1. INTRODUCTION

In the United States, breast cancer is projected to account for 266,120 new diagnoses and 40,920 deaths in 2018 with 89.7% surviving at five years. Imaging is essential for the early detection and accurate diagnosis of breast cancer. Population screening with mammography aims to reduce mortality by detecting the disease at an earlier stage Stage 0-1, before it has spread beyond the breast. Mammography and ultrasound are the first-line imaging investigations in women with breast symptoms. Magnetic resonance imaging (MRI) is established as an adjunctive diagnostic tool because of its high sensitivity for invasive breast cancer. Percutaneous image-guided breast biopsy is used for the pathological assessment of breast lesions.

2. METHODS OF EXAMINATION

Mammography

Mammography remains one of the principal imaging modalities for diagnosis, although its use is rarely indicated in women under the age of 30. The main indications for mammography are:

• breast cancer screening;
• evaluation of breast symptoms and signs, including masses, skin thickening and retraction, nipple retraction, nipple discharge and eczema, localized pain;
• follow-up of patients with previously treated breast cancer; and
• guidance for biopsy, or localization of lesions not visible on ultrasound.

Mammography places stringent demands on equipment and image quality. The breast is composed predominantly of fatty tissue and has a relatively narrow range of inherent densities. Consequently, special X-ray tubes are required to produce the low-energy radiation necessary to achieve high tissue contrast, enabling the demonstration of small changes in breast density. High spatial resolution is required to identify tiny structures within the breast, such as microcalcifications measuring in the order of 100 μm; and short exposure times are necessary to limit movement unsharpness. Where the breasts are thicker or are composed of denser glandular tissue, higher energy radiation is required, although radiation dose must be kept to a minimum.
Standard Projections: MLO and CC

Mammograms are displayed in conventional manner paired (to permit bilateral comparison) MLO followed by CC with patient’s right breast on the left side of the screen and left breast on the right side of the screen. There are two standard mammographic projections: a mediolateral oblique (MLO) view and a craniocaudal (CC) view. Correct positioning is crucial to avoid missing lesions situated at the margins of the breast. The MLO view is taken with the X-ray beam directed from superomedial to inferolateral, usually at an angle of 30–60°, with compression applied obliquely across the chest wall, perpendicular to the long axis of the pectoralis major muscle. The MLO projection is the only projection in which all the breast tissue can be demonstrated on a single image. A well-positioned MLO view should demonstrate the inframammary angle, the nipple in profile, and the nipple positioned at the level of the lower border of the pectoralis major, with the muscle across the posterior border of the film at an angle of 25°–30° to the vertical.

For the CC view, the X-ray beam travels from superior to inferior. Positioning is achieved by pulling the breast up and forward away from the chest wall, with compression applied from above. A well-positioned CC view should demonstrate the nipple in profile. It should demonstrate virtually all of the medial tissue and most of the lateral tissue except the axillary tail of the breast. The pectoralis major is demonstrated at the center of a CC film in approximately 30% of individuals and the depth of breast tissue demonstrated on the CC should be within 1 cm of the distance from the nipple to the pectoralis major on the MLO projection.
Supplementary views may be taken to solve specific diagnostic problems. For example, the CC view can be rotated to visualize either more of the lateral or medial aspect of the breast, compared to the standard CC projection. Localized compression views can be performed. This involves the application of more vigorous compression to a localized area using a compression paddle. These views are used to distinguish real lesions from superimposition of normal tissues and to define the margins of a mass. A true lateral view may be used to provide a third imaging plane in order to distinguish superimposition of normal structures from real lesions, to increase the accuracy of wire localizations of non-palpable lesions, or to ascertain the presence of layering in the case of milk of calcium or fat-containing oil cyst / galactoceles. The true lateral view is performed with the mammography unit turned through 90° and a mediolateral or lateromedial X-ray beam. Magnification views are frequently performed to examine areas of microcalcifications within the breast, to characterize them and to establish their extent. These magnification views are typically performed in the craniocaudal and lateral projections. The magnified lateral view will demonstrate ‘teacups’ typical of benign microcalcifications, described later in the chapter. Mammographic technique may need to be modified in women with breast implants. Silicone and saline implants are radioopaque and may obscure much of the breast tissue. Consequently, mammography is of limited diagnostic value in some women. The Eklund (Implant displaced) technique can be employed to displace the implant posteriorly, behind the compression plate, maximizing the volume of breast tissue that is compressed and imaged. Mammography-induced implant rupture is not a consideration.

Breast Compression

Compression of the breast is essential for good mammography, for the following reasons:

- It reduces geometric unsharpness by bringing the object closer to the film.
- It improves contrast by reducing scatter.
- It diminishes movement unsharpness by permitting shorter exposure times and immobilizing breast.
- It reduces radiation dose, as lesser thickness of breast tissue needs to be penetrated and scatter is reduced.
- It achieves more uniform image density: a homogeneous breast thickness prevents overexposure of the thinner anterior breast tissues and underexposure of thicker posterior breast tissues.
- It provides more accurate assessment of the density of masses. As cysts and normal glandular tissue are more easily compressed, the more rigid carcinomas are highlighted.
- It separates superimposed breast tissues so that lesions are better seen.

