Introduction

Welcome to the Hitachi Medical Systems America, Inc. MRI Anatomy and Positioning Series. We offer teaching modules to allow users of Hitachi MRI scanners to advance their positioning skills and review the anatomy that will be seen on common MRI exams. Our intention is to discuss and review the anatomy that is most often seen, and the positioning that is most often used in your MRI studies. Good positioning skills are needed to ensure the best possible image quality for your studies.

As stated in the IAC (Intersocietal Accreditation Commission) MRI Standards, “MRI is a valuable diagnostic tool in assessing breast health when used in conjunction with a clinical examination, mammography and ultrasound. MRI scans are used to produce high quality images that show increased or abnormal blood flow in the breast (often a sign of early cancers); aid in the detection of abnormalities in dense and fatty breast tissues; and use subtraction and 3-D imaging to delineate suspicious lesions.” MRI of the breast holds a high place in the future of breast imaging.

In this sixth module, we will examine the anatomy of the breast, including the lymphatic system. We will discuss the relevance of MRI in the characterization and diagnosis of pathology and disease of the breast. We will also review the imaging sequences and post processing applications available for breast MRI on Hitachi systems. Procedures for scanning breast implants as well as various breast biopsy methods will be presented.

A dedicated bilateral breast coil is recommended for breast MRI scanning, and is in fact required for accreditation purposes. We will review proper patient positioning on the Hitachi breast coils, and offer hints and suggestions for artifact-reduced breast scanning. RF coil cables should always be routed in a manner that will avoid contact with the patient.

We will also discuss the use of the various pads that are furnished with our MRI systems (trough pads, table pads, accessory pads, coil cable pads, etc.), and their proper uses in conjunction with the breast coil. It is important to use the various pads that are provided to assist in eliminating or at least minimizing, the amount of each patient’s skin-to-skin, skin-to-bore, or skin-to-cable contact. Reducing the amount of each of the aforementioned contacts reduces the patient’s chances of thermal injury. Please refer to the MR Patient Warming Prevention Plan published by Hitachi Medical Systems America, Inc. for more information concerning the prevention of patient warming.

CAUTION

- Always route coil cables away from the patient, using pads and/or cable covers to eliminate or minimize the chances of contact between the coil cable and the patient. Failure to do so could result in a thermal injury.
- Always use the pads that are provided to eliminate or minimize the patient’s skin-to-skin, skin-to-bore, and skin-to-cable contact. Failure to do so could result in a thermal injury.
Breast Anatomy

The female breasts are composed of glandular, ductal, connective, and adipose tissue that has been adapted to secrete milk after a woman gives birth. Boundaries of the breasts include the clavicles superiorly, the lateral borders of the latissimus muscles laterally, the sternum medially, and the inframammary folds inferiorly (Figure 1). The roughly circular bodies of the breasts typically extend from the second to the sixth ribs. The breasts overlie the pectoralis major, serratus anterior, and external oblique muscles, but do not contain any muscle tissue (Figure 2). Rather, a layer of fat surrounds the mammary glands and extends throughout the breasts.

Connective tissue structures known as Cooper’s ligaments, or suspensory ligaments, serve to support and attach the breasts to the front of the chest wall on either side of the sternum. These suspensory ligaments run from the clavicle and the clavipectoral fascia to the dermis of the skin overlying the breast, branching out through and around the breast tissue (Figure 3). They suspend the breast from the clavicle and the underlying deep fascia of the upper chest, supporting the breast in its normal position, and maintaining its normal shape. The Cooper’s ligaments can become stretched and lose their structural integrity after repeated pregnancies, or repeated weight losses and gains. Because the breast tissue is heavier than the surrounding fat, and the internal support of the Cooper’s ligaments has decreased, the breasts will sag under their own weight and lose their normal shape and contour.
Cooper’s ligaments also play an important role in the change in appearance of the breast that often accompanies the development of inflammatory breast cancer (IBC). With IBC, local lymphatic ducts may become blocked and cause swelling of the breast. The skin of the breast remains tethered by the suspensory ligaments of Cooper, and takes on a dimpled appearance that resembles the peel of an orange (peau d’orange). Carcinomas of the breast can also decrease the length of the Cooper’s ligaments, leading to this dimpled appearance (Figure 4).

The mammary glands are modified sweat glands that lie within the subcutaneous tissue of the breasts, between the pectoral fat pad and the fascia covering the pectoralis major muscle. They are normally mobile on this fascia. The mammary glands may extend beyond the breast toward the axilla, forming an axillary process or “axillary tail”. The adult woman’s mammary glands are arranged as fifteen to twenty separate lobes, with each lobe containing several secretory lobules (Figure 5).
The lobules are composed of grape-like clusters of alveoli, which are the hollow sacs that make and hold the breast milk (Figure 6). Appropriate hormonal stimulation is necessary for milk production, as well as milk release. Milk leaves the lobules through numerous interlobular ducts, which converge into single lactiferous ducts that exit the lobes. Just before reaching the nipple, the lactiferous ducts dilate to form lactiferous sinuses, or milk storage cavities. Milk collects here during nursing, and is “let down” by the infant’s suckling action. The lactiferous ducts become narrow again within the nipple.

The nipples consist of pigmented skin with some smooth muscle fibers set in fibrous tissue. They contain the multiple minute openings of the lactiferous ducts. The smooth muscle within the nipples compresses the lactiferous ducts and makes the nipples erect, which may enhance the flow of milk through the ducts.

The areolas are the pigmented areas around each nipple. Small oil glands, named Montgomery’s glands after their founder, are located on and around each areola (Figure 7). These glands make oily secretions (lipoid fluid) that keep the areola and the nipple lubricated and protected during lactation. Certain compounds within these secretions may also serve as an olfactory stimulus for the newborn appetite. The number of Montgomery’s glands can vary greatly, averaging from four to twenty eight per areola and nipple. The portions of these glands that are on the skin’s surface are called Montgomery tubercles. These round bumps are found on the areola, as well as the nipple. They can become exposed and raised when the nipple is stimulated, and become more pronounced during pregnancy.
Breast Development

Breast tissue begins to originate by the fourth week of fetal life. It forms along the mammary ridges, or milk lines, on the trunk (Figure 8). These ridges are two vertical ectodermal thickenings that extend from the axilla to the inguinal region. Breast tissue can develop anywhere along the milk lines in both men and women, resulting in a complete auxiliary breast, or supernumerary nipples. The mammary glands develop from the nipples during fetal life. The breasts are incompletely developed at birth. In males, they remain small and undeveloped, unless subjected to abnormal hormone stimulation. Throughout childhood, females have a small patch of immature breast tissue. When they reach puberty, hormones produced by the ovaries and pituitary gland cause the breasts to grow. The surge of estrogens in the female encourages the growth process, while the male’s androgens, such as testosterone, discourage breast growth. Breast formation is usually complete within a year or two after the start of menstruation, but growth continues. The ducts stretch out and become more branched, and the breast tissue develops into a mature system of lobules and ducts. The acini continue their growth, and fibrous and fatty tissues are continually added during adolescence. The breast tissue remains inactive until pregnancy, when true secretory alveoli develop, and the lobules grow and begin to produce milk (Figure 9). The milk is released into the ducts for breastfeeding.

When a woman reaches menopause, the ovaries stop producing hormones, and menstrual periods end. The number of breast lobules decreases, and the remaining lobules atrophy. This loss of breast tissue during menopause means that breast density also decreases. Before menopause, the breasts are of higher density, as they typically have more breast tissue than fat. After menopause, the breasts are of lower density, as they have more fat than breast tissue (Figure 10).
This “natural” change typically makes it easier to read the low breast density mammograms of postmenopausal women as compared to their high breast density premenopausal counterparts (Figure 11).

**Blood Supply and Nerves**

The breasts are highly vascular, and have both medial and lateral arterial supplies (Figure 12). The medial supply comes from internal mammary arteries, which are branches of the internal thoracic artery. Laterally, arterial supply is from mammary branches of the lateral thoracic artery and the thoracoacromial artery, which are both branches of the axillary artery. The fourth, fifth, and sixth posterior intercostal arteries, which are branches of the thoracic aorta, provide additional arterial blood supply.

Venous drainage of the breasts is accomplished mainly through the axillary vein (Figure 12). The subclavian, internal thoracic, and intercostal veins also aid in returning blood to the heart. Unfortunately, the connections between the intercostal veins and the veins of the vertebral plexus allow metastasis to the bones and nervous system.
Innervation of the breast is mainly accomplished by the anterior and lateral cutaneous branches of the fourth through sixth intercostal nerves (Figure 13). Branches of these intercostal nerves convey sensation to the skin of the breast, as well as sympathetic fibers to the blood vessels and smooth muscle cells in the overlying skin and nipple.

Additional discussion should be given to nerves in the axillary area, as they could be damaged or compromised during axial node dissection. The dissection procedure is often performed on breast cancer patients, either alone or in conjunction with lumpectomy or mastectomy. The lateral and medial pectoral nerves pass around the pectoralis minor, but injuries to these nerves are rare. The thoracodorsal nerve lies medial to the thoracodorsal vein, running along to enter the latissimus dorsi (Figure 14). Injury to this nerve results in slight weakening of the latissimus muscle. The long thoracic nerve is located more medially to the axilla, running just beneath the serratus anterior. Injury to the long thoracic nerve results in “winging” of the scapula on extension (Figure 15). Keeping the axillary dissection inferior to the lower border of the axillary vein can prevent brachial plexus injuries. The skin of the axilla and upper arm is supplied by the intercostobrachial nerve. Numbness of these areas can be the result of sacrificing the intercostobrachial nerve during axillary node dissection.
**Lymph Nodes and Lymph Drainage**

Lymph is a clear, tan fluid that contains lymphocytes, which are white blood cells that fight disease. In addition to lymph fluid, the lymphatic vessels of the breast drain the fat portion of the milk produced during lactation, and transfer infected material or neoplastic cells from the breast to more distant parts of the body. The lymph vessels connect with a network of lymph nodes that are located around the edges of the breast, or in nearby tissues of the axilla and clavicle. Lymph nodes and the routes of lymph drainage from the breast play a central role in the metastasis of breast cancer. The axillary lymph nodes are among the first places that cancer is likely to be found if it spreads from the breast. The breasts’ lymph nodes are not linked in a straight line, but are staggered and fixed within fat pads. This arrangement further complicates lymph node removal that may be performed during breast cancer surgery.

The majority of breast lymph fluid (> 75%) drains to the axillary lymph nodes, particularly the fluid from the lateral quadrants of the breast (Figure 16). The axillary nodes are further divided into five groups:

1. **Anterior group**- Also called the pectoral nodes; located at the inferior border of the pectoralis minor muscle; receive lymph from the major part of the breast

2. **Posterior group**- Also called the subscapular nodes; located at the anterior border of the subscapularis muscle; receive lymph from the axillary tail of the breast and posterior shoulder

3. **Lateral group**- Located behind the axillary vein; drain lymph from upper limb

4. **Central group**- Located near the base of the axilla; receive lymph from preceding three groups; most likely group to be palpable (against the lateral thoracic wall)

5. **Apical group**- Located medial to the axillary vein and superior to the pectoralis minor; receive lymph from all other groups, and sometimes directly from the breast
From the five groups of axillary nodes, the lymph fluid drains into infraclavicular and supraclavicular nodes, and then into the subclavian lymphatic trunk (Figure 17). Free communication exists between the nodes below and above the clavicle, as well as between the axillary and cervical nodes.

Figure 17 Lymph drainage routes

Lymph from the skin of the breast, with the exception of the nipple and areola, drains into the axillary, inferior deep cervical, infraclavicular, and parasternal lymph nodes on each side. The remainder of the lymph (<25%) drains to either the parasternal nodes, the inferior phrenic nodes, or to the opposite breast (from medial quadrants).

