis occurring as the implant ages (Figure 9).[11,12]

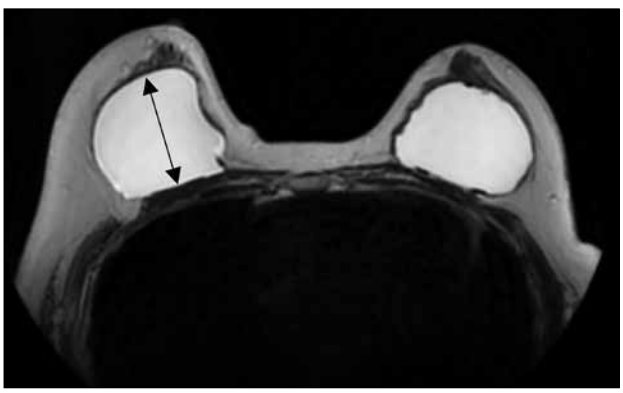

Figure 8. Capsular contracture. T2-weighted axial magnetic resonance imaging demonstrates bilateral single-lumen saline bag prostheses in the subglandular location. They are more rounded in shape with an increased anteroposterior diameter (double arrow). The outline of the implants is smooth, without focal invagination of the implant shell against the fibrous capsule. Radiological features can aid the diagnosis of capsular contracture on top of clinical findings.

Implant Rupture

Implant rupture is one of the commonest reasons for implant removal and can occur without an obvious traumatic cause, frequently in asymptomatic patients.[13] The clinical diagnosis of implant rupture can be challenging as it can present with nonspecific findings such as palpable nodules, asymmetry, or tenderness.[14] A slowly developing breast implant rupture without loss of breast volume or shape can be difficult to detect during clinical evaluation. Contour deformity is the most frequent sign of implant rupture, followed by displacement, mass formations, pain, and inflammation.[15]

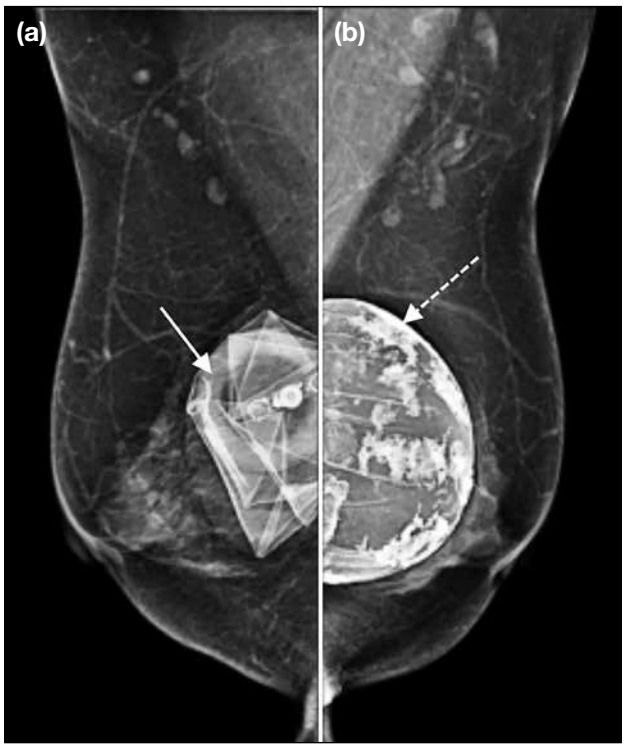

Figure 9. Bilateral subglandular saline implants. (a) Mammography showing that the right breast implant is collapsed, suggestive of implant rupture (solid arrow). (b) The left breast implant appears spherical, with peri-implant capsular calcifications (dashed arrow), suggestive of capsular contracture.

Saline implant rupture can usually be clinically identified by a significant reduction in size, while the detection of silicone implant rupture may be challenging clinically. The body normally creates a fibrous capsule around a breast implant. Intracapsular rupture indicates rupture via the implant shell, but the fibrous capsule remains intact, whereas extracapsular rupture means there is further rupture through the fibrous capsule. MRI has a high sensitivity and specificity of >90% for identification of breast implant rupture and is considered the criterion standard.[15]

Intracapsular Rupture

On MG, intracapsular rupture appears as progressive contour deformity and undulation of implant shell (Figure 9).[3] USG can also demonstrate a 'stepladder sign', due to the collapsed and infolded elastomer shell producing multiple thin echogenic lines parallel to the probe surface, which is equivalent to the 'linguine sign' on MRI.[3]