Digital Breast Tomosynthesis

One of the limitations of mammography is that it produces a two-dimensional (2D) radiographic view of a three-dimensional structure and, as a consequence, a cancer may not be detected due to overlapping normal glandular tissue obscuring the presence of a tumor. Too, lesions may be simulated by the superimposition of normal tissue, leading to unnecessary recalls following screening mammography. These factors result in a reduction in the sensitivity and specificity of mammography. Breast tomosynthesis is an emerging digital mammographic technique where thin slices through the breast are reconstructed from multiple low-dose projections acquired at different angles of the X-ray tube. The resulting thin sections can be scrolled through by the reporting radiologist, with the potential to alleviate the effects of tissue superimposition.

When DBT is used as a screening tool, studies show improvement in specificity, with a reduction in recall rates as well as improvements in sensitivity over conventional 2D mammography.
Ultrasound

The main indications for breast ultrasound are:
• characterization of palpable mass lesions;
• assessment of abnormalities detected on a mammogram;
• primary technique for the assessment of breast problems in younger patients; and
• guidance for biopsy and wire localizations.

Breast ultrasound requires high-quality, high-resolution grey-scale imaging, using linear probes with high frequencies typically between 7.5 and 15 MHz. Ultrasound higher frequencies result in greater resolution, but as the frequency increases, the ability of the ultrasound beam to penetrate to deeper breast tissue decreases. Consequently, the frequency selected has to be appropriate for the size of the breast to be examined. Parameters such as harmonics and compounding are available on modern ultrasound machines and can be applied to enhance the displayed image.

Ultrasound Technique

The patient is examined in the supine position with the ipsilateral arm placed behind the patient's head. When imaging the outer portion of either breast it helps to turn the patient into a more oblique position. The aim is to flatten the breast tissue against the chest wall, reducing the thickness of breast tissue to be imaged. It is best to image the breast tissue in two planes perpendicular to each other. A transverse and a sagittal plane is a common combination, as is examining the breast in a radial and anti-radial direction. The theory behind this method is that the ducts of the breast are positioned in a radial direction, running towards the nipple rather like the spokes of a bicycle wheel. Most breast cancers begin in the ducts and so tumors extending along the ductal system may be better visualized in this plane.

3. NORMAL ANATOMY

The breast lies on the chest wall on the deep pectoral fascia with the superficial pectoral fascia enveloping the breast. Suspensory ligaments called Cooper's ligaments connect the two layers, providing a degree of support to the breast and giving the breast its shape. Centrally, there is the nipple-areolar complex. Collecting ducts open onto the tip of the nipple. There are sebaceous glands within the nipple-areolar complex called Montgomery's glands. Small raised nodular structures called Morgagni's tubercles are distributed over the areola, representing the openings of the ducts of Montgomery's glands onto the skin surface. Deep to the
nipple-areolar complex, the breast is divided into 15-25 lobes, each consisting of a branching duct system leading from the collecting ducts to the terminal duct lobular units (TDLUs), the site of milk production in the lactating breast.

Breast Density
The number of TDLUs per lobe varies according to age, lactation, parity and hormonal status. At the end of reproductive life there is an increase in the amount of adipose tissue and, although the main duct system is preserved, there is considerable loss of lobular units. These changes in breast composition are manifested by changes in the breast density on mammography. Younger women tend to have denser glandular breast tissue. In older women, the mammographic density tends to decrease, with replacement of the glandular tissue by fatty tissue. Classification systems have been developed to describe the density of breast tissue on mammography. The American College of Radiology (ACR) breast imaging reporting and data system (BIRADS®) lexicon defines four patterns of increasing density, so called Breast Composition:

a. Almost entirely fatty, less than 25% glandular
b. Scattered fibroglandular density, 25-50% glandular
c. Heterogeneously dense, 50-75% glandular
d. Extremely dense, >75% glandular

Mammographic density is a risk factor for the development of breast cancer, with a dense background pattern (heterogeneously dense and extremely dense patterns) associated with a higher than average risk of developing breast cancer and more aggressive tumor characteristics. The mechanism through which increased density contributes to breast cancer risk remains unclear. In addition, dense breast tissue may hide abnormalities in the breast, making cancer detection more difficult. The sensitivity of mammography for detecting breast cancer is directly related to the density of the breast tissue. In general, mammography is more sensitive at detecting breast cancer in older, postmenopausal women because the breast tends to be composed of more fatty tissue.

4. BREAST PATHOLOGY

BENIGN MASSES
Cysts
Cysts are the most common cause of a discrete breast mass, although they are often multiple and bilateral. They are common between the ages of 20 and 50 years, with a peak incidence between 40 and 50 years. Simple cysts are not associated with an increased risk of malignancy and have no malignant potential. On mammography they are seen as well-defined, round or oval masses. Sometimes a characteristic halo is visible on mammography. Ultrasound also demonstrates well-defined margins, with an oval or round shape. There is an absence of internal echoes indicating the presence of fluid. The area of breast tissue behind a cyst appears bright on ultrasound (posterior enhancement) due to improved transmission of the ultrasound beam through the cyst fluid. When these features are present, a cyst can be diagnosed with certainty. Aspiration is easily performed under ultrasound guidance to alleviate symptoms or when there is diagnostic uncertainty. Cytology on cyst fluid is not routinely performed unless there are atypical imaging features or the aspirate is bloodstained.