**Breast Pathology**

MRI of the breasts offers valuable information about many breast conditions and pathologies that cannot be obtained using other imaging modalities, such as mammography and ultrasound. MRI should not be considered a replacement for the aforementioned imaging modalities, but rather a supplemental tool with many important uses, including:

- Screening for women at high risk for breast cancer, typically due to family history
- Determining the extent of cancer after a new breast cancer diagnosis; assist in staging of cancer
- Further evaluation of abnormalities that are difficult to assess on mammography, including palpable masses and lesions in dense breasts
- Evaluation of lumpectomy sites after breast cancer treatment; scarring and recurrent cancer can look identical on mammography and ultrasound
- Monitoring of neoadjuvant chemotherapy; breast cancer may be treated with chemotherapy before surgical removal of the tumor
- Evaluation of breast implants

MRI continues to have a positive and growing impact in the field of women’s breast health, and in the diagnosis and treatment of breast cancers.
**Malignant Breast Diseases**

Breast cancer is the most common cancer among women in the United States, with one out of every eight women likely to develop breast cancer during her lifetime. Normal breast cells may grow out of control for a number of reasons. The cells will change in appearance and function, and become abnormal. These malignant, or cancerous, cells may then spread to surrounding tissues or organs. Malignant changes that occur in the cells lining the breast lobules, or more commonly the breast ducts, result in breast cancer.

The exact cause or causes of breast cancer remain unknown. However, a number of risk factors have been identified that increase a person’s chance of acquiring this disease. Some risk factors can be modified, while others are beyond our control. Risk factors include:

- **Age**- Approximately 80% of breast cancers develop in women over the age of 50

- **Previous breast cancer**- Once a woman has had breast cancer, she has a greater chance of developing a new cancer in the opposite breast (not a recurrence or metastasis); previous diagnosis of lobular carcinoma in situ is associated with a 10%-30% greater breast cancer risk, while a previous diagnosis of ductal carcinoma in situ is associated with a 30%-50% greater risk

- **Family history of breast cancer**- Approximately 85% of women with breast cancer DO NOT report a history of breast cancer within their families; risks increase with first-degree relatives, breast cancer before menopause, or cancer that involved both breasts

- **Genetic mutations**- Approximately 5%-10% of all breast cancers are hereditary; genetic mutations on the BRCA1 and BRCA2 genes have been highly studied; some American women, many of whom are descendants of the Ashkenazi Jews from Eastern and Central Europe, have an inherited BRCA1 mutation, which presents them with a 90% lifetime risk of developing breast cancer

- **Hormones**- Breast cancer risk is increased in women with the longest known exposure to the female sex hormone estrogen, which includes those with early first menstrual periods, late menopause, late or no pregnancies, and those who have taken birth control pills; both benefits and risks have been found for women using estrogen (or hormone) replacement therapy; exposure to estrogen is lowered by exercise, which affects the menstrual cycle and can inhibit ovulation, thereby indirectly lowering the risk of breast cancer; postmenopausal women are at an increased risk of breast cancer if they have excess body fat, as excess fat contributes to high levels of circulating estrogen

- **Alcohol use**- Women who consume one alcoholic beverage per day have a slightly increased risk of breast cancer, while the risk is nearly doubled for women who have more than three drinks daily; a recognized relationship has been found between an increased level of estrogen in the blood and the consumption of more than two drinks per day

- **Radiation exposure**- Women who received radiation therapy in the chest area during childhood or young adulthood have a significantly increased risk of breast cancer; in general, women over age 45 have more exposure to radiation than younger women

- **Additional potential, but unproven risk factors**- Dietary fats, environmental pollutants, cigarette smoking, history of abortion/miscarriage, above-average body height/weight
Factors exist that may actually reduce one’s risk of breast cancer, in contrast to the many harmful effects of lifestyle or family history. Protective or preventive benefits may be found from:

- **Regular exercise**: Researchers report a risk reduction for early breast cancer of more than 50% for women aged 40 and younger who exercise for 4 hours per week; exercise on a regular basis may reduce the risk of breast cancer for all women; the greatest benefits were found for women who keep their weight proportional to their height; exercise has estrogen-lowering effects, changes body fat composition, influences ovulation, and has a favorable effect on natural immunity.

- **Early pregnancy**: Research suggests that a full-term pregnancy before age 30 reduces a woman’s risk of breast cancer; however, a woman’s overall risk of breast cancer remains low until menopause, whether she gives birth or not.

- **Breastfeeding**: Debates continue on this topic; some studies suggest protection against early breast cancer (occurring before age 50) for women aged 20 or less who breastfeed for 6 or more months; other studies claim a risk reduction after breastfeeding for 1½-2 years; breastfeeding does not appear to influence the development of late (postmenopausal) breast cancer.

The two major types of breast cancer are ductal carcinoma and lobular carcinoma. The term “carcinoma” is used to describe cancers that arise from the surface or lining cells. Ductal and lobular carcinomas are further classified as invasive (spreading) or non-invasive (in situ- confined to the original site). The majority of breast cancers (70-80%) arise from the ducts, as they make up the bulk of breast tissue. Both lobular and ductal cells are found in the glandular tissues of the upper, outer, and central regions of the breast, so most breast cancers occur in those locations (Figure 18). Inflammatory carcinoma and Paget’s disease of the breast (cancer of the nipple and areola) account for most of the remaining types of breast cancer. Breast tumors that arise in the fatty or nonglandular tissues are rare, and are typically sarcomas when they do appear.

![Figure 18 Formation sites for ductal and lobular carcinoma](image-url)
The most common non-invasive carcinomas include ductal carcinoma in situ (DCIS) and lobular carcinoma in situ (LCIS). Both are usually discovered at an early stage, when they are still small and confined. When they remain within the borders of the duct or lobule they are called “in situ”, meaning they remain “in the site” of origin. Often, these tumors are too tiny to even form a lump, so they are not palpated or detected during a physical exam, but are discovered and diagnosed through mammography. Ductal carcinoma in situ (DCIS), also known as intraductal carcinoma, or non-invasive ductal carcinoma, contains breast duct cells with malignant characteristics. DCIS is generally unifocal, meaning confined to one location, or at least limited to one region of the breast (Figure 19). Each year, approximately 1% of women with high-grade DCIS develop invasive breast cancer after lumpectomy. For this reason, DCIS is considered a potential marker for invasive carcinoma. It is usually treated with some form of breast-conserving surgery (lumpectomy), followed by radiation therapy.

![Figure 19 Linear microcalcifications (arrows) indicate ductal carcinoma in situ (DCIS)](image)

Lobular carcinoma in situ (LCIS), also known as non-invasive lobular carcinoma, typically occurs in women prior to menopause. LCIS is often multifocal, or located in more than one area, and often affects both breasts (Figure 20). This multifocal characteristic increases the importance of careful examination of both breasts for patients with this disease. Fortunately, the great majority (over 99%) of people with LCIS do not develop invasive breast cancer.

![Figure 20 Lobular carcinoma in situ (LCIS) indicated by white arrows in mediolateral view (on left) and craniocaudad view (on right)](image)
Once breast cancer penetrates the membranes surrounding the ducts or lobules, it is called an infiltrating or invasive carcinoma. Invasive carcinomas can grow into the supporting tissue between the ducts, blood vessels, lymph nodes, and other breast structures, so they offer a higher chance of metastasis. Approximately 75% of all invasive breast cancers are invasive ductal carcinomas. As they invade the fatty tissue around a duct, invasive ductal carcinomas cause the formation of fibrous, scar-like tissue which can make the cancer appear larger than its actual size (Figures 21, 22). Depending on the location of the tumor, symptoms of invasive ductal carcinoma can include retraction of the nipple or nipple discharge, as well as wrinkling or dimpling of the skin.

Three well-recognized types of invasive ductal breast cancer include:

- **Tubular carcinomas** - Generally low grade tumors that affect older patients (Figure 23); represent 3-5% of all invasive ductal carcinomas; not likely to metastasize; generally have an excellent prognosis.
• **Medullary carcinomas** - Named for their color, which is close to the color of brain tissue (medulla); represent 2% of all invasive ductal carcinomas; tumors tend to form clear-edged borders separating them from healthy tissue; tumor may feel like thick, spongy breast tissue, or similar to cyst (Figure 24); can be high-grade (fast-growing) and aggressive; respond well to treatment with little metastasis.

![Figure 24](image)

**Figure 24** Smooth mass is infiltrating medullary ductal carcinoma; BB indicates palpable mass

• **Mucinous carcinomas** - Formed by mucous producing cancer cells; contain large amounts of extracellular epithelial mucin surrounding and within tumor cells; account for less than 5% of invasive breast cancer cases; typically found in women over age 60; if palpable, tend to manifest as soft masses; appear homogeneous and well-circumscribed on mammography (Figure 25); in MRI, one of the few cancers that has very high signal on T2-weighted images, due to water component of mucin (Figure 26); better prognosis for “pure” form, as opposed to “mixed” mucinous form, whose tumors contain areas of infiltrating ductal carcinoma without extracellular mucin.

![Figure 25](image)

**Figure 25** Invasive mucinous carcinoma

![Figure 26](image)

**Figure 26** Mucinous carcinoma with enhancing internal septations
Invasive lobular carcinomas account for about 10% of all invasive breast cancers, with that number on the rise for postmenopausal women. They are sometimes difficult to detect on mammography, as they are usually more subtle in appearance than invasive ductal carcinomas. Invasive lobular carcinomas may simply appear as irregular thickenings in the breast, rather than distinct masses, making it difficult to determine the extent of the disease during surgery, and to achieve negative margins of resection (Figure 27). They also have a higher incidence of multifocality (multiple deposits of the same cancer cells around the main tumor within the same breast quadrant) and multicentricity (multiple tumor deposits throughout the breast). These characteristics make breast conservation challenging, so many physicians favor mastectomy for invasive lobular carcinomas. Prior and concurrent carcinoma of the opposite breast has been reported in the range of 6-28% of cases, while 10-14% of patients with a history of infiltrating lobular carcinoma may develop another cancer in the opposite breast.

Inflammatory breast cancer accounts for 1%-5% of all breast cancers diagnosed in the United States. This is a rare, but very aggressive type of breast cancer. It is typically diagnosed at Stage III or IV, and progresses in just a matter of weeks or months. Most inflammatory breast cancers begin as invasive ductal carcinomas, developing from cells lining the milk ducts of the breast and spreading beyond those ducts (Figure 28). It is called inflammatory because the breast often looks inflamed, due to cancer cells blocking the lymph vessels in the skin of the breast.
Symptoms include swelling and redness affecting a third of the breast or more, and breast skin that appears pink, reddish purple or bruised (Figure 29). As previously mentioned, inflammatory breast cancer can cause the breast skin to appear pitted, similar to the skin of an orange (peau d’orange). Additional symptoms may include a rapid increase in breast size, sensations of heaviness, burning, or tenderness in the breast, an inverted nipple, and swollen axillary lymph nodes. A delay in diagnosis of this disease may occur because its symptoms are similar to those indicating an infection or injury, or another type of breast cancer that is locally advanced. Unfortunately, because of the quick development and aggressive spread of inflammatory breast cancer, women’s survival rates for this disease are lower than rates for other types of invasive breast cancer. Research from the time period 1988-2001 reveals a 5-year survival rate of 34% for inflammatory breast cancer, compared to a 5-year survival rate of 87% for women with other stages of invasive breast cancers.

Paget’s disease of the breast is another rare type of breast cancer that involves the skin of the nipple and the areola. It represents less than 4% of breast cancers, and actually has a higher incidence in males. This disease was named after its founder, British doctor Sir James Paget. (Paget’s disease of the bone is also named for him). In Paget’s disease of the breast, malignant cells known as Paget cells are found in the epidermis of the skin of the nipple and areola. Patients diagnosed with Paget’s disease of the breast typically have one or more tumors inside the same breast, either DCIS or an invasive ductal carcinoma. It is theorized that cancer cells from a tumor inside the breast travel through the milk ducts to the nipple and areola. However, the cells of the nipple and areola can become cancerous on their own, with no underlying tumor. This disease is often misdiagnosed, as its symptoms are similar to those of some benign skin conditions. Symptoms such as itching, tingling or redness in the nipple or areola, yellow or bloody discharge from the nipple, and flaking, crusty, or thickened skin on or around the nipple can be mistaken as signs of dermatitis or eczema (Figure 30).
Paget’s disease of the breast can be distinguished by the fact that it does not involve the surrounding skin, and is typically limited to one breast. Positive findings for Paget’s disease on mammography include nipple and areola thickening, subareolar microcalcifications, nipple retraction, architectural distortion, and a mass or masses (Figure 31). Diagnosis can be confirmed by a nipple biopsy, as a negative mammogram does not rule out Paget’s disease of the breast.

