

Breast ultrasound: A bright future

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Ultrasound is being increasingly used to characterize breast lesions

Until a few years ago, ultrasound evaluation of the breast was mainly used to determine whether a mass found on mammography or physical examination was cystic or solid. Little attempt was made to characterize the solid lesion as benign or malignant. Today, ultrasound is used with increasing frequency to characterize lesions [1]. Ultrasound-guided biopsy is faster and more comfortable to the patient than stereotactic breast biopsy. The accuracy of image-guided biopsy is comparable to that of surgical biopsy, with a significant reduction in cost and patient inconvenience.

Ultrasound technology continues to improve, with higher frequency transducers, harmonic imaging and spatial compounding. All of these techniques have significantly improved ultrasound imaging of the breast. The future of breast ultrasound is bright, including screening patients with dense breasts, further refinement of the characterization of lesions as benign or malignant, and improved visualization of microcalcifications. This article discusses the present state of the art in breast ultrasound, and reviews future applications.

TECHNIQUE

The patient is placed in the supine position, with the ipsilateral hand behind the head. The patient is then rolled to a contralateral posterior oblique position, which minimizes breast thickness. This position flattens the breast tissue, maximizing the high-frequency probe scanning characteristics. The tissue planes are pulled from their usual conical orientation, when the patient is in the upright position, into a plane parallel to the skin line. This minimizes critical angle shadowing, improves penetration and prevents degradation of focusing characteristics. Scanning is performed in the radial (spokes of a wheel) or antiradial position. ACR accreditation requires all abnormalities to be documented in at least two projections. The size and location of all lesions should be correlated with the abnormalities found on physical exam and X-ray mammography.

There are various methods for labeling the position of the lesion: the side of the patient imaged (right

or left), image orientation and anatomic location. One can also use a clock notation, which identifies both the hour location of the lesion and the distance from the nipple.

At least two sets of images of a lesion should be obtained: one with and one without measurements (calipers obscure the marginal detail). To document that no ultrasound lesion is present to account for a palpable abnormality, an image should be taken at the exact location of the palpable abnormality, and clearly labeled with the indication that this image corresponds to the area of palpable abnormality. If a breast survey is being performed, images should be acquired at 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock, in order to document all areas of the breast. If the ultrasound examination is being performed for a targeted lesion or palpable abnormality, the corresponding quadrant of the breast should be examined.

LESION CHARACTERIZATION

If a breast lesion is anechoic, thin walled, and has good through transmission, it can be confidently diagnosed as a cyst and no further work-up is needed. However, lesions in the form of complicated cysts or solids are problematic. They may require aspiration or biopsy. Ultrasound can be used to characterize these lesions with respect to the probability of their benignity or malignancy. Stavros et al. [2] have developed a grading system based on the ultrasound characteristics of breast lesions. This system classifies lesions into risk categories that parallel the BI-RADS mammographic grading scale. The further work-up of the lesion can then be based on the risk of cancer. The grading system places lesions into one of five categories: benign, probably benign, intermediate, probably malignant, malignant.

Cystic lesions

Simple cysts

Simple cysts are completely anechoic, well circumscribed and thinly encapsulated. They have enhanced through transmission and thin edge shadows (Figure 1) A lesion must meet all these criteria to be called a simple cyst. If all these

Lesions can be graded in categories that parallel the BI-RADS grading scale.

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criteria are met, there is virtually no chance of malignancy. It is not necessary to biopsy, aspirate, or follow up these lesions. However, if it is not certain that a cyst corresponds to a mammographic or palpable abnormality, the lesion can be aspirated to confirm its disappearance on mammography or that the lesion is no longer palpable after aspiration. Some cysts may be painful, and the cyst can be aspirated for symptomatic relief.

Complex cysts

Complex breast cysts represent a very heterogeneous group of entities with significantly different risks of malignancy.