Fibroadenomas and Related Conditions
Fibroadenomas are the most common cause of a benign solid mass in the breast. They present clinically as smooth, well-demarcated, mobile lumps. They are most frequently encountered in younger women with a peak incidence in the third decade. With the advent of screening, many previously asymptomatic lesions are detected. On mammography, fibroadenomas are seen as well-defined, rounded or oval masses. Coarse calcifications may develop within fibroadenomas, particularly in older women. Ultrasound features have been described that are characteristic of benign masses. These include hyperechogenicity relative to fat, an oval or well-circumscribed lobulated or gently curving shape and the presence of a thin echogenic pseudocapsule. If these features are present with no features suggestive of malignancy, then a mass can be confidently classified as benign. Most fibroadenomas are isoechogenic or mildly hypoechoic relative to fat, with an oval shape and lobulated contour. A thin echogenic pseudocapsule may be seen. Percutaneous biopsy may be avoided in women under the age of 25, where the risks of any mass being malignant are very small; however, in many other cases, even though the mass appears benign, percutaneous biopsy is undertaken to confirm the diagnosis. Fibroadenomas must be distinguished from well-circumscribed carcinomas; this is done by percutaneous biopsy. Phyllodes tumor can also have a similar appearance to fibroadenoma, leading to diagnostic difficulties. The pathological characteristics of phyllodes can also be similar to those of large fibroadenomas. Most phyllodes tumors are benign, but a small fraction are locally aggressive and may even metastasize. When a diagnosis of phyllodes tumor is made, surgical excision must be complete with clear margins to prevent the possibility of local recurrence. Many larger fibroadenomas (over 3 cm) and those that show a rapid increase in size are excised in order to avoid missing a phyllodes tumor.

Hamartoma
Hamartomas are benign breast masses composed of lobular structures, stroma and adipose tissue—the components that make up normal breast tissue. They occur at any age. On imaging they may be indistinguishable from other benign masses, such as fibroadenomas. Sometimes large hamartomas are detected on screening mammograms and are impalpable. On mammography hamartomas classically appear as well-circumscribed masses containing a mixture of dense and lucent areas, reflecting the different tissue components present. Diagnostic difficulty may be encountered because percutaneous biopsy specimens may be reported as normal breast tissue.

Papilloma
Papillomas are benign neoplasms, arising in a duct, either centrally or peripherally within the breast. Many papillomas secrete watery material, leading to a nipple discharge. As they are often friable and bleed easily, the discharge may be bloodstained. On mammography, they may be seen as a well-defined mass, commonly
in a retroareolar intraductal location. Sometimes the mass is associated with microcalcifications. On ultrasound, they typically appear as a filling defect within a dilated duct or cyst. On aspiration, any cyst fluid may be bloodstained. Papillomas are associated with an increased risk of malignancy when multiple or when occurring in a more peripheral duct within the breast. Papillomas may also contain atypia. Consequently, excision of papillary lesions may be desirable or needed, and may also be therapeutic in cases of nipple discharge.

**Lipoma**
Lipomas are benign tumors composed of fat. They present clinically as soft, lobulated masses. Large lipomas may be visible on mammography as a radiolucent mass. On ultrasound their characteristic appearance is that of a well-defined lesion, hyperechoic compared with the adjacent fat.

**MALIGNANT MASSES**

**Invasive Carcinoma**
Breast carcinomas originate in the epithelial cells that line the terminal duct lobular unit (TDLU). When malignant cells have extended across the basement membrane of the TDLU into the surrounding normal breast tissue, the carcinoma is invasive. Malignant cells contained by the basement membrane are termed non-invasive or in situ.

Classification of Invasive Breast Cancer
Regarding the classification of breast cancer: some tumors show distinct patterns of growth, allowing certain subtypes of breast cancer to be identified. Those with specific features are called invasive carcinoma of a specific special type, while the remainder are considered to be Invasive mammary (ductal) of no special type (NST). Special-type tumors include lobular, medullary, tubular, tubular mixed, mucinous, cribriform and papillary, among others. Different types of tumor have different clinical patterns of behavior and prognosis. It should be understood that when a tumor is classified as of a special type this does not imply a specific cell of origin, but rather a recognizable morphological pattern. Histological grade has implications for tumor behavior, imaging appearances and prognosis. The morphological features on which histological grade is
based are tubule formation, nuclear pleomorphism and frequency of mitoses. Low-grade tumors that are well differentiated are less likely to metastasize.

Imaging Appearance of Invasive Breast Cancer
Mammography: Carcinomas typically appear as ill-defined or spiculated masses on mammography. Lower-grade cancers tend to be seen as spiculated masses, due to the presence of an associated desmoplastic reaction in the adjacent stroma. Higher-grade tumors are usually seen as an ill-defined mass, but sometimes a rapidly growing tumor may appear relatively well defined, with similar appearances to a benign lesion such as a fibroadenoma. Calcifications, representing DCIS, may be found in association with invasive carcinoma. Many breast cancers arise from areas of ductal carcinoma in situ (DCIS) and are associated with microcalcifications on mammography. This is particularly true for high-grade invasive ductal carcinomas that are often associated with high-grade DCIS.

Special-type tumors can have particular mammographic characteristics:
- Lobular carcinomas can be difficult to perceive on a mammogram due to their tendency to diffusely infiltrate fatty tissue. Compared with ductal NST tumors, lobular cancers are more likely to be seen on only one mammographic view, are less likely to be associated with microcalcifications and are more often seen as an ill-defined mass or an area of asymmetrically dense breast tissue.
- Tubular and cribriform cancers often present as architectural distortions or small spiculated masses.
- Papillary, mucinous and medullary cancers may appear as new or enlarging multilobulated masses and may be well defined, simulating an apparently benign lesion.