As previously mentioned, most breast cancers are carcinomas, originating from surface or lining tissues. Cancer can directly strike the lymphatic tissue within the breast, resulting in a primary lymphoma. There are also a small number of breast cancers that arise from the muscle, fat or connective tissues of the breast, which are called sarcomas. Rare types of sarcomas that may be diagnosed in the breast include:

- **Angiosarcoma**: Highly malignant but rare vascular neoplasms; primary form accounts for 0.04% of breast cancers, arising sporadically in premenopausal women (average age late 30s to early 40s); the more common secondary angiosarcomas are found in postmenopausal women who have undergone treatment for breast cancer- postirradiation angiosarcoma secondary to irradiation, or lymphedema-associated cutaneous angiosarcoma secondary to lymphedema; both primary and secondary usually present as palpable masses that are best seen on MRI (Figure 32); mammograms often reveal benign findings, or may identify ill-defined mass without spiculations or calcifications that typify breast carcinoma; primary angiosarcomas may display bluish discoloration of skin due to presence of blood vessels, which are not as well seen in secondary cases, due to postoperative changes and/or skin thickening from chronic lymphedema and radiation; breast angiosarcomas rarely metastasize to lymph nodes, but undergo hematogenous spread to lung, liver, and bones; five-year disease-free survival of 76% and 70% for low-and intermediate-grade disease, respectively, compared to 15% for high-grade angiosarcoma; tumor size and resection margin status are significant prognostic factors.
**Cystosarcoma phyllodes** - Name is derived from Greek word “phullon” or leaf, due to its leaf-shaped pattern of growth; rare but large, fast-growing breast tumor, usually affecting pre-menopausal women in their 40’s; can be benign, suspicious of malignancy, or overtly malignant, depending on histological findings in each case (Figures 33, 34); referred to as a sarcoma because they develop in the connective tissue of the breast (the stroma) rather than in the epithelial tissues; account for about 0.5% of all breast neoplasms, with 20%-50% presenting as malignant; treatment is typically wide local excision, without radiation or chemotherapy; risk of local recurrence (13-20%) or distant metastasis (19%) related to cancer’s histological grade.

Metastasis is the process by which malignant cells break away, travel, and grow in other parts of the body. Breast cancers often metastasize to the lungs, bones, liver, and brain. If breast cancer is detected at an early stage, before metastasis occurs, it is usually curable. However, if the disease progresses and metastasis occurs, the possibilities of effective treatment are diminished.

Staging is a method used to describe the extent of cancer growth. The information used for staging is gathered from pathology reports after breast surgeries, as well as from reports from various imaging studies. Staging is used by physicians to customize breast cancer treatments, as well as to form a prognosis for the patient. Pathologists use the TNM system for staging, in which “T” refers to the tumor size, “N” refers to lymph node involvement, and “M” refers to the extent of metastasis. The staging category for tumors ranges from T0-T4, with T0 referring to no evidence of a primary tumor, up to T4, which refers to a tumor with direct spread to the chest wall or skin. The “T” category also includes the TX stage, meaning the tumor cannot be assessed, and the Tis stage, referring to carcinoma in situ or Paget’s disease of the nipple, without a detectable tumor mass. Staging categories for lymph node involvement range from N0, meaning regional lymph nodes are metastasis-free, up to N3, which involves metastasis to same-side internal mammary nodes. Metastasis categories include MX, meaning the presence of distant metastasis cannot be assessed; M0, where no distant metastases are found; and M1, indicating that distant metastases are present.
The various combinations of the T, N, and M category numbers are combined to provide a stage number, and sometimes a stage letter, for each breast cancer patient. The stages range from Stage 0, which is in situ cancer, with TNM labels of Tis, N0, and M0, up to Stage IV, which can have various labels for T and N, and an M1 label, which signifies distant metastases (Figure 35). Stages II and III both have subcategories of “a” and “b”. The lower the stage number is, the less the cancer has grown and spread, and the better the chances of survival. A Stage I breast cancer is relatively small and has not yet spread to the lymph nodes or other sites, while a Stage IV breast cancer has already metastasized to the lymph nodes, as well as another location. Recent findings from the National Cancer Institute (NCI) indicate that 5-year survival rates are in the area of 96% for limited, low-stage breast cancers (Stages 0, I, and some Stage II), 75% for breast cancers that have invaded surrounding tissue (Stages II and III), and only 20% for breast cancers that have metastasized (Stage IV).

![Figure 35 Stages of breast cancer](image)

**Breast Cancer Treatments**

Treatment of breast cancer is determined by many factors, including the type, characteristics, and stage of the tumor, the patient’s general health, as well as additional medical conditions that may influence treatment. Once the breast cancer has been staged, a comprehensive treatment plan is developed. Treatment plans typically involve some form of surgery as the primary therapy, to reduce or eliminate the cancer. Various forms of neoadjuvant and/or adjuvant therapy may be used to increase the chance of long-term disease-free survival. Neoadjuvant therapy is treatment given before primary therapy. It is used in situations such as those involving a large tumor, where chemotherapy given prior to surgery may shrink the tumor enough for the patient to receive breast conserving surgery, rather than a mastectomy. Adjuvant therapy is treatment given after the primary therapy to prevent cancer recurrence. Adjuvant therapies typically include a form of radiation therapy, hormone therapy and/or chemotherapy. Hormone therapy and chemotherapy are both systemic treatments, which use substances that travel through the bloodstream to reach and affect cancer cells all over the body.
Physicians must consider both prognostic and predictive factors when determining which adjuvant therapies will be most beneficial for their patients. Prognostic factors involved in determining the risk of breast cancer recurrence include:

- **Age**
- **Menopausal status**
- **Cancer stage**- Determined by tumor size and presence of metastasis to lymph nodes or other parts of body
- **Tumor grade**- Determined by resemblance of cancer cells to normal breast cells; poorly-differentiated tumors have cells that have little or no resemblance to normal breast cells, and are more likely to recur
- **Proliferative capacity of tumor**- Determined by how quickly tumor cells are reproducing; a low proliferative capacity, meaning tumor cells are dividing less often and growing slowly, offers a better prognosis
- **Hormone receptor status**- Breast tumor cells can express receptors for the hormones estrogen and progesterone; tumors with cells that do not express hormone receptors are more likely to recur
- **HER2 (Human Epidermal growth factor Receptor 2) status**- Tumors that produce too much HER2 protein are more likely to recur

Predictive factors are used to determine if cancer cells might respond to specific treatments. The two major predictive factors (already mentioned above as prognostic factors) are:

- **Hormone receptor status**- Breast tumor cells that express receptors for the hormones estrogen and progesterone allow these hormones to bind to the receptors and help cancer cells grow; hormone therapy blocks the activity of these hormones and stops the growth of the cancer cells; hormone therapy will not treat tumors that do not express hormone receptors
- **HER2 status**- Tumors that produce too much HER2 protein (classified as HER2 positive) can be treated with a targeted drug called trastuzumab, better known as Herceptin; approximately 20% of all breast cancers are HER2 positive; Herceptin can decrease the risk of recurrence by approximately one half, but is not a beneficial treatment if a tumor is not HER2 positive

Decisions concerning adjuvant therapies must be made on a case by case basis. In addition to the prognostic and predictive factors mentioned above, the patient’s general health, as well as their treatment preferences must be considered in all treatment plans.
Surgical procedures that are considered primary therapy for breast cancer include:

- **Lumpectomy** - A form of breast-conserving surgery that involves removal of the cancer and its margins (surrounding border of cancer-free tissue), as well as nearby lymph nodes, if required

- **Mastectomy** - Includes various surgeries that involve the removal of all or part of the breast; may include lymph node and/or muscle removal
  - Partial mastectomy - Removal of a portion of the breast, as well as some axillary lymph nodes; also referred to as a quadrantectomy, segmentectomy or tylectomy when one-quarter of the breast is removed along with the tumor
  - Total (simple) mastectomy - Removal of entire breast, without removing axillary lymph nodes or muscular tissue beneath the breast; often used for carcinomas in situ
  - Modified radical mastectomy - Removal of entire breast and some axillary lymph nodes; may include removal of pectoralis minor muscle if it is cancerous or impedes removal of lymph nodes; most frequently performed breast cancer surgery in the U.S., with best long-term results and fewest complications
  - Radical mastectomy - Very invasive surgical procedure that involves removal of entire breast, axillary lymph nodes, chest muscles under the breast, and surrounding skin; rarely performed due to equal effectiveness of modified radical mastectomy with less deformity
  - Skin-sparing mastectomy - Newer surgical procedure involving removal of breast tissue through a tiny circular incision around the nipple; minimizes disfigurement, leaves skin undamaged, and allows for immediate reconstruction with implant or natural tissue

Surgical procedures to assess possible involvement of lymph nodes include:

- **Sentinel lymph node biopsy** - Identify, remove, and examine sentinel lymph node for presence of cancer cells; sentinel node is first lymph node to which cancer cells are likely to spread from a primary tumor; a radioactive substance, a dye, or both are injected near the tumor to locate the sentinel node, which is removed and examined for presence of cancer cells; positive results in sentinel node indicate possibility of malignant cells in additional nodes or other organs; important testing for staging and treatment purposes

- **Axillary dissection** - Removal of a section of underarm fat tissue and adjoining lymph nodes for microscopic analysis; can be performed as part of a modified radical mastectomy, or as separate underarm incision during lumpectomy

Radiation therapy is one type of adjuvant, or assisting, therapy for breast cancer. It involves the use of high energy rays or particles that target cancer cells. Unlike normal cells, cancer cells cannot repair radiation-induced damage. Breast radiation is often performed after breast-conserving surgery (lumpectomy or partial mastectomy) to help lower the chance of cancer recurrence in the breast or lymph nodes. In these cases, radiation therapy is considered to be part of the primary therapy. Follow-up studies indicate that women who undergo lumpectomy with radiation therapy survive as long as women who undergo mastectomy. However, women who have a local recurrence after lumpectomy usually require a mastectomy, since cancerous breast tissue cannot be irradiated twice. A second round of radiation therapy to the same breast can have damaging side effects, such as death of
normal breast tissue, skin ulceration, or radiation-induced cancer. The two main methods for radiation delivery are through external beam radiation, and brachytherapy.

External beam radiation is the most common type of radiation therapy for women with breast cancer. The radiation is focused on the area affected by cancer from a machine outside the body. When treatment is prescribed after surgery, radiation therapy may not begin for a month or longer, to give breast tissues time to heal. Radiation may also be delayed if the patient is to receive chemotherapy. Radiation treatments last for a few minutes at a time, and are performed five days a week for five or six weeks. Newer approaches involving external beam radiation include:

- **Accelerated breast irradiation** - Also called hypofractionated radiation therapy; larger doses are given over a shorter time period, reducing treatment time to three weeks, or even one week
- **Intraoperative radiation therapy** - A single large dose of radiation is given while still in the operating room after breast conserving surgery
- **3D-conformal radiotherapy** - Considered to be a form of accelerated partial breast irradiation; radiation is given with special machines that are better aimed at the area where the tumor was; only part of the breast is treated, so more of the healthy breast is spared; treatments are typically twice a day for five days

External radiation therapy is often accompanied by short-term side effects such as swelling and heaviness in the breast, sunburn-like skin changes in the treated area, and fatigue. The breast may become smaller and firmer after radiation, which could affect a woman’s options in terms of breast reconstruction. Radiation can also cause brachial plexopathy, in which the nerves of the arm are damaged, leading to numbness, pain, and weakness in the shoulder, arm, and hand. External therapy to the axillary lymph nodes can cause lymphedema, which is a build-up of lymph fluid in the affected arm after the removal/irradiation of axillary lymph nodes.

Brachytherapy is a procedure used to deliver radiation internally. It consists of radiation seeds or pellets being placed into the breast tissue next to the cancer. It can be used as the sole method of radiation therapy, or it may be used as the extra “boost” of radiation to the tumor site after breast conserving surgery and external radiation. Tumor size, location, and other factors may limit who receives this type of radiation therapy. Brachytherapy used for breast cancer treatment includes:

- **Interstitial brachytherapy** - Several small catheters are placed in the breast around the area that the cancer was removed from; the catheters are left in place for several days; radioactive pellets are placed in the catheters for short periods of time each day, then the pellets are removed; this method has been available for a longer time than other methods, and has more evidence to support it; however, newer methods are used more often
- **Intracavitary brachytherapy** - Considered a form of accelerated partial breast irradiation, and the most common way to give brachytherapy; a device is placed into the space left from breast conserving surgery, and remains there until treatment is complete; the device goes into the breast as a small catheter, with the end that remains in the breast expanded to hold it in the correct place, and the other catheter end sticking out of the breast; during treatment, one or more radiation sources, typically pellets, are placed down through the catheter and into the device for a short time, then removed; treatments are typically performed twice a day for five days; after the last treatment, the device is collapsed down and removed; side effects may include redness, bruising, breast pain, infection, and a break-down of an area of fat tissue
in the breast; studies investigating the benefits of intracavitary brachytherapy vs. whole breast radiation for decreased rates of breast cancer recurrence are not conclusive.