- *Cysts with low-level internal echoes.* With high-resolution, near-field imaging systems, many cysts which would previously have been classified as simple cysts have low-level internal echoes, which are most likely secondary to floating cholesterol crystals. Low-level internal echoes may also be secondary to internal pus or blood. The wall of an infected or hemorrhage cyst is thicker and less well defined than that of a simple cyst with floating crystalline material. In small cysts deep to fibroglandular tissue, low-level echoes can be seen secondary to artificial scatter echoes; in this case a 5 MHz transducer may decrease the artifact. A small minority of complex cysts with low-level echoes may be indistinguishable from solid lesions, despite all diagnostic maneuvers, and may need to be biopsied or followed up.

- *Complex cysts with fluid-debris levels.* Cysts that contain fluid-debris levels are more likely to be infected or hemorrhagic cysts, although the debris may be 'milk of calcium' calcifications or cholesterol crystals. These cysts should probably be aspirated.

- *Septated complex cysts.* Septated complex cysts that have thin septations are usually not suspect. Thin septations may represent the walls between adjacent cysts. The presence of thick septations in a cyst are suspect for intracystic malignancy, especially if color Doppler shows blood flow. A thick septated cyst should undergo aspiration and core biopsy, or be excised.

- *Sponge-like cluster of cysts.* Some complex cysts represent clusters of many small cysts. The size of the individual cysts can vary from too small to resolve to large enough to be easily demonstrated.

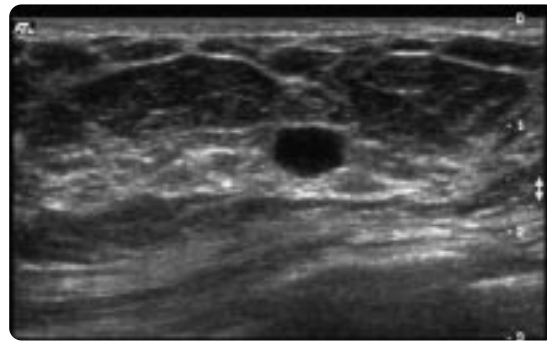


Figure 1. Radial image obtained with spatial compounding demonstrates the characteristics of a simple cyst.



Figure 2. Antiradial image demonstrates the several malignant characteristics in this invasive ductal carcinoma.

The number of cysts in the complex can range from just a few to several hundreds. When individual cysts are resolvable, the risk of malignancy is very low. However lesions with multiple unresolvable cysts cannot be distinguished from solid lesions.

- *Complex cyst with thickened walls.* Complex cysts with thickened walls or mural nodules are suspect for cystic malignancy and should be biopsied. Simple aspiration of the fluid is probably inadequate to exclude malignancy. A large majority of these cysts will be intracystic papillomas, but a small group will be intracystic papillary carcinomas.

Solid lesions

In the past, ultrasound was used simply to distinguish cystic from solid breast lesions, with no differentiation of solid lesions into benign or malignant [3]. Recently, B-mode characteristics of benign and malignant lesions have been evaluated, and lesions can now be characterized into BIRAD-like categories of benign, probably benign, indeterminate, probably malignant or malignant. Color Doppler evaluation of solid lesions has not been found sensitive enough to distinguish benign from malignant lesions. Evaluation of sonoelasticity and fremitus are being evaluated to determine whether they provide any additional diagnostic information on solid breast lesions.

If a lesion meets all the criteria for a simple cyst, there is virtually no chance of malignancy.

Complex cysts represent a heterogeneous group of entities with significantly different risks of malignancy.

Characteristic	Sensitivity	PPV	Relative risk
Spiculated capsule	36.0	91.8	5.5
Taller than wider*	41.6	81.2	4.9
Angular margins	83.2	67.5	4.0
Shadowing	48.8	64.9	3.9
Branching pattern	29.6	64.0	3.8
Markedly hypoechoic	68.8	60.1	3.6
Calcification	27.2	59.6	3.6
Duct extension	24.8	50.8	3.0
Microlobulation	75.2	48.2	2.9

Table 1. Malignant characteristics of solid breast nodules.

* 'Taller than wider' indicates that the nodule has a greater AP dimension than the transverse or CC dimension.

Figures on the sensitivity and positive predictive value of ultrasound findings for solid breast lesions were compiled by Stavros et al. in 1995 [2]. Their findings are shown in Table 1.