The 'linguine sign' on MRI is characterised by hypointense wavy lines inside the fibrous capsule (Figure 10a).[16] The 'keyhole sign' shows silicone on both sides of the implant (Figure 10b).[3] The 'droplet

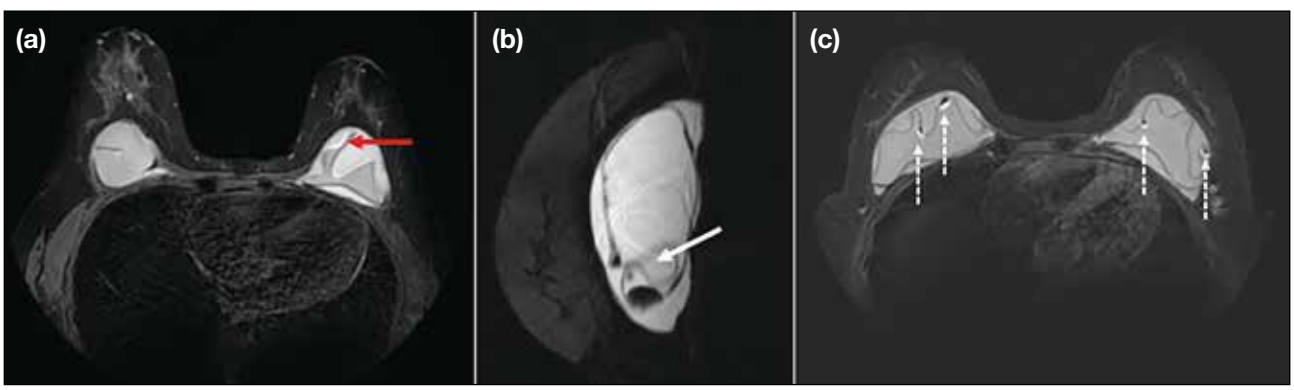

Figure 10. (a) Short-tau inversion recovery (STIR) axial magnetic resonance imaging (MRI) reveals a left breast single-lumen implant intracapsular rupture with wavy lines within the capsule (red arrow) [the 'linguine sign']. (b) T2-weighted STIR silicone-only sagittal MRI showing focal invagination of the breast single-lumen implant shell against the fibrous capsule (white arrow) [the 'keyhole sign']. (c) STIR axial MRI showing multiple T2-weighted hyperintense foci within the single-lumen implant (dashed arrows) [the 'droplets sign'].

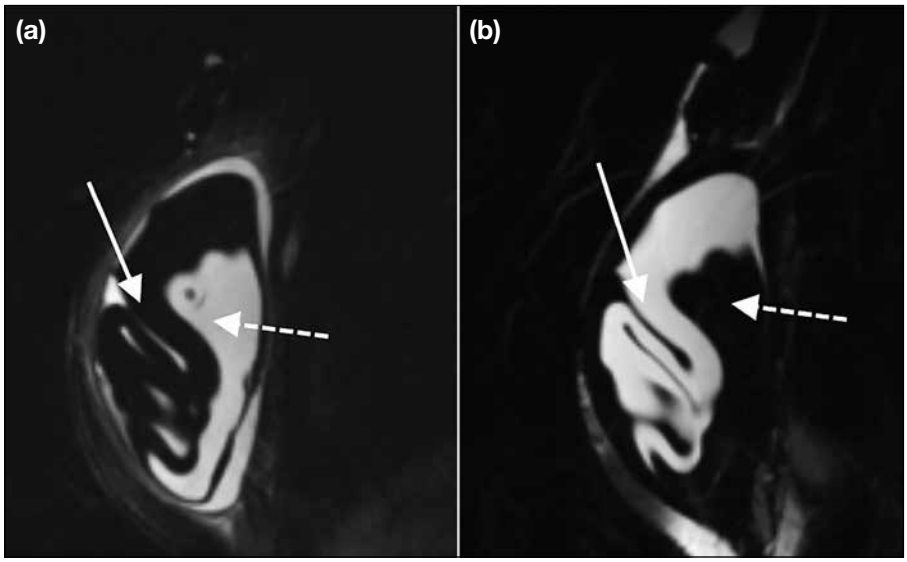

Figure 11. Inverse double-lumen implant (outer silicone layer and inner saline component) complicated by intracapsular rupture. Note the characteristic signals of silicone and saline on the magnetic resonance imaging (MRI) sequences. (a) In T2-weighted fat-suppressed silicone-suppressed MRI, the outer silicone layer (solid arrow) shows hypointense signal and inner saline layer (dashed arrow) shows hyperintense signal. (b) In T2-weighted saline-supressed MRI, the outer silicone layer (solid arrow) shows hyperintense signal and inner saline layer (dashed arrow) shows hypointense signal. Note the wavy appearance of the silicone material (solid arrow), which is confined within the fibrous capsule with no evidence of extracapsular leakage.