Chemotherapy involves the use of anticancer drugs to destroy cancer cells. These drugs are given in the hopes that small groups of cancer cells, termed micrometastases, will be eliminated before they spread to other tissues. Many chemotherapeutic drugs interfere with cell division or other metabolic processes, so they are most harmful to the rapidly-dividing cancer cells. Chemotherapy is commonly given as an adjuvant therapy to reduce the chance of cancer recurrence after surgery, radiation therapy, or both. It is typically started approximately four weeks after surgery. Chemotherapy can also be a neoadjuvant therapy, in which case it is given before surgery to shrink a breast tumor and make it easier to remove.

Adjuvant chemotherapy is given orally or intravenously. Combination chemotherapy, which is a mix of two or more drugs, often is more effective than a single medication. Due to the difficult side effects from various types of chemotherapy, treatment is usually done in cycles, with a treatment period followed by a recovery period. The number of cycles needed depends on the chemotherapy drug being used, with most treatments being completed in six months.

Although chemotherapy is most harmful to the rapidly-dividing cancer cells, it is also harmful to rapidly-dividing normal cells. This includes blood cells, which fight infection, cause the blood to clot, and carry oxygen throughout the body. When blood cells are affected by chemotherapy drugs, patients become more prone to infections, as well as to bruising or bleeding easily. Cells in hair follicles divide rapidly, so chemo can cause patients to lose their hair. The cells lining the digestive tract also divide rapidly, resulting in a loss of appetite, nausea, vomiting, diarrhea, and mouth sores from chemotherapy. These are typically temporary side effects that disappear once chemotherapy has ended. There can be more permanent side effects for premenopausal women, including impaired function of the ovaries, and sterility.

Adjuvant hormone therapy for breast cancer is based on the observation that estrogen speeds up cancer cell growth. "Antiestrogen" medications are used to counteract this effect. Hormone therapy typically begins within four weeks of surgery. One of the most common medications used in hormone therapy is tamoxifen. It is an estrogen-like compound that binds to the breasts' estrogen receptors, making them unavailable to estrogen's cancer-promoting activity. Tamoxifen also stops angiogenesis, which is the blood vessel growth required by tumors. Studies indicate that Tamoxifen is beneficial for most women with early breast cancer. It is typically recommended for ER/PR positive breast cancers, which means that the cancer contains estrogen and progesterone receptors. Tamoxifen may also be used with ER/PR positive cancers that have metastasized or recurred. Studies show that it helps prevent the original cancer from returning, as well as helping to prevent the development of new cancers in the other breast. Tamoxifen is administered in pill form, and is most effective when given daily for a period of five years. It has additional beneficial effects including increased bone production and the prevention of plaque buildup within the blood vessels. Tamoxifen can be given to both premenopausal and postmenopausal women and is usually well tolerated. However, it does have side effects related to its estrogen-like properties, including hot flashes, nausea, vomiting, endometrial hyperplasia, and early or temporary menopause in premenopausal women. Women who have not had a hysterectomy have an increased risk of developing uterine cancer. Those receiving chemotherapy along with tamoxifen have a greater risk of developing a blood clot.
Raloxifene is another medication that acts like an anti-estrogen on breast tissue, as well as the uterus. It is classified as a selective estrogen receptor modulator (SERM), and works like estrogen on bone. Raloxifene slows bone thinning, and increases bone density in the bones of the spine and neck. Its primary use is to prevent and treat osteoporosis in women. However, it has also been found to lower the risk of breast cancer in high-risk women. Common side effects of this medication include hot flashes, vaginal dryness, and leg cramps. It is not recommended for women who already have breast cancer.

Aromatase inhibitors are a newer type of drug being used for hormone therapy for postmenopausal women. Three common brand names are Arimidex, Aromasin, and Femara. Aromatase inhibitors prevent the body from making estrogen, as opposed to blocking estrogen’s activity like tamoxifen does. They work by blocking the enzyme aromatase, which turns the hormone androgen into small amounts of estrogen in the body. This means that less estrogen is available to stimulate the growth of hormone-receptor-positive breast cancer cells. The use of these drugs in premenopausal women is not effective, because the ovaries are stimulated to make more estrogen when blood levels of estrogen fall below normal. That situation does not occur in postmenopausal women, as their ovaries have stopped making estrogen. The most common side effects of aromatase inhibitors are joint stiffness or joint pain, as well as menopause symptoms. When compared to tamoxifen, they may cause more heart problems and more osteoporosis, but fewer serious side effects such as blood clots, stroke, and endometrial cancer. A number of studies have concluded that aromatase inhibitors are the best hormonal therapy to start with for early-stage, hormone-receptor-positive breast cancer in postmenopausal women. Recommendations have been made to have patients switch to aromatase inhibitors after two to three years on tamoxifen, for up to a total of five years of hormone therapy. Many doctors are also recommending five years of aromatase inhibitors after five years of tamoxifen to continue to reduce the risk of a cancer recurrence.

Many additional hormone therapy medications are available for more aggressive tumors, each with their own benefits and side effects.

**Benign Breast Diseases**

Fortunately, most “lumps” found in the breasts are caused by benign breast diseases that do not metastasize, and are not life-threatening. A breast lump is considered benign if it is limited to a few cell layers, and it does not invade surrounding tissues or organs. Benign breast diseases differ from each other in their cellular appearances at the microscopic level. Most benign breast diseases do not increase the risk of breast cancer, but some have specific characteristics that are indicative of an increased risk for malignancy. Patients should be made aware of the type of benign breast disease or fibrocystic changes that are occurring in their breasts, in order for them to better understand their risk of developing a malignancy.
The most common benign breast condition is fibrocystic disease, which causes temporary changes in the breasts that typically coincide with the menstrual cycle. In this disease, fibrous tissue combines with cysts to form lumps in the breast. Fibrocystic disease does not increase the risk of breast cancer. Additional common benign conditions include:

- **Hyperplasia** - Refers to an abnormal increase in cell number; usually occurs on the inside of the lobules or milk ducts in the breast; two main types of hyperplasia include:
  - **Usual** - Moderate or severe proliferation of cells that increases breast cancer risk by 1.5 to 4-fold
  - **Atypia** - Breast cells become abnormal in number, size, shape, growth pattern, and appearance; breast cancer risk increases by 5-fold; risk jumps to 11-fold with family history of breast cancer in first degree relatives

- **Cysts** - Typically benign fluid-filled sacs that do not increase the risk for breast cancer (Figure 36); more common in premenopausal women; diagnosed with ultrasound or mammogram; can be aspirated if they become too large or painful

- **Fibroadenomas** - Fibrous, benign tumors of glandular tissue (Figure 37); typically found in younger women, ages 15-35; do not increase the risk of breast cancer; do not need treatment, unless warranted due to size or discomfort

![Figure 36 Breast cyst; smooth, benign type palpable mass](image)

![Figure 37 MR image of fibroadenoma; displays heterogeneous contrast enhancement during arterial phase (A and B) with homogeneous filling during late phase (C and D); lobular-shaped mass with some deep undulations, along with smooth margins](image)
- **Intraductal papillomas** - Small growths that occur in the milk ducts of the breasts (Figure 38); can cause nipple discharge; occur most often in women ages 35-55; may present as a painful lump; can be removed surgically, with no further treatment necessary; do not increase the risk of breast cancer, unless abnormal cells are found, or ductal carcinoma in situ (DCIS) is found in surrounding tissues.

![Figure 38 Papilloma](image)

- **Sclerosing adenosis** - Small breast lumps caused by enlarged lobules (Figure 39); lumps may be palpated, and may be painful; distorted shape of lumps may be mistaken for breast cancer on mammogram, leading to biopsy to confirm the diagnosis; benign condition that does not need treatment; may be found with atypical hyperplasia, lobular carcinoma in situ or ductal carcinoma in situ; recent studies suggest this disease does not increase risk of breast cancer.

![Figure 39 This cranio-caudal view shows a large area of parenchymal distortion with a small number of concerning microcalcifications; center of the lesion has a relatively low density](image)

- **Radial scars** - Also termed complex sclerosing lesions; have core of connective tissue fibers; milk ducts and lobules grow out from this core; may appear like cancer on mammogram; often found during biopsy on breast tumor removed for other reasons; no further treatment after removal; mixed findings on whether or not they cause an increase in risk of breast cancer, as they are often found alongside other breast conditions.
Breast Reconstruction and Breast Implants

Breast reconstruction is not a treatment for breast cancer. Rather, it is a surgical procedure performed to restore a woman’s appearance after breast surgery. For best results, decisions about reconstruction should be made before a mastectomy is performed. This allows the surgeon to plan for, or even perform, reconstruction at the time of the mastectomy. Advantages of immediate reconstruction include the preservation and immediate use of uninvolved breast skin, the completion of both procedures with one anesthetic risk, and lessening of the impact of breast loss on the patient. Delayed reconstruction may be preferable if the patient has doubts about the procedure, if prolonged anesthesia will increase the risk of the operation, or if postoperative radiation therapy is being considered. Since the reconstructed breast may appear different in size and/or shape from the remaining normal breast, some women choose to have plastic surgery on the normal breast so that both breasts appear similar.

The method of choice for breast reconstruction is use of the woman’s own tissue, as skin and fat from elsewhere in the woman’s body can be used to create a more natural-looking breast. If radical surgery has involved the removal of chest muscles, myocutaneous (muscle and skin) “flaps” may be transferred from a donor site to the chest wall. Types of “flaps” include:

- **LD flap**- Latissimus dorsi (back muscle)
- **TRAM flap**- Transverse rectus abdominis myocutaneous (abdominal muscle)
- **Gluteus maximus flap**- An unattached or free flap made from the tissue of the buttocks or thigh

Reconstruction of the nipple and areola is usually conducted a few months after breast reconstruction, in order to position the nipple correctly. Efforts are made to create the correct nipple projection, and to match the color of the areola.

Breast implants are designed for use for reconstruction, as well as for cosmetic enhancement. They will be reviewed in this text from the perspective of reconstruction only. The two main types of breast implants are saline-filled and silicone gel-filled. Saline-filled breast implants consist of a silicone outer shell filled with sterile saline. Silicone gel-filled breast implants also have a silicone outer shell, but are filled with silicone gel of varying consistencies. Similarities include both being available in multiple sizes, and both having smooth or textured surfaces to their shells. Features that differentiate saline vs. silicone implants include:

- Saline implants can be pre-filled, or initially empty, with filling occurring during the implantation procedure; can be placed with integrated remote-fill ports, allowing for postoperative adjustment of implant saline volume
- Saline implants are less costly than silicone-filled products
- Saline implant ruptures are quickly detectable; “silent ruptures” are usually associated with silicone
- Saline implants may display visible implant rippling on the surface in women with thin breast tissue; rippling is less noticeable with silicone
- Silicone gel-filled implants have a more natural feel than saline-filled implants
Comparisons have also been made between textured vs. smooth implant surfaces, round vs. anatomical implant shapes, and the availability of adjustable implants. Textured vs. smooth relates to the implants surface type and its effect on capsular contracture. Theory states that textured surface implants may decrease capsular contracture, due in part to breast capsule growth onto the implant surface. Anatomically shaped implants may provide a more natural shape to the reconstructed breast compared to round implants (Figure 40). The disadvantage associated with anatomically shaped implants is that they can rotate within the breast capsule, and leave the patient with an inferior cosmetic outcome. Adjustable implants are available for saline only, and allow for adjustment of the implant size for up to 12 months postoperatively. Saline is injected into a subcutaneous injection port, or via an exteriorized injection port (which should be removed one week postoperatively) (Figure 41).