The 'taller than wider' characteristic, shown in Table 1, means that the nodule has a greater AP dimension than its transverse or CC dimension (Figure 2). This appearance is found in invasive cancer of the breast, and indicates that the lesion is growing *across* tissue planes rather than within them, and is more likely to be seen in malignant lesions than in benign lesions. Intraductal carcinoma may not demonstrate these findings. Such intraductal lesions may have duct extension, branch pattern, extension into ducts, or microlobulation. To demonstrate these findings, the lesion must be scanned in the plane of the ductal system (i.e. radially and anti-radially). The finding of one or more malignant characteristics in this series had a malignancy rate, proven by biopsy, of 73%.

Benign characteristics in solid lesions

The typical fibroadenoma is a well-circumscribed ellipsoid with a horizontal diameter greater than the AP diameter. Unfortunately, as fibroadenomas enlarge, they have a tendency to become multi-lobulated and more irregular in shape. Masses are most likely to be benign when they display one or more of the following characteristics: a well-circumscribed purely hyperechoic structure, a thinly encapsulated perfectly ellipsoid solid nodule, a thinly encapsulated well-circumscribed solid nodule with three or fewer smooth, gentle lobulations. If there are no malignant findings and the lesion

does not display any of these benign findings, the lesion should be classified as indeterminate.

ULTRASOUND-GUIDED BIOPSY

Ultrasound is excellent for real-time guidance of a needle for biopsy of a lesion. We find it more comfortable to the patient and less time-consuming than a stereotactic biopsy. The accuracy of ultrasound-guided biopsy has been confirmed in several studies [4]. Ultrasound-guided aspiration of cystic lesions is helpful in draining painful cysts, for diagnosis in complicated cysts, and for draining a cyst to determine if it corresponds to a mammographic abnormality.

TECHNOLOGY

Imaging of the breast requires a high-frequency transducer for maximal resolution. The minimum frequency recommendation is 10 MHz. Manufacturers continue to develop higher frequency probes that have better penetration and improved near-field imaging.

Harmonic scanning

Harmonic imaging is a scanning technique in which the image is generated from the 2nd harmonic frequencies returned to the probe. Many of the artifacts which degrade the quality of the image, such as clutter, are much less evident in the harmonic signal. This means that harmonic imaging of cysts is free of artifactual errors, making the diagnosis of a simple cyst easier.

Inverted phase imaging, i.e. pulse inversion, is a variant of 2nd harmonic imaging in which an image based on the 2nd harmonic image is generated by imaging with two pulses that are 180° out of phase. Linear signals, such as primary frequency imaging and most artifacts, are cancelled out when the two returning pulses are summed. However, non-linear signals such as the 2nd harmonic signals are not in phase, and therefore do not cancel each other out. This technique has been shown to greatly improve image quality.

Spatial compounding

Within the last few years, spatial compounding (SonoCT, ATL Ultrasound) has become available. The technique has been described in detail in a previous issue of Medica Mundi [5] and several recent publications have appeared on its clinical

Images generated from the 2nd harmonic frequencies are free of artifacts, making diagnosis easier.

SonoCT provides up to nine times more image information.

applications [6, 7, 8]. It creates real-time ultrasound images in which several (five to nine) images are acquired using different angles of insonation. The images obtained from the different angles highlight different segments of the reflecting interfaces. The set of images is then combined to provide a single composite image (Figure 3). The composite image has an improved signal-to-noise ratio and sharper borders, with reduced speckle and clutter. The technique is performed with preservation of frame rate, and contains up to nine times more tissue information than conventional ultrasound imaging.

- *Speckle*. Speckle is created by the interference of coherent waves. Sonographically, speckle can be visualized as small-scale brightness fluctuations or 'snow' superimposed on all parts of the image, but especially evident in homogeneous regions. Speckle also appears as small discontinuities in specular reflectors such as tissue interfaces and organ boundaries. The patterns of speckle are dependent on imaging specifics, such as view direction and wavelength. Speckle is a significant artifact in breast ultrasound because it reduces contrast resolution and obscures small structures. Compounding decreases speckle because images obtained from different view angles have different speckle patterns, which average out when combined in the final image.