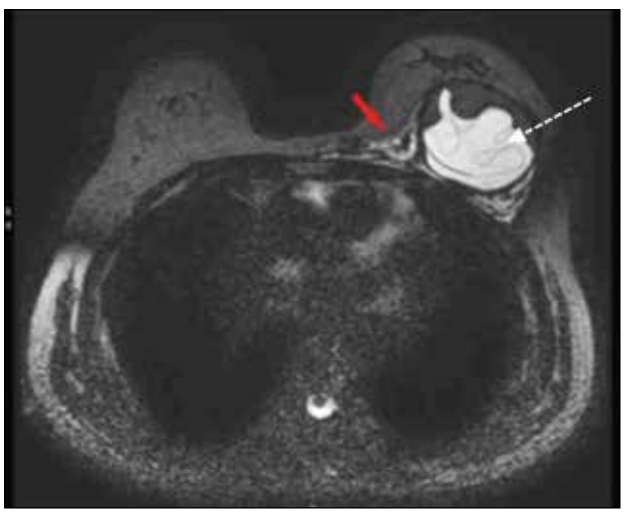

Figure 12. Silicone-only axial magnetic resonance imaging showing free silicone at the thickened peri-glandular stromal tissue extending to the midline and the left pectoralis muscle, representing extracapsular rupture (red arrow) of a unilateral left-sided implant. Note that there is also the 'linguine sign' (dashed arrow) representing intracapsular rupture.

sign' is seen when there are saline drops in the silicone gel as a result of intracapsular rupture, presenting as small, hyperintense foci within the silicone gel on T2-weighted MRI (Figure 10c). The presence of the droplet sign alone is not enough to confirm intracapsular rupture but should alert the interpreter to that possibility.[12,17] Double-lumen implants can also undergo intracapsular rupture as demonstrated in Figure 11.

Extracapsular Rupture

Extracapsular rupture means the implant material has migrated freely beyond the fibrous capsule into the surrounding breast tissues via defect of the implant shell and fibrous capsule.[17] It cannot occur without intracapsular rupture. Therefore, on radiological examination, features of extracapsular rupture are usually found with the accompany sign of intracapsular rupture.[18] This would be shown on images with free silicone present outside the capsule as well as other intracapsular rupture features (Figure 12). On USG, free silicone would manifest as a moderately echogenic mass with posterior echoic shadowing.

'Gel Bleed'

A 'gel bleed' is defined as microscopic silicone transudation through an intact implant shell. It is due to the chemical affinity of the silicone gel for the silicone elastomer of the implant shell.[19,20] This would appear as extracapsular echogenic silicone (e.g., in the axilla or more distant sites) on USG (Figure 13) and MRI with posterior acoustic shadowing.[18]

Large Cell Lymphoma

Breast implant–associated anaplastic large cell lymphoma is a rare complication of breast implant augmentation, which would present as early as 3 months to as late as 25 years after implantation.[21] Its incidence is rare, estimated between 1:500,000 and 1:3,000,000.[22] Its aetiology and pathogenesis remain poorly understood.[23] While its clinical presentations are rather nonspecific,

including pain, inflammation, breast asymmetry or breast mass, up to 80% of cases present with peri-implant effusion.[24] Should there any late-onset effusion (defined as occurring >1 year of implantation) or breast mass formation, further investigations should be performed, including such as MRI and pathological analysis with flow cytometry.[25,26] USG has a high sensitivity in detecting the peri-implant effusion; however, it has limited specificity. MG is not accurate for the diagnosis of implant effusion or mass-forming breast implant–associated anaplastic large cell lymphoma. MRI can detect peri-implant effusion and small peri-implant mass lesions, which may not be visualised on USG.[26] Small amount (5-10 ml) of peri-implant fluid is considered normal, thus the presence of such amount is not representative of the overall condition.[26]