There are five basic surgical approaches for breast implants, each with associated advantages and disadvantages. They include the inframammary approach, the periareolar approach, the transareolar approach, the transaxillary approach, and the transumbilical approach. The inframammary (IM) approach involves an incision at the inferior fold of the breast, enabling the surgeon to have good control and flexibility related to implant pocket creation, and device placement of all sizes (Figure 42).
The periareolar (PA) approach involves an incision along the inferior half of the outer circumference of the nipple. This incision line can be better hidden than the IM incision line, and provides good access to adjust the inframammary fold. However, the patient may experience hypopigmentation compared to the darker color of the areola. The PA incision may also limit the exposure for pocket dissection, as well as limiting the size of the silicone implant that can be placed. In addition, the bacterial contamination risk to the implant may be raised due to the proximity of the PA incision to the incised lactiferous ducts. This might, in turn, raise the risk for capsular contracture and implant infection. The transareolar approach has similar advantages and disadvantages to the PA approach. This incision can be well hidden in a wrinkle within the nipple-areola complex.

The transaxillary technique involves a short transverse incision in the axilla. This approach may be best suited for patients with a poorly defined inframammary fold and small areolar diameter, although some surgeons use this approach routinely. The incision is well hidden with this approach, but it has its disadvantages, including implants that ride high on the chest wall, difficulty controlling the inframammary fold precisely, and challenges with the placement of large silicone implants without the use of a funnel device. This approach also carries the risk of injury to the intercostobrachial and medial brachial cutaneous nerves, which supply sensation to the distal medial portion of the arm.

The transumbilical (TUBA) approach hides the incision remotely through the umbilicus. Breast access is gained through the use of long, blunt dissection instruments (Figure 43). Saline implants are inserted through tubes into the breasts, and filled to the desired sizes. This approach has numerous disadvantages, including non-visualization of the breast pockets, unreliable control of the inframammary fold position, inability to place silicone implants using this method, and the need for a second incision if revision breast surgery is required. This technique is not ideal to use with thin patients, or patients that have abdominal scars or hernias.
Breast implants can be placed either subglandular, subfascial, submuscular, or in a dual plane, where the superior part of the implant is submuscular, and the inferior part is subglandular (Figure 44). Each patient’s special circumstances will help to determine which implant position is best for them, as each site has advantages and disadvantages.

Subglandular, or prepectoral, placement does an excellent job of restoring breast shape, including correcting for minor breast ptosis, or drooping. However, in patients with minimal breast tissue, or soft tissue cover, there is a higher incidence of visualization of the external contour of the implant, and rippling of the implant may occur.

Subfascial placement locates the implant under the deep pectoral fascia, under the top layer of the pectoralis muscle. This placement is sometimes termed “in between” or “inside” the muscle. The subfascial dissection is a natural plane of dissection, which preserves breast tissue, and allows for a more natural anatomic placement. This surgery is performed under direct vision, and allows for more accuracy and consistency because the surgeon’s dissection is guided by the fascia layer. There is no implant displacement with arm movements, and the implants look more natural, as they can assume a more normal teardrop position.

Submuscular, or subpectoral, placement has the advantage of lower capsular contracture rates, and thicker soft tissue coverage to minimize the appearance of ripples. A disadvantage for patients with well-developed pectoralis muscles is that they may show “dancing” or animation of the implants with muscle flexion. Implants can also ride high on the chest, or migrate laterally over time with this placement. Submuscular placement may involve more postoperative pain for the patient, as the pectoralis muscle must be detached from the ribs for implant placement.

The dual plane placement technique combines the advantages of the submuscular and subglandular placements. Soft tissue coverage is improved at the superior pole of the breast with the lower contracture rate that is associated with submuscular placement. With the inferior portion of the implant undergoing subglandular placement, there is less problem with implant animation, as well as fewer “double bubble” deformities, which occur when the gland slides inferiorly off of the implant.

Adverse outcomes from breast implant procedures can range from patient complications such as hematomas, seromas, infections, and an increased risk of a specific type of lymphoma to implant issues such as asymmetry, rippling, displacement, contracture, and rupture. Complication rates are typically higher when breast implants are used for breast reconstruction as compared to their use in primary cosmetic surgery.
Patient complications from breast implant surgery may include hematomas, which are blood collections within the breast that can cause localized swelling and pain, and may require evacuation. The incidence of hematomas is not associated with any particular type of implant, or particular surgical approach. A seroma is a thin fluid collection that may be found around the implant (Figure 45).

They typically resolve themselves in a few days, but can be aspirated under ultrasound guidance if necessary. Aspiration carries the risk of damage to the implant, as well as an increased rate of hematomas, so closed suction drains are recommended when implants are placed. Seromas rarely occur more than one year postoperatively, and may present as asymmetric breast swelling. This swelling can be due to mechanical friction between the prosthesis and the capsule, as well as implant biofilm formation. A seroma can indicate infection, or tumor recurrence in patients with a history of breast cancer. Wound infections most commonly result from Staphylococcus aureus bacteria from the skin or lactiferous ducts, but other rare pathogens may be involved. Anaplastic large T-cell lymphoma of the breast has been identified as a potential association with breast implants, without proof of causation. Only 27 cases have been described through 2011, and the incidence has been defined in women with or without breast implants as 0.1 per 100,000. This disease is exceedingly rare, and can often be treated with less complexity than primary breast cancer. Current recommended treatment for implant-associated anaplastic large T-cell lymphoma is capsulectomy and implant removal.

Implant complications that can become quite serious include capsular contracture and implant rupture. A shell, or capsule, of fibrous scar tissue naturally develops around the breast implant as healing occurs. Over time, this capsule may contract or thicken, and squeeze the breast implant. This contracture can cause pain, shifting, distortion, and hardening of the reconstructed breast.
Contractures are graded by severity using the Baker scale as follows:

- **Grade 1** - Soft breast in which the implant and capsule are not noticeable
- **Grade 2** - Minimally palpable implant and capsule
- **Grade 3** - Firm breast and capsule in which the implant can be palpated and distortion might be seen
- **Grade 4** - Firm, painful, and tender breast with significant visible breast distortion (Figure 46)

![Figure 46 Grade 4 capsular contracture in right breast of 29-year old woman 7 years after placement of silicone gel-filled breast implants](image)

Capsular contracture occurs less often with saline implants, as opposed to silicone. There is also less capsular contracture when implants are placed within the muscle, rather than beneath the mammary gland. Capsular contracture can also develop due to an infection contracted during the implant surgery, or it can develop due to a seroma or hematoma.

Rupture of an implant occurs when there is a tear or hole in the outer shell of the implant. This can be caused by capsular contracture, compression during a mammogram, damage by surgical instruments, damage during procedures to the breast, such as a biopsy or fluid-drainage, normal aging of the implant, overfilling or underfilling of saline-filled implants, physical stresses such as trauma or intense physical pressure, too much handling during surgery, or placement through a non-FDA approved incision site. Rupture of a saline implant causes the implant to deflate, and the saline leaks from the shell into the body (Figure 47). The implant will lose its original size or shape. This is termed an extracapsular rupture, and accounts for 11-23% of all ruptures.

![Figure 47 Deflation of left saline-filled breast implant](image)
Rupture of a silicone gel-filled implant may not be immediately noticed, since the gel is thicker than saline, and may remain in the scar tissue that forms around the silicone implant. This type of rupture is termed an intracapsular rupture, or a “silent rupture”. Intracapsular ruptures account for 77-89% of ruptures. There are no changes to the look or feel of the implant, because the rupture occurs within the capsule. A physical examination by a doctor often shows no evidence of a silent rupture. MRI is the most effective method for detecting the silent intracapsular rupture of silicone gel-filled breast implants. In MR imaging, the ruptured implant shell appears as a group of thin hypointense bands floating within the silicone, which is termed the “linguine sign”. The “keyhole, noose, or teardrop signs” describe silicone that has leaked out of the ruptured implant and has gotten trapped in one of the radial folds (Figure 48).

![Figure 48 Intracapsular rupture of single-lumen silicone implant. a- Axial T2-weighted FSE; b- Axial silicone-excited sequence; open black arrows in a and b indicate “teardrop sign” and “keyhole sign”; white open arrow in a indicates focal change in signal at anterior margin of implant; solid black arrow in b indicates hypointense subcapsular line at anterior margin of implant](image)

Symptomatic ruptures of silicone gel-filled implants usually indicate an extracapsular rupture, or one that occurs outside of the capsule. A woman may notice a decrease in breast size, change in breast implant shape, hard lumps over the implant or chest area, an uneven appearance of the breast, pain or tenderness, tingling, swelling, numbness, burning, or changes in sensation. Silicone gel that leaks outside the capsule surrounding the implant may migrate away from the breast, and cause the formation of lumps in the breast or other tissue, typically the chest wall, axilla, or arm (Figure 49).

![Figure 49 Extracapsular rupture of silicone implant; a and b- Sagittal silicone-excited sequences demonstrate presence of free silicone gel around the implant (white arrows); c- Axial silicone-excited sequence shows free silicone gel in internal mammary chain (black arrow)](image)
It may be difficult or impossible to remove silicone gel that has traveled to other parts of the body. It is important for radiologists to know which implant the patient has, as each type of silicone gel-filled implant has slightly different imaging findings for implant failure (Figure 50). These differences are related to the manufacturing process and viscosity of the silicone gel.

![Image of ruptured breast implant confirmed at surgery]

**Figure 50** Ruptured breast implant confirmed at surgery; a- Axial silicone suppression; white arrows indicate droplets within the implant; b- Axial silicone excitation sequence; white asterisks indicate silicone gel inside and outside the implant; c- Axial T2-weighted fast spin echo; black asterisks indicate a moderate amount of water and probably serum mixed in the silicone gel around the implant; d- Axial T1-weighted fast spin echo; white arrowheads indicate calcifications in the implant periphery.

The FDA recommends the removal of both saline and silicone-gel filled implants if they have ruptured. Replacement of the implant, or removal of the implant without replacement are decisions to be made by the patient and their physician. If the implants are not replaced, or additional reconstructive surgery is not performed, a woman may be left with cosmetically undesirable dimpling, puckering, or sagging of their natural breasts (Figure 51).

![Image of cosmetic deformity]

*Photo courtesy of Walter Peters, Ph.D., M.D., F.R.C.S.C., University of Toronto.*

**Figure 51** Major cosmetic deformity in 29-year old patient one year after silicone gel-filled implants were removed without replacement.
The longer a breast implant is in place, the greater the chance of implant rupture. Saline implant ruptures have been reported at a level of 5-10% at the ten year mark. Silicone implants are often found to have been ruptured when the implants are being exchanged for a different reason. In a study of 478 “explanted” prostheses, a 34% overall rupture rate was determined, with 33% for first-generation implants, 65% for second-generation implants, and 9% for third-generation implants. The FDA recommends MRI at three years after silicone gel-filled implantation, and every two years after that to screen for rupture. Patients with saline implants should proceed with their recommended mammography protocol for breast cancer screening.

Breast implants are not considered “lifetime devices”, so the longer a woman has implants, the more likely it is that she will need to have additional surgery to remove and/or replace them. There is no apparent association between saline-filled or silicone gel-filled breast implants and connective tissue disease, breast cancer, or reproductive problems. However, in order to rule out these and other rare complications, studies would need to be more extensive than those conducted to date. The FDA is the governing body that grants approvals for saline and silicone breast implants, as well as the agency that requires updated safety information on implant product labeling. In March of 2012, the FDA approved the use of cohesive silicone-gel implants, commonly referred to as “gummy bear” implants. These implants have a strong outside lining made up of many layers of silicone to keep the gel inside from leaking out. In addition, the gel that fills the inside of the implant is a cohesive material that sticks together if broken, or if the implant ruptures. Due to their inherent stability and “shape memory”, capsular contractures occur less often with cohesive implants when compared to other types.

**MRI-Guided Breast Biopsies**

MRI of the breasts has the potential to identify occult disease that cannot be detected by physical examination, and is not seen on mammography or sonography. Technical improvements allow us to use MRI guidance for biopsies in cases where suspicious MRI findings have been identified. The term “stereotactic” is often used in conjunction with MRI-guided biopsies, which simply means that coordinates in three planes are provided by medical imaging to “direct” a needle or surgical device to a specific location in the body.