- *Clutter*: Side lobes, grating lobes and reverberations, all of which are angle-dependent, cause clutter artifact. Clutter reduces contrast resolution and the ability to correctly identify anechoic structures. Compounding reduces this artifact by obtaining images from different viewing angles (Figures 4, 5).

The use of spatial compounding causes a change in the appearance of through-transmission and shadowing. Both through-transmission and shadowing are cast in the same direction as the ultrasound beam. Thus, compounding causes both through-transmission and shadowing to be dispersed over a wider angle with a lesser effect. The through-transmission and shadowing are concentrated behind the attenuating structure. This may create diagnostic problems when these artifacts are used to diagnose cystic structures or calcifications. If the conventional through-transmission or shadowing is needed for diagnosis, however, compounding can be turned off at the touch of a button, so that a conventional image can be obtained. Compounding can then be turned on again to continue scanning.

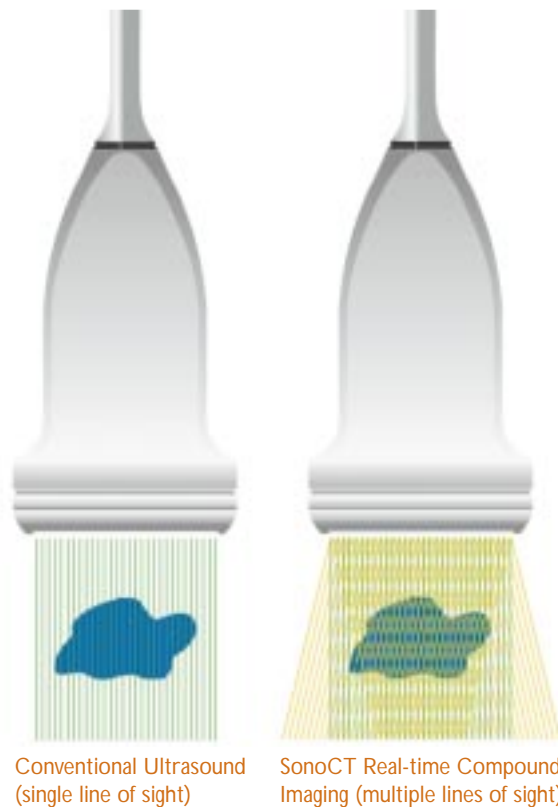


Figure 3. Principle of SonoCT technology imaging. Images obtained from different viewing angles are combined to produce a single composite image with improved signal-to-noise ratio and sharper borders.

Extended field of view

One of the problems with breast ultrasound is the difficulty in documenting the position of a lesion within the breast. If a lesion is to be followed up, or

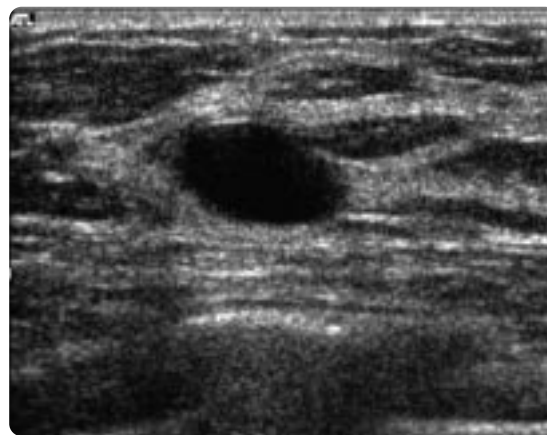


Figure 4. Breast cyst.

Figure 4a. Conventional image. Low-level artifactual echoes can be seen near the capsule of the cyst.