Sometimes the only clue to the presence of an invasive tumor may be abnormal trabecular markings, known as an architectural distortion, or the presence of microcalcifications, which tend to be visible even when the breast parenchyma is dense. The ability to perceive small or subtle cancers on a mammogram is improved by having the two standard mammographic views available and seeking out previous studies for comparison. An increase in the size of a mass or the presence of a new mass is suspicious of malignancy, whereas a lesion that remains unchanged over many years is invariably benign. Multiple masses in both breasts would favor a benign disease such as cysts or fibroadenomas.
Ultrasound
There are characteristic malignant features on ultrasound:
• Carcinomas have irregular shape and not circumscribed margins, present as masses that are hypoechoic and may demonstrate posterior acoustic shadowing.
• Carcinomas tend to be taller than they are wide (the anterior to posterior dimension is greater than the transverse diameter), so-called not parallel orientation.
• There may be an ill-defined echogenic halo around the lesion, particularly around the lateral margins, and distortion of the adjacent breast tissue may be apparent, analogous to spiculation on the mammogram.
• Posterior acoustic shadowing is frequently observed, due to a reduction in the through transmission of the ultrasound beam in dense tumor tissue.

![Ultrasound Image](image)

Classic appearing CA: Irregular, Not parallel, Not circumscribed mass

Poorly differentiated, high-grade tumors are more likely to be well defined, without acoustic shadowing; hence, the importance of carrying out a biopsy of solid masses even when the ultrasound appearances are benign. Microcalcifications are sometimes observed, associated with high-grade tumors arising in areas of DCIS, although this is less frequently encountered than with mammography. Lobular carcinomas can be difficult to demonstrate on ultrasound (as on mammogram). They may produce vague abnormalities, such as subtle alterations in echotexture or dense shadowing, or the ultrasound findings may even mimic dense normal tissue.
Ultrasound is a useful tool in the local staging of breast cancer preoperatively. It tends to be a better predictor of tumor size than mammography and may detect intraductal tumor extension. Ultrasound may also detect small satellite tumor foci not visible on mammography.
It has long been recognized that involvement of axillary lymph nodes is one of the most important prognostic factors for women with breast cancer. Traditionally, the axilla has been staged at the time of surgery by lymph node sampling procedures, sentinel node biopsy or clearance of the axillary lymph nodes. Surgical clearance of axillary lymph nodes carries the risk of significant postoperative morbidity, with some women developing disabling lymphedema in the arm. Ultrasound can identify abnormal nodes preoperatively that can then be biopsied percutaneously under ultrasound guidance, allowing a preoperative diagnosis of lymph node involvement to be made in just over 40% of patients who are lymph node positive. This enables the more radical axillary clearance to be targeted to those patients with a preoperative diagnosis of axillary disease, with the sampling or sentinel node procedures reserved for those patients with a much lower risk of axillary involvement. Axillary lymph nodes can be assessed on the basis of shape and the morphology of the cortex. Nodes are likely to contain tumor if their longitudinal-to-transverse diameter ratio is less than 2 (the node appears round rather than oval). Nodes are more likely to contain tumor if the cortex is thickened to more than 2.5mm.
The Differential Diagnosis of Malignancy

Many apparently suspicious findings seen on mammography or ultrasound can be caused by benign disease or even normal breast tissue. A surgical scar may result in a spiculated mass or an architectural distortion. Radiographers should be encouraged to record the presence and position of any scars when performing a mammogram to aid image interpretation by the film reader.

Infection and inflammatory processes in the breast can be mistaken for malignancy on mammography and ultrasound. Breast abscesses are typically encountered in young lactating women. Treatment is with antibiotics and aspiration of the pus, frequently under ultrasound guidance. Inflammation in a non-lactating breast is a more worrying feature, although infections and more unusual inflammatory conditions such as granulomatous mastitis can occur. Skin erythema and edema may be caused by an underlying carcinoma, termed ‘inflammatory carcinoma’. In this situation, skin thickening and edema may be the only signs of malignancy recognized on the mammogram. In any case of unexplained inflammation, or when infection fails to resolve, percutaneous biopsy is required to make the diagnosis or exclude malignancy. Radial scars, also called complex sclerosing lesions, can produce a spiculated lesion, indistinguishable from malignancy on both mammography and ultrasound. Many of these lesions are asymptomatic and are encountered on screening mammography. Superimposition of normal breast tissue may produce apparent masses, distortions or worrying asymmetries on mammography. These summation shadows are usually evaluated with additional mammographic views. Localized compression magnification views are particularly helpful in deciding whether a lesion is real or just a summation shadow. Ultrasound or digital breast tomosynthesis of the area of mammographic concern can help to determine whether a lesion is truly present.

CALCIFICATIONS

Microcalcifications are frequently encountered on routine screening mammograms. In many cases these microcalcifications are found to be benign, but occasionally are an important feature of DCIS. Some calcifications have a characteristic benign appearance and require no further action. There is a considerable overlap between the appearance of benign and malignant microcalcifications, necessitating percutaneous biopsy in many cases.