Breast biopsies are performed to remove cells from a suspicious area in the breast for microscopic examination, and ultimately, a diagnosis. MRI guidance can be used in the following four types of biopsy procedures:

- **Fine Needle Aspiration**- A very small needle (22-25 gauge) is used to extract cells from superficial lesions into a syringe; benign and atypical findings can raise the question of false-negative findings, which can be as high as 32%; this method has largely been replaced by core needle procedures in the United States

- **Core Needle Biopsy**- Larger hollow needle (11-14 gauge) is used to withdraw small cylinders (or cores) of tissue from the abnormal area; needle is typically inserted three to six times to get the core samples; offers clearer results than fine needle aspiration, as more tissue is acquired for examination; can be performed in Dr.’s office with local anesthetic; may cause bruising, but usually no internal or external scars
• **Vacuum-Assisted Device** - Disposable probe connects to suction unit to remove tissue samples by pulling tissue into cutting chamber (Figure 52); samples are suctioned from patient while probe remains in place; can collect larger, less fragmented samples, and more samples in less time, as multiple samples (8-10) from different directions are acquired during a single needle placement; probe may also allow for deployment of biopsy marker (tiny surgical clip) when procedure is complete; can be performed in outpatient setting; small incision is made to insert probe, but usually results in little scarring.

![Figure 52 Example of vacuum assisted biopsy device (ATEC)](image)

• **Wire Localization** - Used in conjunction with surgical biopsy; a hollow needle is used to deploy a guide wire with a hook on the end that anchors the wire in the suspicious area; the needle is removed, and the wire is left in place to guide the surgeon; the wire is removed with the samples of the suspicious tissue.

There are two basic methods used for MRI-guided biopsy- the post and pillar method and the grid method. Both methods can be used with or without a Computer-Aided Detection (CAD) system. Basic equipment and set-up are similar, and will be discussed first. All equipment and instruments must be compatible with the magnetic field, without sacrificing functionality (Figure 53).

![Figure 53 Sagittal MRI shows titanium needle (gray arrow) positioned along the enhancing lesion (white arrow) with minimal artifact](image)

The patient is placed in the dedicated breast coil in a prone position, or slightly oblique decubitus position. Motion artifacts can be reduced if the patient can tolerate the prone position. The patient should be positioned as close to isocenter as possible to minimize magnetic field inhomogeneities. If possible, orienting the patient in the feet first prone position is preferable for easier access to the patient during the procedure. The patient’s breasts are suspended in the individual compartments of the breast coil. The coil should have immobilization plates that can be used to apply mild compression to the breasts to limit motion during the procedure. Too much compression during imaging can obscure lesions and reduce blood flow, which will restrict IV contrast. Not enough compression can result in failed or multiple attempts to sample the lesion in question.
Good patient positioning is as important in breast MRI as it is in mammography. There should not be any folds in the breast tissue. Medial breast tissue should be pulled away from the center support of the breast coil to enable all tissue to fall freely within the field of view. Positioning should include as much of the breast and axilla as possible. Each breast should be centered to the coil to avoid artifacts and uneven fat suppression. The imaging field of view must cover all of the breast and the fiducial markers on the biopsy system device. The equipment may allow for either a medial or lateral biopsy approach, with some offering a cranial approach.

Pre-biopsy imaging is performed on the patient to localize the lesion and the fiducial markers on the grid or pillar and post biopsy system. Fiducial markers are tubes filled with a gadolinium/saline solution that are used as points of reference in biopsy procedures. The lesion in question must be confirmed as to its location, and the fact that it can be visualized on MRI. T1-weighted imaging is typically performed pre and post contrast, with the pre-contrast scan serving as the mask for subtraction. If a CAD system is being used, the post-contrast images are sent to the system for measurement of the lesion in relation to the fiducial markers on the biopsy system. CAD stereotactic planning systems improve the efficiency, accuracy, and ease of targeting breast lesions. The CAD assigns the lesion a specific location that is identified in terms of X, Y, and Z coordinates that are relative to the fiducial markers or a set point of reference. Targeting software can be used to find the shortest distance and best needle trajectory for accurate sampling. The same calculations can be made without CAD assistance, but they can result in calculation errors, and are typically more time consuming.

Once the coordinates have been determined, the patient is moved out of the magnet. The breast skin is cleansed, and a local anesthetic is injected into the breast tissue. A small incision is made where the needle will enter. Using the predetermined coordinates, the radiologist will advance the biopsy needle to the specified depth, which can be visualized by the increments along the needle. Before the tissue sampling is made, the patient should be imaged to confirm needle placement in relation to the lesion (Figure 54).

![Figure 54 Images from MRI-guided stereotactic biopsy (grid method); A- Sagittal 3D T1-weighted image shows both fiducial markers and part of the lateral immobilization grid; B- Axial T1-weighted post-contrast image demonstrates the 6 mm. enhancing mass that will be targeted; C- Needle is inserted and aligned with the lesion for sampling; D- Signal void results from needle insertion and tissue retrieval](image)

Imaging should be performed after each needle adjustment, if any are made. Once the location is confirmed, the actual tissue sampling is performed, typically using the core needle or vacuum assisted biopsy method. Multiple samples should be collected from various positions surrounding the lesion. Eight to ten samples are usually adequate for a pathologist to make a definitive diagnosis. When sampling is complete, the cutting portion of the biopsy device can be removed, with the needle remaining in place. A confirmation scan should be performed to verify that the sample was obtained.
A titanium marker/clip is usually placed in the area that was sampled to make identification of the area easier for follow-up or further intervention (Figure 55).

![Shape 1 (buckle), Shape 2 (infinity), Shape 3 (stoplight)](image)

**Figure 55** Examples of MRI biopsy site markers (Hologic)

If the equipment permits, the marker or clip can be placed through the hollow of the needle. The needle can then be removed, and a final scan performed to confirm accurate placement of the marker (Figure 56). The patient can then be removed from the scanner, and post-procedure care can be provided.

![MRI image with biopsy marker in place (SecurMark)](image)

**Figure 56** MRI image with biopsy marker in place (SecurMark)

**Post and Pillar Method**

The post and pillar method uses a needle guide that slides on a pillar that is attached to the breast stabilization plate (Figures 57-60). The needle block can be maneuvered vertically and horizontally on a ruler-axis, allowing for precise positioning of the needle. Depth measurements can be read from the needle. This method also allows for angling of the needle upon insertion into the breast, which is helpful for hard to reach lesions, and lesions that are close to the chest wall.

![Figure 57 Example of a post and pillar device set up for lateral biopsy approach using an adjustable pillar post needle guide](image)
Grid Method

The grid method uses a block needle guide that is inserted into a grid stabilization plate. Determination of placement of the block needle guide can be calculated manually using a grid worksheet, or through the use of a CAD device (Figures 61-65). The block is placed in the appropriate grid location, and the needle is inserted through a specified hole in the block to guide it into the lesion. Depth measurements can be read from the needle. The breast must be sufficiently compressed between the coil’s stabilization plate and the grid stabilization plate to permit an indentation of the grid on the skin. The grid is not visualized by MR, but can be identified by its impression on the skin.
Figure 61 Biopsy grid, immobilization plate, and medial and lateral biopsy mechanism arms (Hitachi Oasis system)

Figure 62 Introducer set, which includes introducer stylet, localizing obturator, introducer sheath and needle guide (ATEC)

Figure 63 Example of a grid worksheet for manual calculation of block needle guide placement

Figure 64 Example of a CADstream report using the grid method

Figure 65 Grid biopsy in progress with vacuum-assisted device
Wire Localization

In cases where MRI-guidance is used for wire localization prior to surgical excision of a breast lesion, a guide wire is deployed through the needle, rather than a cutting device. The hollow needle has a hooked wire inside that anchors into the suspicious area (Figure 66). The wire must be placed as close as possible to the lesion to ensure accurate sampling. Once the area is localized, the needle is retrieved, leaving only the wire in place to guide the surgeon. The end of the wire indicates to the surgeon where tissue should be extracted (Figure 67). The wire is removed along with the tissue samples.

In order to achieve the best results, MRI-guided biopsy procedures require technical skill, accuracy, and high-quality efficient scanning techniques. Technologists will have a significant role in patient positioning and equipment set-up, including the safety considerations for MRI compatible biopsy instruments and equipment. In addition, technologists must possess solid knowledge of imaging techniques and parameters in order to obtain effective fat suppression, good contrast weighting, and an acceptable balance between spatial and temporal resolution, while decreasing or eliminating susceptibility issues. Signal voids and misregistration caused by magnetic susceptibility from a biopsy needle can obscure a small lesion. Susceptibility also increases when the needle is positioned perpendicular to the main magnetic field. Accurate calculation of stereotactic coordinates as well as image interpretation can be affected by magnetic susceptibility, as it can create distortion or obscure the area of interest. Obtaining uniform fat suppression in the breasts can be challenging at the higher field strengths recommended for biopsy procedures, as well as in patients with higher ratios of fatty tissue to breast parenchyma.

MRI-guided stereotactic biopsy offers a high-quality alternative to surgical biopsy for lesions that are visible only on MRI. It is also a cost-effective means of reducing surgical biopsies while achieving comparable results. Additional advantages of MRI-guided biopsies include excellent sample retrieval, low occurrence of complications, procedure efficiency, easier accessibility, and faster patient recovery. MRI is typically not the modality of choice for the biopsy of lesions that are easily identified by mammography or sonography. In any modality, it is possible to miss a lesion or obtain an inadequate sample. Small lesions or lesions near the chest wall are especially challenging for MRI-guided biopsies. MRI of the breast and MRI-guided biopsies offer an additional means of detecting and confirming breast cancer, which ultimately improves the management of breast disease.
Breast Imaging Sequences

There is no set standard or single protocol for MRI of the breast. However, the majority of MRI breast imaging protocols that are being used for cancer evaluation will include T1-weighted pre- and post-contrast-enhanced sequences, T2-weighted sequences, and the use of fat suppression techniques. Fat suppression is necessary to detect lesions that might otherwise appear isointense to fat. On post-contrast imaging, enhancing lesions and fat both appear hyperintense. MR sequences may be 2D or 3D, and spin echo or gradient echo, depending on site and radiologist preferences. 3D sequences benefit from increased SNR, which allows for thinner slices. Isotropic voxel dimensions make it easier to reconstruct 3D scans with less distortion. Imaging can also be performed either unilaterally or bilaterally. Bilateral imaging is preferred when there is concern for asymmetry or a question of malignancy bilaterally. The sagittal scan plane typically requires more slices than the axial plane for bilateral coverage, resulting in an increase in scan time, and a decrease in spatial resolution.

T1 and T2-Weighted Sequences

T1-weighted sequences are used to evaluate anatomic structures, architectural distortion, and changes in enhancement after contrast. Non-enhanced and enhanced T1-weighted images with identical parameters are essential for the performance of subtractions after the administration of contrast. A pre-contrast T1-weighted non-fat suppressed sequence can show the presence of fat in a lesion. Central high signal on a T1-weighted image can be seen in intramammary lymph nodes or fat necrosis. Fat is also seen in hamartomas, which are typically benign growths of normal tissue elements that grow in a disorganized mass (Figure 68).

![Figure 68 Example of a fat-containing hamartoma in the breast (blue arrow); breast lesions that contain fat are usually benign unless they are rapidly growing, in which case they should be biopsied](image)

T2-weighted sequences are fluid-sensitive and may show fluid-filled abnormalities, such as cysts or fibroadenomas. In T2-weighted fat suppressed images, you are looking for water, so bright lesions would include lymph nodes, fat necrosis, and cysts, which are all benign (Figure 69).

![Figure 69 Multiple bright rounded areas in both breasts are multiple cysts](image)
One type of malignant lesion that displays high signal intensity on T2-weighted fat-suppressed images is colloid (or mucinous) carcinoma (Figure 70). Moderate and low signal intensities on T2-weighted fat-suppressed sequences can be caused by cancer. Moderate signal may be a sign of invasive lobular cancer, DCIS, or simply fibrocystic change. Low signal may be invasive ductal cancer, sclerotic fibroadenoma, or a scar.

Breast imaging requires that careful attention be given to the Frequency Prescan graph that your system may display prior to fat saturation sequences. Due to the variety of breast composition amongst patients, the graph’s center frequency line may shift its center to be on fat rather than on water. The graph for patients that have fattier breast tissue may display a minimal water peak, and the system will center on a more dominant peak, which could be fat or silicone.