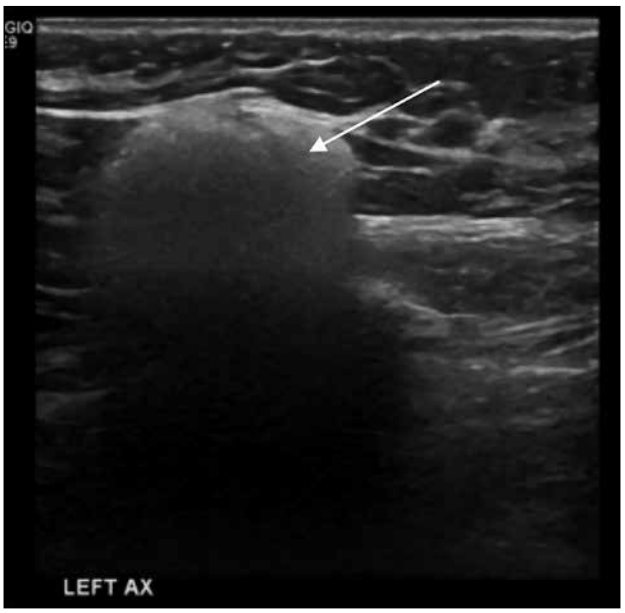

Figure 13. Ultrasonography showing an enlarged left axillary node (arrow) with posterior shadowing representing silicone lymphadenopathy. Free silicone appears echogenic lesion with a well-defined anterior border and posterior acoustic shadowing. Note that silicone lymphadenopathy can also be encountered in physical transudation of silicone through an intact implant capsule into the surrounding tissue and lymphatics, i.e., a 'gel bleed'.

INJECTION AUGMENTATION

Injection augmentation is tissue filler injection into the breast tissue using a needle or cannula without a shell. Various materials have been used as the fillers; the three major ones include paraffin, liquid silicone, and polyacrylamide hydrogel (PAAG).[27]

Paraffin

Paraffin is a purified mineral oil which was first used in vehicles for oil-soluble substances. Paraffin breast augmentation was introduced in the early 20th century as an alternative to other methods of breast augmentation.[27] Despite its early promising cosmetic result, the complications did not manifest until later stage. These complications include paraffin migration, 'paraffinoma' formation, and foreign body reaction with fibrosis and calcification and has been largely abandoned.[28,29]

Within a few months after injection, the injected paraffin would be shown on MG as circumscribed and non-calcified masses that were largely indistinguishable from the surrounding glandular tissue. At later stages, rings and other coarse calcifications usually develop and can be manifested on MG and USG (Figure 14).[29]