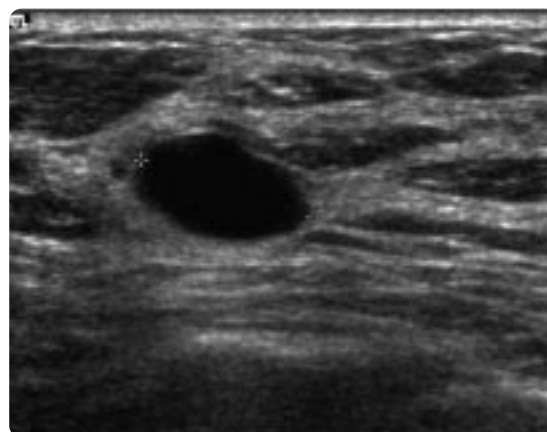
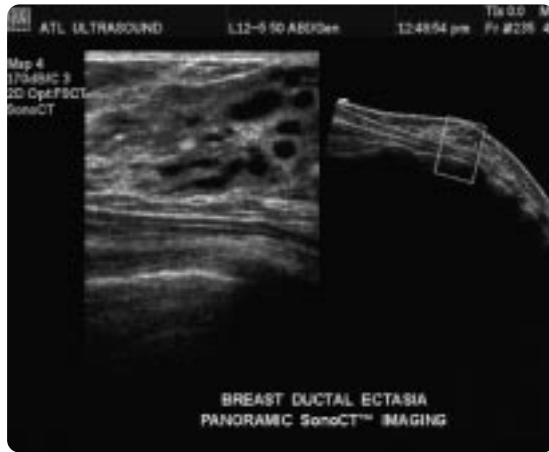


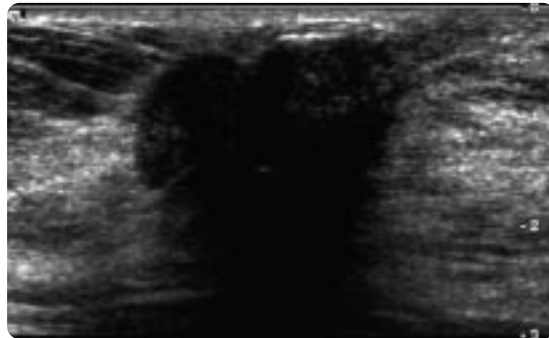
Figure 4b. Image of the same cyst as in Figure 4, obtained with spatial compound imaging. The artifactual internal echoes are removed, as is the speckle artifact throughout the image.

Figure 5. Extended field of view image of the breast, demonstrating the relationship of ductal ectasia to the remainder of the breast tissue.



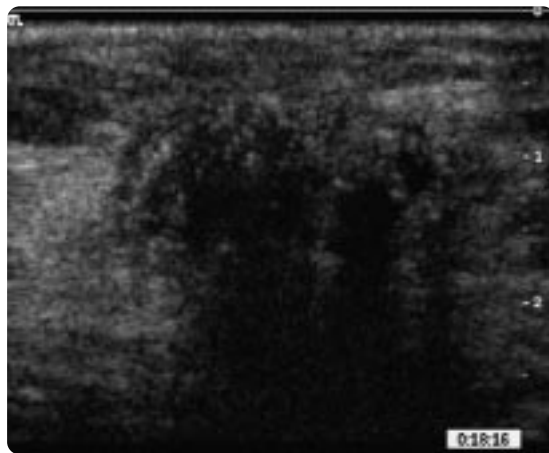
Extended field of view (Panoramic Imaging, ATL Ultrasound) makes it easier to document the exact location of a lesion and its relationship to other structures (Figure 6). Extended field of view is a technique in which a compound image is built from multiple images obtained during scanning. The resulting image resembles the static scans obtained with articulated arm scanners. The technique allows a plane through the entire breast to be obtained, including a marker such as the nipple. Accurate and reproducible measurements can be made from the marker.

Figure 6. Patient with a previous lumpectomy for malignancy.



Another technique which may help to determine the exact position and size of a lesion is 3D imaging. As 3D technology continues to improve, imaging is becoming more real-time, without the need for a workstation. The use of 3D may also make evaluation of the lobulation of a lesion more accurate. Volume measurement will be possible, allowing for more accurate follow-up measurements.

Figure 6a. Compound image of the breast. The scar demonstrates shadowing, as well as a hypoechoic area adjacent to the scar, corresponding to tumor recurrence found at biopsy.