**Dynamic Contrast-Enhanced Imaging**

Dynamic contrast enhanced imaging of the breasts produces both kinetic and morphologic information. This imaging requires superior temporal and spatial resolution, which can be acquired from 3D T1-weighted gradient echo sequences (TIGRE on Hitachi systems). Evaluation of kinetic information requires high temporal resolution, as it focuses on enhancement features such as peripheral enhancement, increased angiogenesis, etc. Evaluation of morphology requires high spatial resolution, as it focuses more on size and shape, such as asymmetries, irregular borders and architectural distortions. Dynamic contrast enhanced sequences are used to generate time-intensity curves that show the uptake and washout of contrast material. (Time-intensity graphs will be discussed further in Post Processing). After a bolus injection of gadolinium contrast, the volume is scanned repeatedly over time. Imaging must be performed in a timely manner to acquire filling in the arterial phase. Appropriate temporal resolution allows for imaging of lesions as they enhance, prior to the enhancement of the surrounding breast parenchyma, which can mask lesions. The early phases of dynamic contrast imaging are best for the evaluation of lesion borders. Malignancies tend to demonstrate strong rapid enhancement during the early phases, followed by rapid signal loss or a signal plateau. Invasive malignant lesions may show peak enhancement in as little as 90-120 seconds. DCIS can be an exception, with only 70% of DCIS exhibiting rapid enhancement early on (Figure 71).
Additionally, not all enhancing lesions are malignant. Fibroadenomas and hyperplasia are benign findings that can demonstrate enhancement patterns similar to malignancies (Figure 72). Both false-positive and false-negative enhancement results can occur. False-positive enhancement can be related to previous surgery or biopsy, radiation therapy, or changes during the patient’s menstrual cycle. False-negative enhancement can be demonstrated by breast abnormalities, resulting in misdiagnosis, and a lack of or delay in treatment. Caution must be exercised in the interpretation of both time intensity curves and enhancement patterns.

**Diffusion Weighted Imaging**

Diffusion-weighted imaging (DWI) can be used in breast imaging to improve specificity, as well as to evaluate early response to neoadjuvant chemotherapy. DWI measures the restriction of water molecules. Diffusion restriction between normal and pathologic tissue can be quantified by measuring apparent diffusion coefficient (ADC) values. In general, malignant lesions have more tightly packed cells with a more compact architecture, with consequently lower ADC values as compared to benign lesions. There is inhibition of effective movement of water molecules and restricted diffusion in dense malignant lesions (Figure 73). ADC values vary between malignant and benign breast masses, but the values are difficult to normalize, and benign breast changes can mimic malignancies. ADC values are also affected by the hormonal status of the female body, and can vary by 5.5% among the different phases of the menstrual cycle. False-negative ADC values can be obtained from cystic/necrotic malignancies, as their higher ADC values reflect their lack of significant restriction of water diffusion. Studies performed as recently as five years ago are now providing cut-off ranges for ADC values for benign and malignant lesions with high sensitivity and specificity. Results can be hampered if lesions are not of adequate size to contain an ROI, increasing the possibility of false sampling from adjacent tissues.
Silicone and Saline Suppression

Silicone or saline suppression sequences can be performed on patients with silicone or saline breast implants. Silicone suppression scans are performed to evaluate the integrity of silicone implants. A FIR sequence can be used, with the TI time set to null the signal from silicone, while the fat and water signals remain bright. TI times can be adjusted to offer light, medium, or heavy silicone suppression, depending on the preferences of the radiologist (Figure 74).

![Figure 74 Silicone suppression images from the Hitachi Oasis system demonstrate light silicone suppression on the left (TI=400) and heavy silicone suppression on the right (TI=650)](image)

The integrity of saline implants can usually be decided by observation, as saline implants will deflate if ruptured. However, saline suppression scans can also be performed using FIR sequences with the TI time set to null the signal from saline, while the fat signal remains bright (Figure 75). Specific TR and TI times may be required for optimized saline suppression.

![Figure 75 Axial image from the Hitachi Oasis system displaying saline suppression](image)

Patients with silicone implants may also require scans that display bright signal from only the silicone, with nulling of both fat and water signals (Figures 76, 77).

![Figure 76 Sagittal silicone-only images](image)
Figure 77 Axial silicone-only images

These scans can be acquired by using a fat sat pulse set to null signal from water, and an inversion pulse with a TI time set to null signal from fat. Only the bright silicone signal remains. The precessional frequency of silicone is slightly less than the precessional frequency of fat, so the peaks on the Hitachi Frequency Prescan graph will display with silicone to the left, fat in the middle, and water to the right. Three peaks may not always be well visualized, depending on the size of the implant, and the type and amount of breast tissue that surrounds the implant.

The blue line on the graph should be centered over the water peak (Figure 78). The offset frequency field must be set to a number specific to your magnetic field strength (+260 for Hitachi Oasis system) to ensure optimal water suppression, while the fat and silicone signals are unaffected. The fat signal will be suppressed by an inversion pulse with a TI time specific to your field strength to null fat signal (130ms for Hitachi Oasis system).

Figure 78 Frequency Prescan graph from Hitachi Oasis system demonstrating silicone, fat, and water peaks; RF “FatSat” pulse (green line) is shifted to the right of the Center Frequency (blue line) due to +260 setting in Offset Frequency field
MRI’s sensitivity and specificity is higher than either mammography or ultrasound in the area of silicone implant ruptures. Silicone generally exhibits a low signal in T1-weighted sequences, and a high signal in T2-weighted sequences (Figure 79).

![Figure 79 Axial T2-weighted FSE with water suppression shows several small foci of silicone gel (curved arrows) anterior to implant; collapsed shell (red arrows) indicates rupture](image)

Free silicone, which is silicone that has moved beyond the implant capsule to the breast or axilla, will not enhance in T1-weighted fat suppression sequences, but will display increased signal in T2-weighted STIR sequences (Figure 80).

![Figure 80 Axial T2-weighted IR with water suppression shows silicone gel (arrows) in breast; extensive silicone granulomata adjacent to implant anteriorly and laterally; offers good view of soft-tissue silicone](image)

**Post Processing**

Dynamic Analysis is Hitachi’s post processing task that provides information for the kinetic analysis of dynamic contrast-enhanced sequences. The arrival, uptake, and washout of contrast material can be plotted over time as a time-signal intensity curve. This kinetic data is used to show enhancement patterns that may help establish a differential diagnosis between benign and malignant lesions. Time-intensity curves and enhancement patterns alone are not 100% accurate, as both false-positive and false-negative results can occur.

In the analysis of time-intensity curves, the initial upslope occurs during the first one to two minutes of the dynamic scan. The upslope is determined to be slow, medium, or rapid. The delayed portion, which occurs two minutes or more after the contrast injection, shows an increase, a plateau, or washout of the curve. Kinetic analysis takes about six minutes of repetitive scanning, and can lead to three types of curves. These three types of curves are presented for general explanation only; they were not acquired on Hitachi systems.
A Type 1 curve has a slow rise, and a continued rise with time. A lesion with a Type 1 curve has an approximate 6% chance of malignancy (Figure 81).

Figure 81 Type 1 curve created from breast image on the left; low chance of malignancy

A Type 2 curve is considered to be “in the middle”, and has a wide range of malignancy percentages. It has a slow or rapid initial rise, followed by a plateau in the delayed phase, which is allowed a variance of 10% up or down (Figure 82). Malignancy chances for lesions with Type 2 curves lie between the 6% of the Type 1 curve, and the 29-77% of the Type 3 curve. Many physicians will biopsy lesions with Type 2 curves. Areas of “non-mass enhancement” cannot be easily diagnosed with kinetics.

Figure 82 Type 2 curve created from breast image on the left; range of malignancy chances is between 6% and 77%

The most important non-mass enhancing pattern to recognize is clumped enhancement, as this pattern has a 60% chance of malignancy, typically DCIS (Figure 83). Areas of “clumped enhancement” in the breast should be biopsied, even if there are no areas with a Type 3 curve.

Figure 83 Examples of clumped enhancement in DCIS
A Type 3 curve demonstrates a rapid initial rise, followed by a drop-off with time (washout) in the delayed phase (Figure 84). A lesion with this type of curve is malignant in 29-77% of cases.

![Figure 84 Type 3 curve created from breast image on the left; rate of malignancy with this type of curve is 29-77%](image)

**Dynamic Analysis Task**

The Dynamic Analysis task window on the Hitachi system displays an image in the viewport in the upper left corner, and three viewports that display various time-intensity graphs (Figure 85). An ROI can be placed in a questionable area on the breast image, and data for that ROI can be displayed on the three graphs. The graph in the top right is called the Intensity graph, which displays the change in the ROI’s mean value over time. The graph in the bottom left of the Dynamic Analysis window is the Intensity [Ratio] graph, which displays the time change based on the first image’s ROI mean value. The graph in the bottom right is the Intensity Change per Second graph, which displays the change rate of the ROI mean value. Parameters that can be manipulated for each graph viewport are found on the right side of the Dynamic Analysis window. These time-intensity graphs are sent to the radiologist for interpretation.

![Figure 85 Dynamic Analysis task window; breast image with ROI displays in top left corner; A- Intensity graph; B- Intensity [Ratio] graph; C- Intensity Change per Second graph](image)
**Computer Aided Detection**

Computer Aided Detection (CAD) programs have been developed to aid radiologists in their interpretations of dynamic contrast-enhanced MRI of the breasts. A high number of false-positive results are reported based on the image analysis of enhancement patterns of lesions in dynamic breast MRI. The primary aim in the development of CAD for breast MRI was not solely to identify lesions, but to assist the radiologist in determining which lesions are benign and which are malignant.

CAD systems automate many of the processing and analysis functions that are normally performed manually by MRI technologists and radiologists. The automated kinetic assessment of CAD generates a color-coding based on the signal intensity voxel changes during the enhancement of breast tissue. This provides an easier way of interpreting the patterns of contrast enhancement (persistent, plateau, and washout) across a series of images, which may help identify lesions and their likelihood of being malignant. The CAD system compares pixel intensity values between pre-contrast and post-contrast series in order to specify minimum enhancement thresholds. Once a pixel is identified as enhancing above the threshold, the CAD system compares pixel signal intensity values on immediate and delayed post-contrast series. Through this comparison, CAD can indicate if the signal intensity is washout enhancement, plateau enhancement, or persistent enhancement (Figure 86). A specific color or color intensity is assigned to each pixel for different types of tissue enhancement. The end result is a color overlay on each MRI slice indicating regions of significant enhancement, and providing details about enhancement type and extent (Figure 87).

![Figure 86](image1.png)  
**Figure 86** Top image shows a large, abnormally enhancing area in the left breast; CAD image on bottom detected some very small areas with type 3 washout (red areas); diagnosed as large invasive ductal carcinoma

![Figure 87](image2.png)  
**Figure 87** CAD shows large area of red superimposed on breast lesion; red color on CAD typically means type 3 washout, and probable malignancy
**BI-RADS Reporting for Breast MRI**

BI-RADS (Breast Imaging Reporting and Data System) is a program established by the American College of Radiology (ACR). It was initially applied only to mammograms, but has been adapted for use with MRI and ultrasound as well. Using the BI-RADS program, mammogram, ultrasound and MRI findings are placed into a small number of well-defined categories, which include recommendations for the management of each case, and percentages indicating the likelihood of malignancy. BI-RADS classifications have helped in monitoring breast cancer treatment and supporting breast cancer research, as they have made statistics easier to calculate. Radiologists benefit from BI-RADS, as this program makes it easier to calculate their accuracy statistics. In addition, the wording used in mammography, ultrasound and MRI reports has become more standardized due to the BI-RADS categorization scheme. This has reduced confusion and improved communication between radiologists, patients, and ordering physicians. An understanding of the BI-RADS assessment categories, their management recommendations, and the likelihood of malignancy associated with each category can provide MRI technologists with increased insight for their performance of breast MRI examinations.

**Category 0: Incomplete- Need Additional Imaging Evaluation**

Additional imaging is needed due to either a technically unsatisfactory MRI scan, or the need for more information to interpret the initial scan. Management of Category 0 may involve repeating the MRI, or gaining information through the use of other imaging modalities (mammography or ultrasound). The likelihood of cancer in this category is N/A (Not Applicable), as this is not a final assessment. This category should not be highly used with breast MRI reporting, as there is typically enough information on an initial breast MRI examination to provide a management recommendation. A Category 0 final assessment may be helpful when an MRI finding is suspicious, but the use of an additional study to demonstrate that the finding is characteristically benign would avert a biopsy. Radiologists should provide detailed recommendations for subsequent diagnostic imaging, as well as the level of suspicion for malignancy. A final assessment is given once the additional studies are completed.