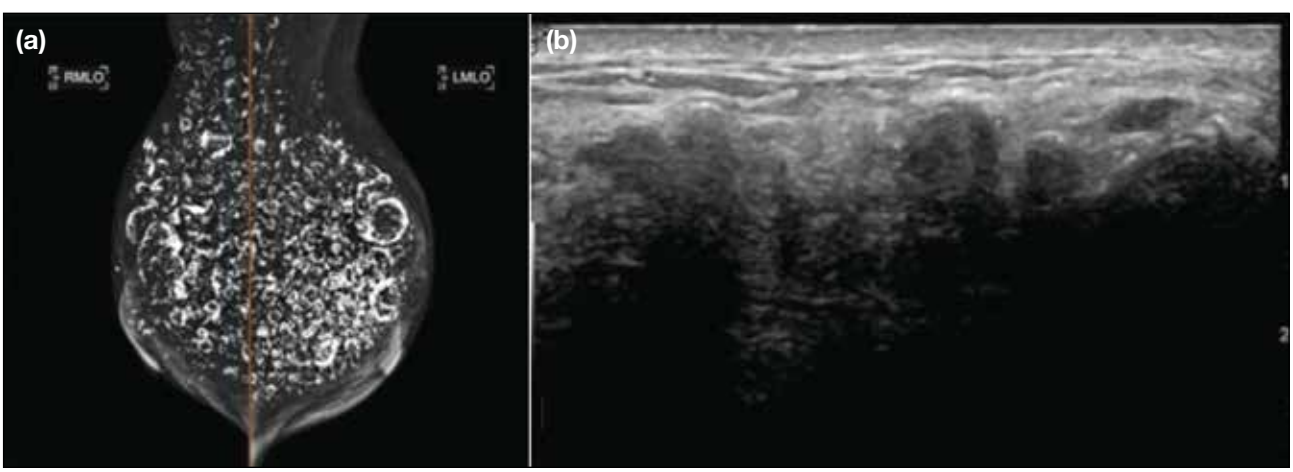

Figure 14. A patient with paraffin injection breast augmentation. (a) Mammography showing multiple coarse calcifications, some ring-shaped, representing previous paraffin injection with calcified granuloma. (b) Ultrasonography of the breast showing these calcified granulomata casting posterior acoustic shadow and limiting the assessment of deep breast tissue.

Liquid Silicone

Free liquid silicone injection has been banned by the United States Food and Drug Administration since 1992 due to safety concerns.[30] Complications include granulomatous reactions, nodule formation, and vascular embolisation.[27] Free silicone manifests as multiple extremely dense lobulated masses of various sizes distributed over both breasts on MG, often accompanied by calcified granulomas (Figure 15a). They also cast dense shadowing known as the 'snowstorm' appearance on USG (Figure 15b).[31]

Polyacrylamide Hydrogel

PAAG is a non-resorbable sterile suspension made with 2.5% acrylamide monomers and 97.5% water that has been used for augmentation. It is injected into the breast tissue, aiming to form a focal large collection at subglandular layer to increase volume and improve the shape of the breasts.[32] This would result in loculated collection formation in subglandular breast and may mimic saline bag implant augmentation on MRI (Figure 16) in uncomplicated and non-displaced case.[32]

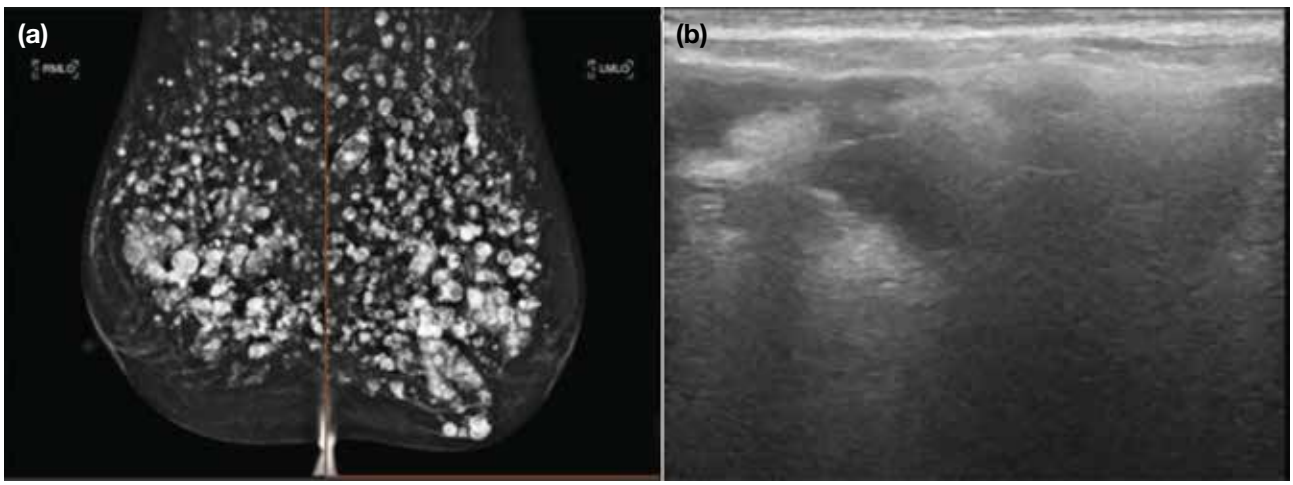

Figure 15. History of freehand silicone injection. (a) Mammography showing multiple dense and calcified nodules in both breasts representing the injected silicone and calcified granulomas in both breasts. (b) Ultrasonography showing silicone injection casting dense shadowing, known as the 'snowstorm' appearance.

Figure 16. A patient with history of polyacrylamide hydrogel (PAAG) injection. (a) T1-weighted axial magnetic resonance imaging (MRI) and (b) short-tau inversion recovery (STIR) axial MRI showing injected PAAG material as loculated collections (asterisks) in the subglandular breast tissues. Note that the PAAG material demonstrates intermediate T1-weighted signal in breast glandular tissue and hyperintense STIR signal, which could mimic saline bag implant augmentation.