Benign Microcalcifications

Many benign processes in the breast can cause microcalcifications, including fibrocystic change, duct ectasia, fat necrosis and fibroadenomatoid change. Fibroadenomas and papillomas can also become calcified. Sometimes normal structures, such as the skin or small blood vessels, calcify. Calcifications can also develop in atrophic breast lobules or normal stroma. Vascular calcifications have a characteristic ‘tramtrack’ appearance caused by calcification in both walls of the vessel. Similarly, duct ectasia has a classical appearance that rarely causes diagnostic difficulty. In this condition, coarse rod and branching calcifications are recognized due to calcification of debris within dilated ducts. These calcifications have been described as having a ‘broken needle’ appearance and are usually bilateral. Fibrocystic change is a common cause of microcalcifications. On
a lateral magnification view, layering of calcific fluid contained within microcysts can be appreciated, producing a characteristic ‘teacup’ appearance. Fat necrosis is a frequently encountered cause of benign calcifications, particularly when there is a history of trauma or previous surgery. It may present as ‘rim’ calcifications within the wall of an oil cyst or as coarse dystrophic calcifications associated with areas of scarring. Fibroadenomas may become calcified, particularly after the menopause. Classically, the calcifications have a coarse, ‘popcorn’ appearance. However, they can be smaller and heterogenous, necessitating a biopsy to establish the diagnosis. Fibroadenomatoid hyperplasia is an increasingly common cause of microlcifications detected during screening. Histologically, there are features of a fibroadenoma and fibrocystic change. There is usually no associated mass lesion and in many cases biopsy is required to exclude DCIS. Skin calcifications are characteristically round, well defined, have a lucent center and are very often bilateral and symmetrical. Talcum powder or deodorants on the skin, as well as tattoo pigments, can mimic microlcifications.

Typically Benign Calcifications

- Skin
- Vascular
- Coarse or Popcorn-like (FA)
- Large Rod-like (Secretory)
- Round
- Rim
- Dystrophic
- Milk of Calcium
- Suture

Malignant Microcalcifications

Microcalcifications are found associated with invasive breast cancer and DCIS. Calcifications are more likely to be malignant if they are grouped rather than scattered throughout the breast, if they vary in size and shape (pleomorphic), and if they are found in a linear or segmental distribution. Malignant microcalcifications associated with high histological grade DCIS are classically fine rod (linear) shaped and branched. These calcifications are known as casting or comedo microcalcifications and represent necrotic debris within the ducts; hence, their linear, branching structure. Approximately one-third of malignant microcalcification clusters have an invasive focus within them at surgical excision. The greater the number of flecks of microcalcification associated with an area of DCIS, the greater the risk of invasive disease. In the screening setting, it is often the presence of mammographically visible calcifications associated with high-grade DCIS that leads to the diagnosis of small, high-grade cancers. Calcifications are much less frequently found in low-grade DCIS, as there is usually no intraductal necrosis. When they do occur, they are grouped, but otherwise may have a nonspecific appearance. The sensitivity of ultrasound for detecting DCIS is significantly lower than that of mammography, which is one of the reasons why ultrasound is not a useful screening test for breast cancer. However, ultrasound may be able to identify areas of microcalcifications seen on a mammogram, aiding percutaneous biopsy.
5. MAGNETIC RESONANCE IMAGING

Breast MRI
Although mammography and ultrasound remain the most frequently used techniques for imaging the breast, contrast-enhanced MRI is becoming increasingly important, largely because of its high sensitivity for detecting invasive breast cancer, which approaches 100%. MRI is the technique of choice for assessing the integrity of breast implants.

Technique
Successful breast MR studies require at least a 1.5-tesla system and the use of a dedicated breast coil. Some breast coils have inbuilt compression devices to stabilize the breast and reduce the number of slices required to cover the whole of the breast. Patients are examined in the prone position, with the breast hanging down into the coil. The intravenous injection of gadolinium-based contrast agent is required; it is the presence of abnormal vasculature within the lesion that enables detection. Some method of eliminating the signal from fat is needed as an enhancing lesion and fat display similar high signal on a T1-weighted image. Fat suppression may be active or passive: active fat suppression is typically achieved by the use of spectrally selective pulse sequences to suppress the signal from fat; passive fat suppression involves subtraction of the unenhanced images from the enhanced images. Subtraction allows faster imaging, with good spatial and temporal resolution, but it requires no patient movement between the two sets of images. Methods of active fat suppression, such as parallel imaging, allow fat suppression to be achieved with shorter examination times while maintaining good spatial and temporal resolution. Fast 3D gradient-echo pulse sequences provide the optimum method for imaging small lesions. Temporal resolution is important because the optimum contrast between malignancy and normal breast tissue is achieved in the first 2 min following the injection of gadolinium. Later, normal breast tissue may start to show non-specific enhancement, masking the presence of disease. Other signs of malignancy, such as a rapid uptake of contrast agent followed by a ‘washout’ phase, may only be apparent if images are acquired dynamically after the gadolinium injection.

Lesion Characterization
There are two main approaches to image interpretation: the first relates to lesion morphology and the second to assessment of enhancement kinetics. The architectural features that indicate benign and malignant disease
are similar to those already described for mammography and ultrasound. Benign lesions tend to be well defined with smooth margins, whereas malignant lesions are poorly defined and may show spiculation or parenchymal deformity. Malignant lesions tend to enhance rapidly following the injection of contrast agent and may show characteristic ring or rim enhancement. Dynamic contrast-enhanced MRI enables more detailed enhancement curves to be calculated to aid characterization. Malignant lesions usually show a rapid uptake of contrast agent in the initial phase of the examination, followed by a washout or plateau in the intermediate and late periods after injection, whereas benign lesions exhibit a steady increase in signal intensity throughout the time course of the examination. There is some overlap in the enhancement characteristics of benign and malignant lesions. One of the strengths of breast MR imaging is that invasive cancer can be effectively excluded with a high degree of certainty if no enhancement is seen. Imagers use a combination of morphologic features and enhancement kinetics to differentiate benign from malignant lesions. The use of the breast imaging reporting and data system (BIRADS®) lexicon aids reporting. Using this system, lesions can be characterized into one of three morphological groups: (1) a focus (a lesion <5 mm, rarely worthy of further investigation); (2) a mass (>5 mm); and (3) non-mass enhancement (an area of enhancement without a morphological correlate). Further descriptors can then be used to describe the shape, margin and enhancement characteristics of mass lesions and the distribution and internal enhancement characteristics of non-mass lesions. Enhancement kinetics are helpful in the assessment of mass lesions, but are not useful in the assessment of non-mass enhancement where DCIS and lobular carcinoma are part of the differential diagnosis. Normal breast tissue may enhance and this enhancement is in part dependent on the phase of the menstrual cycle. The optimum time for performing a breast MRI is during the second week of the menstrual cycle (between days 7 and 13) when background glandular enhancement should be least intense. Timing the MRI examination with the second week of the menstrual cycle may not be possible for patients undergoing cancer staging, but should be undertaken for screening and follow-up studies. Recent surgery or radiotherapy can interfere with image interpretation. Enhancement patterns return to normal between 3 and 6 months after radiotherapy. Percutaneous breast biopsy (FNAC, core, or vacuum-assisted biopsy) rarely interferes with MRI interpretation.