**Category 1: Negative**

This category is used for a normal examination, in which the radiologist has nothing to comment on. Management of Category 1 includes routine breast MRI screening if the patient’s cumulative lifetime risk is ≥20%. There is essentially a 0% likelihood of malignancy. The radiologist’s report should include a normal description of breast composition, which includes the amount of fibroglandular tissue, as well as the degree of background parenchymal enhancement, which is a normal finding.

**Category 2: Benign**

This is a normal assessment, similar to Category 1. However, if the interpreter chooses to describe any benign findings in the MRI report, the examination becomes a Category 2. Benign findings may include cysts, implants, core biopsy or surgical clips, etc. Management of Category 2 includes routine breast MRI screening if the patient’s cumulative lifetime risk is ≥20%. There is essentially a 0% likelihood of malignancy.
Category 3: Probably Benign
Findings in Category 3 should have a ≤2% likelihood of malignancy, but greater than the 0% likelihood of malignancy of a characteristically benign finding. A Category 3 finding is not expected to change over the suggested period of imaging surveillance, but stability of the finding should be established before recommending management that is limited to routine breast screening. If a probably benign finding is smaller or less prominent on the follow-up examination, the finding should be assessed as benign (Category 2), eliminating the need for continued surveillance imaging. A new finding, or probably benign finding that has increased in size, extent, or conspicuity on follow-up may require a biopsy recommendation. Benign hormonal enhancement can be seen in menstruating patients who are scanned in a suboptimal phase of their cycles, as well as in post-menopausal patients on hormone replacement therapy. In both cases, repeat and/or follow-up examinations should be performed at optimal times- week two of their cycle for menstruating patients, and several weeks after hormone replacement therapy is stopped for post-menopausal patients. The recommended 2- or 3-year follow-up schedule for Category 3 cases is 6 months (affected breast only), 6 months (both breasts), 1 year, and 1 additional year to establish stability. After 2 to 3 years of stability, the finding should be assessed as benign (Category 2). Findings typical of this category include round or oval clusters of tiny calcifications, miscellaneous focal findings, and non-calcified well-defined solid nodules.

Category 4: Suspicious
Findings in Category 4 do not have the classic appearance of malignancy, but are sufficiently suspicious to justify a recommendation for biopsy. Almost all recommendations for breast interventional procedures will come from assessments made using this category. Management of Category 4 is listed as “tissue diagnosis”, which is typically ultrasound- or MRI-guided biopsy. This category covers the wide range of likelihood of malignancy between Categories 3 and 5, which is 2%-95%. In mammography, this category is further divided into subcategories A, B, and C. The positive predictive value (PPV) for breast cancer increases from 13% in subcategory A to 79% in subcategory C. However, this subdivision has not yet occurred in breast MRI.

Category 5: Highly Suggestive of Malignancy
A Category 5 assessment carries a very high probability of malignancy, which is ≥ 95%. Management of this category almost always involves a tissue diagnosis of malignancy, to the extent that lesions with a nonmalignant percutaneous tissue diagnosis result in a recommendation for a repeat, usually surgical, biopsy.

Category 6: Known Biopsy-Proven Malignancy
This category is reserved for examinations performed after biopsy proof of malignancy, but prior to surgical excision, in which there are no abnormalities other than the known cancer that might need additional evaluation. In Category 6, a cancer diagnosis has already been established, a lesion is depicted on MRI, and the lesion corresponds to the previously biopsied cancer. Management for Category 6 is surgical excision when clinically appropriate. As with Category 0, the likelihood of cancer in this category is listed as N/A (Not Applicable), as a cancer diagnosis has already been established.
Breast Coils and Positioning

Good patient positioning is as important in breast MRI as it is in mammography. There should not be any folds in the breast tissue. Medial breast tissue should be pulled away from the center support of the breast coil to enable all tissue to fall freely within the field of view. Positioning should include as much of the breast and axilla as possible. Each breast should be centered to the coil to avoid artifacts and uneven fat suppression. The imaging field of view must cover all the breast tissue.

ACR requirements for accreditation in breast MRI state that the MRI system must have a dedicated breast coil that is capable of simultaneous bilateral imaging. They also require that facilities that are performing breast MRI must have the equipment to perform mammographic correlation, directed breast ultrasound, and MRI-guided intervention, or they must create a referral arrangement with a cooperating facility that can provide these services. It is recommended that the cooperating facility also be accredited by the ACR in MRI. The ACR does not specify minimum field strength for MRI systems. We will discuss the breast coils and positioning for the Oasis, Echelon, and Echelon OVAL systems. Laser lights are used for centering purposes on all three systems, which must be used with caution (Figure 88).

![Figure 88 Caution label for laser lights](image-url)
Oasis MR System

The optional Oasis RAPID Breast coil is a low-profile 7-channel coil that is equipped with spacers. A list of items that are provided with the breast coil and basic positioning instructions are discussed below (Figure 89).

The following items are included with the Oasis 7-channel RAPID Breast Coil with spacers:

- A Head rest
- B 7-channel breast coil
- C Torso transition piece
- D Blue head rest pad
- E Blue breast coil positioning pad
- F Blue torso transition piece positioning pad
- G Breast coil spacer
- H Torso transition piece spacer
- I Breast coil cup plug
- J Blue breast coil trough pad
- K Velcro straps (2)
- L Black fat-saturation pad (single or triple-compartment style)
- M Solid immobilization plates (4)
- N Coil biopsy mechanism arms (4 total- 2 medial, 2 lateral)

The 7-channel RAPID breast coil has three different positioning scenarios, determined by the patient’s size. For “Plan A”, the breast coil spacer and the torso transition piece spacer should be placed directly on the patient table, between the red arrows and the head of the patient table (Figure 90). The RAPID breast coil and the torso transition piece should each be placed on top of their respective spacers. The guide on the torso transition piece should fit into the slot in the base of the RAPID breast coil. The head rest should be placed on the table close to the top of the breast coil.
The blue breast coil trough pad should be positioned across the bottom of the breast coil (Figure 91). It should only be removed for biopsies. The black fat-saturation pad should be placed on the sternum portion of the coil, under the blue breast coil positioning pad (Figure 92).

The patient should be positioned on the coil in the head-first prone position (Figure 93). The patient’s sternum should be centered on the bridge that separates the two halves of the coil. The patient’s breasts must be positioned within each open cavity, with the central part of each breast (as observed in the head-to-foot direction) centered on the transaxial positioning mark on the coil. Use the Velcro straps to adjust the side wings of the breast coil so they are firmly against the sides of the patient. The head rest should be adjusted to offer the patient comfortable support. Accessory pads can be placed under the patient’s arms for additional support and comfort, as needed.
Use of the breast coil spacers is always recommended for optimal image quality. If the patient's back will not clear the gantry when positioned on the breast coil with the spacers, proceed to “Plan B”. This involves removal of the torso transition piece and torso transition piece spacer (Figure 94). Replace the transition piece and spacer with pillows or stacked blankets placed under the patient’s lower abdomen to maintain comfort and support. This allows the breast coil to remain on its spacer for optimal image quality.

![Figure 94 Patient positioned on 7-channel Oasis breast coil with coil spacer in place; torso transition piece and transition spacer removed and replaced by pillows (Plan B)](image)

If the patient’s back is still touching the top of the gantry, proceed to “Plan C”. Remove both the breast coil spacer, and the torso transition piece spacer. Place both the breast coil and the torso transition piece directly on the patient table (Figure 95). If additional space is needed, replace the torso transition piece with pillows or stacked blankets under the patient’s lower abdomen to maintain comfort and support.

![Figure 95 Oasis 7-channel RAPID breast coil and transition piece placed directly on patient table (Plan C)](image)
Echelon OVAL MR System

The Echelon OVAL utilizes an optional 7-channel RAPID breast coil (Figure 96).

Breast exams can be performed in either the feet first or head first direction on the Echelon OVAL system. We will discuss the setup for a feet first exam. The 8-channel WIT spine coil should be plugged into the table, and the 12-channel WIT spine coil should be plugged into the table at the end nearest to the magnet (Figure 97). The torso transition piece should be fitted into the voids in the WIT 8-channel spine coil, with its lower end toward the gantry.

The breast coil should be placed on the table next to the higher end of the torso transition piece (Figure 98). The head rest should be placed on the table close to the top of the breast coil.
Figure 98 Placement of breast coil (3a, 3b) and head rest (4) on patient table for feet first breast scanning

The patient should be positioned on the coil in the prone position (Figure 99). The patient’s sternum should be centered on the bridge that separates the two halves of the coil. The patient’s breasts must be positioned within each open cavity, with the central part of each breast (as observed in the head-to-foot direction) centered on the transaxial positioning mark on the coil. Use the Velcro straps to adjust the side wings of the breast coil so they are firmly against the sides of the patient. The head rest should be adjusted to offer the patient comfortable support. Accessory pads can be placed under the patient’s arms for additional support and comfort, as needed.

![Figure 99 Patient positioned on Echelon OVAL breast coil with side wings of coil strapped in place](image)

**Echelon MR System**

Breast exams can be performed either head first or feet first on the Echelon system. The optional 7-channel RAPID breast coil should be placed directly on the patient table (Figure 100). Table pads should be added to support and stabilize the patient, and can also serve to cover the coil cable. The head rest should be placed close to the top of the breast coil.

![Figure 100 Placement of Echelon breast coil (1), table pad (2), and head holder (3) on patient table](image)
The patient should be positioned on the coil in the prone position (Figure 101). The patient’s sternum should be centered on the bridge that separates the two halves of the coil. The patient’s breasts must be positioned within each open cavity, with the central part of each breast (as observed in the head-to-foot direction) centered on the transaxial positioning mark on the coil. The solid immobilization plates can be used for gentle immobilization (Figure 102). However, the breast tissue should not be compressed. The head rest should be adjusted to offer the patient comfortable support. Accessory pads can be placed under the patient’s arms for additional support and comfort, as needed.

Scan Setups

The following are HMSA suggestions for scan setups for basic breast scanning on the Oasis, Echelon, and Echelon OVAL systems. Consult the How-to Manual for your Hitachi MR system for more specific instructions on breast scanning. System-specific breast protocols have been developed for implant and non-implant scanning. These protocols can be found in the System Directory of the Oasis, Echelon, and Echelon OVAL systems.

Axial Scans

Axial slices of the breast can be set up using sagittal and coronal images or scanograms (Figure 103). Slices may be angled in order to remain parallel to the breast on the sagittal image, and perpendicular to the right and left nipples on the coronal image. Slices should be prescribed in a sufficient number to include all breast tissue. When performing axial fat saturation breast imaging, the Regional Shim should cover both breasts.
Sagittal Scans
Sagittal slices of the breast can be set up using axial and coronal images or scanograms (Figure 104). Routine sagittal sequences are typically performed on the right and left breasts separately, while dynamic sagittal sequences are typically performed on both breasts at the same time. Slices may be angled in order to remain parallel to the same laterality breast on the axial image, and perpendicular to the same laterality breast on the coronal image. Slices should be prescribed in a sufficient number to include all breast tissue. When performing sagittal fat saturation breast imaging, the Regional Shim should cover the breast only on the laterality being imaged in that specific sequence.

Coronal Scans
Coronal scans are not typically performed for routine breast imaging. A coronal scan may be one of the slice planes acquired for a scanogram, and might be employed as a post-contrast sequence, at the discretion of the radiologist. Slices may be angled in order to remain perpendicular to the right and left breasts. Slices should be prescribed in a sufficient number to include both entire breasts, from nipples to axillae.

Presats
Presat pulses are employed in breast imaging on the axial Shim tasks of the Oasis, Echelon, and Echelon OVAL systems. For the Echelon and Echelon OVAL, which are both 1.5T horizontal field systems, the presat should be positioned so that it covers the posterior chest wall (Figures 105, 106).

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Figure 104 Sagittal slice setup using axial and coronal images; red arrows point to Regional Shims (purple boxes)

Figure 105 Echelon axial Shim presat placement
On the Oasis system 1.2T vertical system, the presat is to be placed at the most posterior portion of the FOV box. The presat is being used to null signal from the two bright spots that may be seen on the posterior chest wall (Figure 107). The bright spots are caused by the proximity of the chest wall to the transmitter that is located behind the top gantry cover. The presat should not be moved, even if the bright spots are not seen. In addition, the presat should not be re-sized. The presat has been optimized at a thickness of 40mm.

This concludes the Breast Imaging module of the Hitachi Medical Systems America’s MRI Anatomy and Positioning Series. You must receive a passing score on the post-test for this activity in order to receive your Continuing Education credits.
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