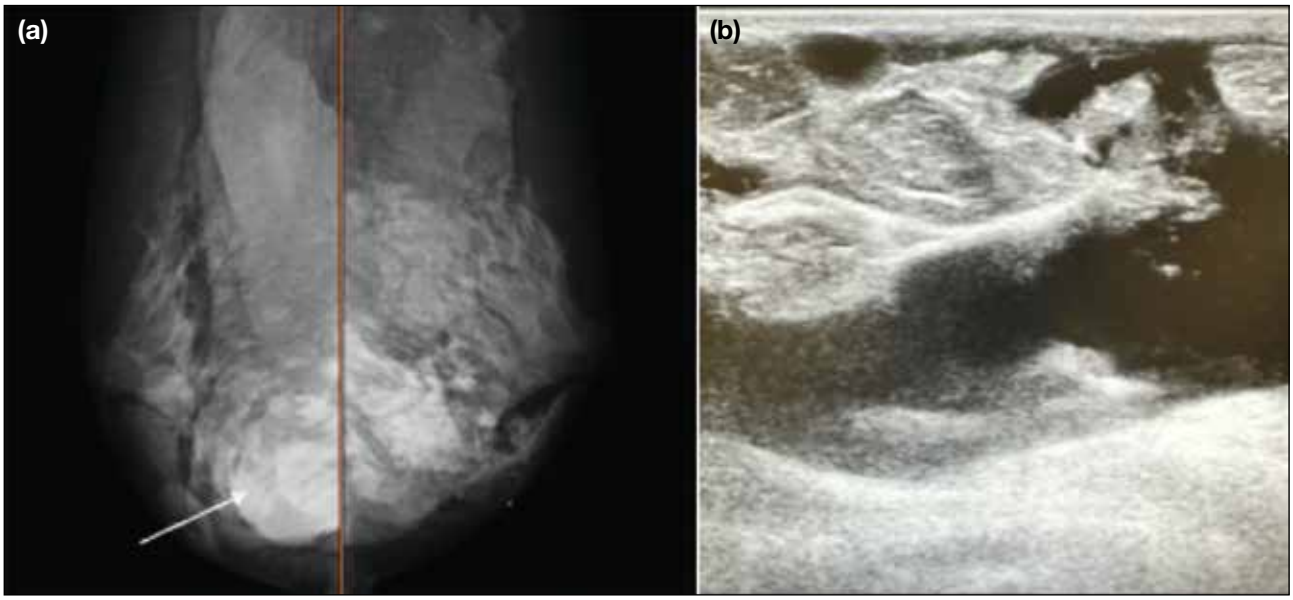

Figure 17. A patient with history of polyacrylamide hydrogel (PAAG) breast augmentation. (a) Mammography showing multiple conglomerated, well-circumscribed, equal density masses of PAAG injection (arrow) within the glandular tissue and in the subglandular and subpectoral planes. (b) Ultrasonography of the breast showing PAAG as heterogenous hypoechoic and mixed cystic lesions with lobulated margin, which may obscure underlying breast lesion (if any).

However, the use of PAAG for breast augmentation has not been approved by the United States Food and Drug Administration and has been associated with several complications including induration, lumps, haematoma, infection, inflammation, persistent mastalgia, glandular atrophy, gel migration, etc.[33,34] There have also been case reports of breast tumours being concealed by the inflammatory reaction to PAAG, misdiagnosed as gel collection.[35,36] On radiological examination, the injected PAAG material would appear as conglomerated, well-circumscribed equal density masses on MG (Figure 17a), and variable-sized, complex solid and cystic or heterogeneous echoic masses on USG (Figure 17b).

Complication

Injection material migration may be seen as an asymmetrical appearance with the filling material displaced from its normal position (Figure 18).

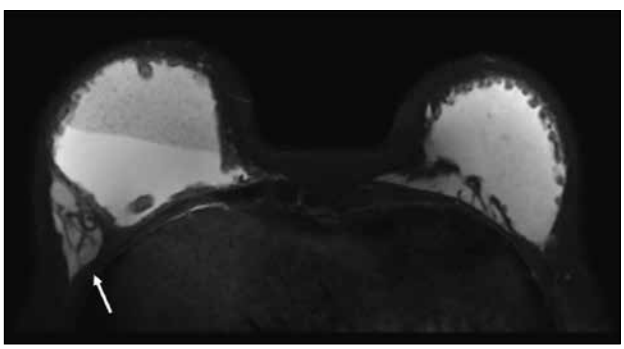

Figure 18. A patient with bilateral polyacrylamide hydrogel (PAAG) augmentation. T2-weighted fat-saturated axial magnetic resonance imaging showing a multi-loculated T2-weighted hyperintense collection (arrow) in the lower outer quadrant of the right breast, outside the expected location of the PAAG collection, suggesting migration of PAAG materials.