Breast MRI BI-RADS® Lexicon At A Word

BENIGN

Mass
Shape: Oval
Margin: Circumscribed
Enhancement:
Homogeneous
Dark internal septations
NME Homogeneous
Multiple
Diffuse

SUSPICIOUS

Mass
Shape: Irregular
Margin: Spiculated
Irregular
Enhancement: Rim Heterogeneous
NME Heterogeneous
Clumped
Clustered ring
Segmental
Linear

Indications for Breast MRI
Contrast-enhanced breast MRI is used for local staging of primary breast cancer. MRI is the most accurate technique for sizing invasive breast carcinomas and will sometimes show unsuspected multifocal or multicentric disease in the same breast or even additional tumor foci in the contralateral breast. MRI can be expected to show additional tumor foci in the affected breast away from the primary tumor site in around 16% of cases and additional disease in the contralateral breast in around 4% of cases. This may lead to a change in the therapeutic approach, potentially avoiding inappropriate breast-conserving surgery or unnecessary mastectomies. The routine use of MRI for the preoperative staging of primary breast cancer remains controversial and so careful patient selection is important. MRI is usually reserved for patients where estimating tumor size is proving difficult by conventional methods, including mammographically occult lesions, patients with mammographically dense breasts, and where there is significant discrepancy between size estimations at mammography, ultrasound and clinical examination. Another group of patients who benefit from preoperative staging with MRI are those whose carcinomas have lobular features. Lobular carcinomas are more likely to be multifocal compared with ductal NST tumors. They are more difficult to detect and their size is more difficult to measure by conventional methods because of their infiltrating growth pattern. In approximately 50% of such patients MRI will show more extensive tumor. Another important role of MRI is identifying an occult primary tumor in women presenting with malignant axillary lymphadenopathy with a normal mammogram and breast ultrasound. In this situation, MRI is highly sensitive for identifying an occult primary. MRI is also useful in the postsurgical breast, differentiating surgical scarring from tumor recurrence. MRI can help to assess the response to treatment in women receiving neoadjuvant chemotherapy for locally advanced primary breast cancers. It can recognize responders to treatment earlier than other imaging methods by demonstrating a reduction in lesion size, or a change in the enhancement pattern, with the level of enhancement reducing or taking on a more benign appearance. Neoadjuvant chemotherapy can also be used to downstage large breast cancers to enable breast-conserving surgery to become a treatment option. MRI can be used to plan the extent of surgical resection in positive responders, with successful breast conservation possible in around 59% of women where mastectomy would have been necessary. MRI has become an important tool for screening younger women with a high familial risk of breast cancer. Some of these women (e.g. known gene mutation carriers) have a lifetime risk of developing breast cancer as great as 85%. In these younger women the sensitivity of mammography for detecting malignancy is low, largely due to the presence of mammographically dense breast parenchyma. Screening with MRI is superior to mammography in detecting invasive breast cancer in such women, although mammography remains more sensitive for detecting DCIS.

**Indications**

- High risk screening
- Local staging and contralateral screening in newly diagnosed breast cancer
- Occult breast cancer in positive biopsy axillary lymph nodes or metastases but negative mammograms
- Assessing response to neoadjuvant therapy
- Implant rupture
- (Problem solving)

**High Risk Screening**

- BRCA1 and BRCA2 mutation
- First degree relative of BRCA mutation, but untested
- Lifetime risk of 20-25% or greater
- Radiation to the chest between age 10 and 30 years
- Li-Fraumeni, Cowden, or Bannayan-Riley-Ruvalcaba syndrome and first degree relatives
Managing MRI-Detected Lesions
Lesions detected at MRI require proper work-up, including histological diagnosis where appropriate. Findings should be correlated with mammography, but probably most useful is a targeted, second-look ultrasound of the area. In many cases, ultrasound will identify any additional lesions and facilitate image-guided biopsy. Lack of an ultrasound correlate makes the chances of malignancy much less likely. In one study, carcinoma was found in 43% of MRI lesions that had an ultrasound correlate compared with 14% of MRI lesions that lacked an ultrasound correlate. An ultrasound correlate is more likely for invasive carcinoma compared with DCIS. However, where MRI lesions are suspicious or indeterminate, the absence of a corresponding ultrasound abnormality does not negate the need to pursue a histological diagnosis and MRI-guided biopsy should be considered. For lesions that are considered low risk, follow-up MRI after a suitable period of time, typically six months, is acceptable. When MRI is used for staging breast cancer, problems arise when additional enhancing lesions are detected away from the primary tumor site. The same principles of mammographic review and second-look ultrasound apply. Surgical management should not be changed unless additional enhancing lesions are histologically proven to represent malignancy.