FUTURE APPLICATIONS

With the increased resolution and improvement in near-field imaging, ultrasound is being evaluated as a screening tool in selected groups of patients. We routinely evaluate all palpable lesions that are not identified or characterized on X-ray mammography. For example, the accuracy of conventional X-ray mammography is reduced in premenopausal patients with dense breasts. Preliminary studies suggest that, in these patients, ultrasound may play a significant role in detection of breast cancers at an earlier stage than X-ray mammography. In general, however, ultrasound and X-ray mammography should be regarded as complementary rather than competing techniques, and results can often be improved by using the two techniques in combination. For screening of both breasts, a technique such as extended field of view or 3D imaging would greatly improve the recording and localization of breast structures for future comparison.

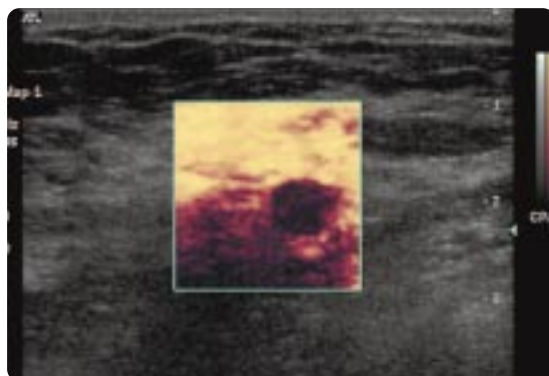
3D ultrasound may also allow for better follow-up of scars to make sure that the lesion is not growing. In patients receiving chemotherapy prior to surgery, 3D ultrasound could provide a better evaluation of size changes in the lesion.

Contrast agents

Ultrasound contrast agents are in various stages of development, and are approved for clinical use in

be matched to a lesion found on X-ray mammography, reproducible positioning is essential. While protocols to ensure reproducible positioning can be used consistently within a given institution, patients are often referred from external facilities, which can make localization difficult.

Figure 7. Power Doppler image obtained during patient's sustained hum (fremitus) demonstrating the decreased amount of tissue vibratory motion in the lesion as compared to the surrounding breast tissue.



many countries. These agents are stabilized microbubbles that are injected intravenously. They are true intravascular agents and have enhancement characteristics similar to MRI or CT. Preliminary work suggests that there may be an overlap of enhancement time and patterns between benign and malignant lesions as is seen in MRI [9]. This means that the role of contrast-enhanced ultrasound in routine evaluation of masses may be limited. On the other hand, contrast-enhanced ultrasound may be of value in evaluating surgical scars or determining the biopsy site in complex lesions. Figure 6a shows a case in which an enlarging surgical scar did not appear to change significantly on mammography. Contrast-enhanced ultrasound (Figure 6b) shows that the lesion has an area of enhancement. On biopsy, the area of contrast enhancement was shown to be a recurrence of breast cancer. Studies are under way to determine whether contrast-enhanced ultrasound will be useful in these specific applications.

Ultrasound elastography

Breast cancers are firm and less mobile than the surrounding breast tissue and fat. Elastography is a technique in which a low-frequency vibration (vibratory pulse, hum) is applied to the breast, and the movement of the lesions is evaluated using Doppler [10]. The breast fatty tissue and benign lesions move, and are therefore shown in color, while breast cancers are firm and immobile and are therefore not depicted in color. If this technique proves to be very sensitive, it may become an additional technique for breast screening. It is certainly very helpful in detecting lesions that are isodense to surrounding tissue. Figure 7 is an image of a breast cancer. The patient was asked to hum while the image was being acquired.

CONCLUSION

Breast ultrasound continues to improve in sensitivity and specificity. Newer techniques will expand the role of ultrasound in the detection and diagnosis of breast pathology. However, the best results can often be achieved by using ultrasound and X-ray mammography in combination. Breast ultrasound is expected to make the work of the radiologists and sonographers easier, enabling them to detect cancers at an earlier more curable stage, detect recurrences earlier, and significantly impact the treatment of breast cancer. In other words, there is every indication that breast ultrasound has a bright future.

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Ultrasound contrast agents have enhancement characteristics similar to MRI or CT.

Elastography distinguishes between elastic healthy tissue and less mobile tumors.

The best results are often achieved by using ultrasound and X-ray mammography in combination.