GENERAL COMPLICATIONS

Infection

Infection is one of the general complications that can occur after injection breast augmentation, with a reported rate up to 2.9% in breast aesthetic augmentation or even a higher rate from 1% to 53% in post-mastectomy reconstruction. Patients present with mastalgia, fever, erythema, or discharge.[37-40] Radiologically, infection can present as an irregular hypoechoic fluid collection with internal debris on USG, while MRI features include skin thickening, oedema, enhancement (Figure 19), and complex fluid collections.[10]

Haematoma Formation

Hematomas can be an early (perioperative period) presentation or delayed presentation (rare, caused by trauma, infection and coagulopathy).[41] This can be

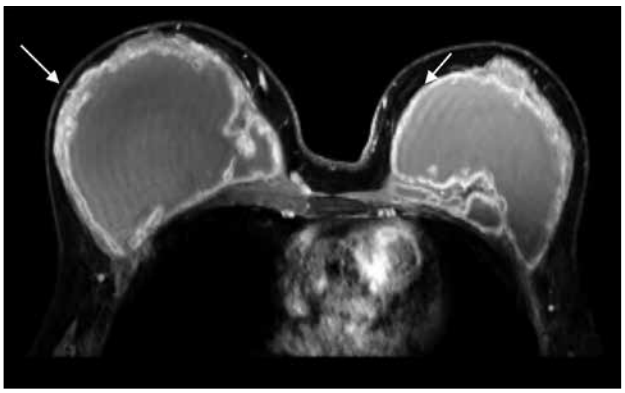

Figure 19. Polyacrylamide hydrogel augmentation complicated by infection. T1-weighted fat-saturated contrast-enhanced axial magnetic resonance imaging demonstrates capsular enhancement (arrows) of both collections, representing infective or inflammatory changes.

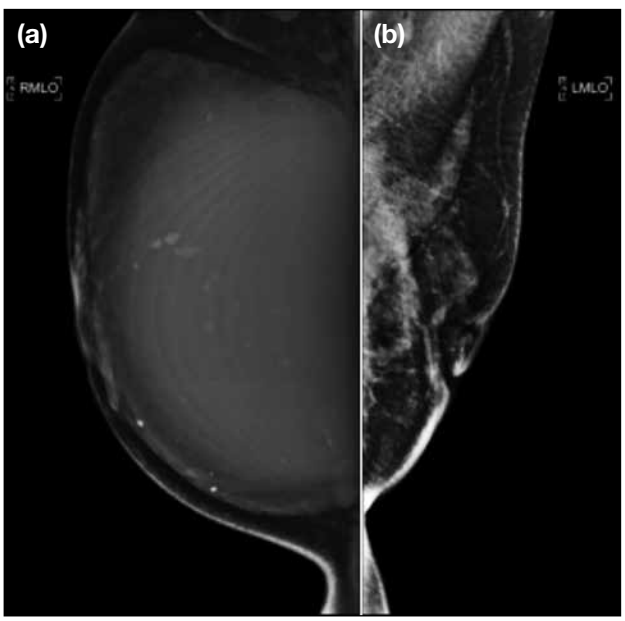

Figure 20. A patient with history of bilateral breast augmentation with polyacrylamide hydrogel and subsequent removal, presented with right breast swelling afterwards. Mammography shows a large hypo-to-isodense collection with a relatively circumscribed border occupying the right breast (a), representing postoperative haematoma. Mediolateral oblique view of contralateral left breast mammography (b) is provided for comparison.

manifested as progressive breast swelling. On MG, haematomas appear as collections of different density depending on the age of the blood products (Figure 20). USG and MRI show complex blood product collections.[10]

CONCLUSION

As breast augmentations are becoming more common, it is crucial for radiologists familiarise themselves with the radiological appearance of various breast implants and injection augmentations and their associated complications on different imaging modalities.

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