MRI for Imaging Breast Implants
MRI is the technique of choice for assessing the integrity of silicone breast implants, with a sensitivity and specificity of over 90%. When imaging breast implants, no contrast agent is required unless malignancy is suspected or possible. Imaging should be performed in the prone position using a dedicated breast coil. The main goal is to determine whether the implant has ruptured and, if so, to establish the location of the leaked filler (silicone). When implants fail, the rupture may be either intracapsular or extracapsular: intracapsular rupture occurs when silicon has escaped from the plastic shell of the implant, but is contained within the fibrous implant capsule and signs of intracapsular rupture include the ‘wavy line’, ‘linguini’, ‘key-hole’ and ‘tear drop’ signs. False-positive interpretations can be made when normal implant folds are mistaken for signs of rupture. Extracapsular silicone rupture yields evident silicone outside the fibrous capsule.

6. INTERVENTIONAL BREAST

Breast radiology requires skills in interventional techniques, particularly ultrasound and X-ray stereotactic-guided needle sampling, percutaneous excision of benign lesions and localization of abnormalities for surgical excision. Eighty per cent of abnormalities detected by screening mammography are nonpalpable and need to be biopsied and localized using image-guided techniques. Needle biopsy is highly accurate in determining the nature of most breast lesions and is now used in place of open surgical biopsy. For patients with breast cancer, needle biopsy provides accurate information on the nature of malignant disease, such as histological type and grade, and allows assessment of tumor biology, cell markers and genetics. The methods available for breast tissue diagnosis are:

- fine-needle aspiration for cytology (FNAC)
- needle core biopsy for histology
- vacuum-assisted biopsy (VAB)
- open surgical biopsy.

Fine-Needle Aspiration for Cytology and Needle Core Biopsy

**FNAC** involves the manual passage of a small-bore needle (usually 23 gauge) repeatedly through an abnormality to shear off clumps of cells into the needle lumen. This is usually performed while applying suction to the aspiration needle. The aspirate is then either smeared onto a microscope slide or washed into a buffer solution ready for cytological assessment. FNAC can be performed freehand on a palpable abnormality or carried out under image guidance. The procedure is quick to perform and associated with minimal morbidity. However, it is associated with significant false-positive and false-negative results, is operator
dependent and relies greatly on the experience and skill of the cytopathologist. It also does not provide reliable information about whether a cancer is in situ or invasive or the pathological type and grade. Core biopsy of breast tissue is carried out using a 14G diameter needle with a 20-mm sample notch attached to an automated spring-loaded device. Smaller-gauge needles give less reliable results. The needle retrieves a core of tissue, approximately 15–20 mg in weight, which is suitable for histological assessment. This technique is less operator dependent than FNAC and breast tissue histological expertise is much more widely available. Core needle biopsy is associated with fewer false-positive and false-negative results than FNAC and is the technique of choice for routine use in breast diagnosis.

Vacuum-Assisted Biopsy
The predominant reasons for failure to achieve accurate diagnosis by needle biopsy are sampling error and failure to retrieve sufficient representative material. Vacuum-assisted biopsy (VAB) addresses these issues. Systems typically use 7 to 11G needles to obtain multiple cores, each weighing up to 300 mg. VAB significantly improves the diagnostic accuracy for borderline breast lesions and lesions at sites in the breast difficult to biopsy using other techniques. The use of VAB to biopsy microcalcifications halves the risk of missing a coexisting invasive cancer in an area of DCIS compared with 14G core biopsy. VAB is ideal or indicated for:

• very small mass lesions
• architectural distortions
• failed ‘conventional’ core biopsy
• microcalcifications
• papillary and mucocele-like lesions
• diffuse non-specific abnormality
• excision of benign lesions
• sentinel node sampling.

VAB can be used under ultrasound, stereotactic or MRI guidance. After needle placement in the breast, suction is applied pulling tissue into a sampling chamber. A rotating or cutting inner cannula automatically advances. In most systems, suction is then used to retrieve the specimen so that multiple cores can be obtained without the need to remove the needle from the breast. Contiguous core biopsies can be obtained by rotating the probe through 360°. Unlike core biopsy, the VAB probe does not have to pass directly through the area being sampled as the suction can be used to draw the abnormality into the sampling chamber, allowing a satisfactory sample to be obtained by placing the probe close to rather than through the abnormality. Ultrasound-guided hand-held vacuum-assisted devices can be used as an alternative to surgery to completely excise benign lesions, such as fibroadenomas, and to widely sample lesions that may be associated with an increased risk of malignancy, such as radial scars and papillary lesions.

Guidance Methods for Breast Needle Biopsy
Ultrasound guidance is the method of choice for biopsy of both palpable and nonpalpable breast lesions, as it provides real-time visualization of the biopsy procedure and visual confirmation of adequate sampling. Between 80 and 90% of breast abnormalities that need to be biopsied are visible on ultrasound. For nonpalpable abnormalities not visible on ultrasound, stereotactic X-ray-guided biopsy is required. A few lesions are visible only on MR and require MR-guided biopsy.

Ultrasound guided 14g core needle biopsy
X-ray-guided stereotactic biopsy is used for nonpalpable lesions that are not visible on ultrasound. Most microcalcifications and mammographic architectural distortions need to be biopsied under stereotactic guidance. Prone stereotactic table devices are expensive and can only be used for breast biopsy; they require a room in the breast imaging department dedicated for this purpose. The main advantage of this type of device is that the patient cannot see the biopsy procedure while it is being done and vasovagal episodes are said to be less frequent. Stereotactic core needle biopsy has a high level of accuracy (95% retrieval of representative material) and is associated with low levels of morbidity and few complications. The stereotactic devices allow precise localization of the lesion by acquiring two images, 15° on either side of the central axis of the X-ray gantry. The x, y and z coordinates of the lesion are calculated from the relative positions of the target lesion on the two stereotactic images compared with a fixed reference point. After injection of local anesthetic, the biopsy needle is advanced into the breast via a small skin incision through a needle holder that guides it to the correct depth. It is possible, particularly after VAB, that the whole of the mammographic abnormality may have been removed, so a marker should be placed at the biopsy site. A variety of metal clip markers are available for this purpose.

Number of Samples
Sufficient material must be obtained but it is unnecessary to take multiple cores as a matter of routine. For ultrasound-guided biopsy, a minimum of three-five core specimens recommended. Stereotactic biopsy is typically used for abnormalities that are more difficult to define or sample, and so a minimum of five core specimens should be obtained. Core specimen radiography is performed when sampling microcalcifications to prove that representative material has been obtained. The identification of microcalcifications in at least three separate cores and/or a total of five separate flecks of calcification in the biopsy specimen should allow an accurate diagnosis to be made.

MRI-Guided Biopsy
A few breast lesions are only visible with MRI and therefore have to be biopsied under MRI guidance. A number of different approaches have been developed for this procedure, but the most widely used system involves the patient lying prone within the breast coil with the breast immobilized between compression plates. Vacuum-assisted biopsy is the preferred method of tissue sampling under MRI guidance. Compression is important to stabilize the breast and keep a lesion's location fixed once initially localized. It is important to avoid over-compression, as this can interfere with lesion conspicuity. A vitamin E capsule is placed over the expected lesion position and sagittal imaging performed following intravenous gadolinium injection. The position of the lesion within the breast relative to the skin can then be determined by reference to the skin marker and the gridlines; depth is calculated on the basis of the slice thickness and the number of slices between the skin and the lesion. Following the injection of local anesthetic, an introducing cannula is inserted through a needle guide into the breast with the correct position confirmed by further imaging. The biopsy device is inserted through the introducing cannula and the biopsy samples obtained. The patient is re-imaged to ensure that the correct area has been sampled and a biopsy marker deployed. MRI-guided biopsies are more challenging than other breast biopsies, due to lesion access and visibility. Most modern breast coils enable the breast to be accessed from both the medial and lateral directions, but problems can be encountered with posterior lesions that cannot be captured within the compression grid. Lesion visibility tends to decrease with time following the injection of gadolinium due to a combination of contrast washout from the lesion and increased background enhancement. Despite these limitations, vacuum-assisted MRI-guided biopsy offers a safe and accurate way of obtaining a tissue diagnosis from MRI only-visible breast lesions.

Managing the Result of Needle Biopsy: RadPath Review
It is important that the result of needle breast biopsy is correlated with the imaging and clinical findings. In the case of benign or benign high risk diagnoses, this is important to do to assure benignity and establish follow up interval. In the case of malignant diagnoses, this is best achieved by reviewing each case at a multidisciplinary meeting at which the imaging, clinical and pathological findings are reviewed and management decisions and choices to be offered are discussed and agreed before the patient is seen with the results.

Preoperative Localization of Nonpalpable Lesions
The purpose of preoperative localization is to ensure that an nonpalpable lesion is accurately marked, facilitating complete surgical excision. For malignant lesions, the aim is to remove a minimum of 5 mm (and preferably 10 mm) of surrounding normal tissue at all margins. Without localization, much larger volumes of tissue may be removed, with the potential to cause unnecessary deformity of the breast. There are a number of methods available for pre-operative localization. These include simple skin marking over the lesion, insertion of a wire, injection of radioisotope-labelled seeds, or placement of a radio transmitter device. The ideal wire is easy to deploy and maintains a stable position in the breast. An introducing needle is used through which the wire is advanced into the breast. For mass lesions and small clusters of microcalcification, the wire should be placed directly through the lesion or area, with the tip of the wire just beyond it. For a larger area of microcalcifications, several wires may be used to bracket the area to be removed. Diagnostic mammograms should be performed to confirm that the correct area has been localized; these should be available to the surgeon. Specimen radiography is used to confirm that the lesion has been removed and that adequate margins have been achieved. The specimen is orientated using radio-opaque markers to identify the margins. If excision appears inadequate, further margin excision can be carried out at the same operation. A specimen radiograph of a marker localization should show surgical biopsy showing the hook wire through the small mass lesion. The specimen is orientated by surgical clips and should show clear margins of excision.

![Specimen radiography demonstrates wire, localized calcifications, clear margins](image)

Conclusion
Mammography and ultrasound continue to be the primary imaging tools for the assessment and diagnosis of breast disease. The development of digital mammography and high resolution ultrasound has led to improvements in image quality and breast cancer detection. MRI is an important additional tool for local staging of breast cancer in carefully selected cases, aiding surgical planning. The modern breast radiologist requires interventional radiology skills, with biopsies performed under ultrasound, X-ray and MRI guidance. Accurate preoperative diagnosis with image-guided percutaneous core biopsy is crucial in the management of breast disease, with surgery reserved for treatment rather than diagnosis. The past 20 years have seen a significant reduction in breast cancer mortality despite increasing incidence of the disease. Population-based breast cancer screening with mammography aims to reduce mortality by early detection.