Review Article

Breast Sonography

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Sonographic equipment for breast imaging has continued to improve, and the role of breast sonography has evolved to that of an indispensable adjunct to mammography. Breast sonography is not useful for screening for breast cancer in any age group. Its main use is for the differentiation of cystic vs solid palpable and mammographically visible masses. If strict sonographic criteria are used for a simple cyst, the diagnostic accuracy approaches 100%. Sonographic diagnosis of a simple cyst precludes the need for further workup, including aspiration, biopsy, or follow-up. This article emphasizes the technical aspects of breast sonography, especially those factors that alter the diagnostic information on the images. These factors can be especially problematic in differentiating cysts and solid masses, the most common diagnostic use of breast sonography. Selection of equipment depends largely on the requirements of a specific practice. Optimally, the sonographic equipment is located close to where mammography is performed, and the sonographic and mammographic findings are interpreted together.

The breast was one of the first organs examined with sonography when in 1952 Wild and Neal [1] investigated the potential usefulness of A-mode techniques for defining the texture of normal breast tissue and breast lumps. Breast sonography came into wider use after the introduction in the 1970s of equipment specially designed for breast imaging [2–6]. In the late 1970s, because of nationwide concerns over the possibility of radiation-induced breast carcinoma from screening mammography, clinical research on breast sonography emphasized its potential use as a breast cancer screening tool [7–9]. Equipment for breast sonography has continued to improve; but rather than supplanting mammography, the role of sonography has evolved to that of an indispensable adjunct to mammography [10].

Current Role of Breast Sonography

Early clinical investigations of the value of sonography for breast cancer detection showed results approaching those of mammography [6, 9]. However, these clinical studies included many patients who were symptomatic, and the carcinomas generally were larger than those found in a screening population [11]. In addition, while the sonograms were usually of high technical quality and were obtained by the same technologist, the mammograms came from many different facilities and varied in quality. Later investigators reported poor results for sonography when compared with state-of-the-art mammography in the screening of asymptomatic women [10, 12, 13]. For example, in 1983 Sickles et al. [12] reported that in a prospective study of 1000 women, sonography detected only 58% of 64 pathologically proved cancers, compared with 97% detected by mammography. In that study, sonography detected only 48% of the cancers that had not yet spread to the axillary lymph nodes (mammography detected over 90%), 30% of the nonpalpable malignant lesions (mammography

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detected over 90%), and only 8% of the cancers smaller than 1 cm (mammography detected over 90%). Although anecdotal reports of sonographic detection of nonpalpable, mammographically normal cancers have continued to surface [14], the yield of sonography for breast cancer screening has been found to be too low to be of any practical value [10, 12, 13]. The limitations of sonography in screening for breast cancer include inability to depict microcalcifications, difficulty in imaging fatty breasts, inability to differentiate benign from malignant solid masses, and unreliable depiction of solid masses smaller than 1 cm.

Many breast carcinomas are infiltrating, and the sonographic appearance of these cancers is typically that of an irregular, hypoechoic (relative to surrounding parenchymal tissue) mass with inhomogeneous low-level echoes and a poorly visualized posterior wall (Fig. 1) [15]. The echoes distal to an infiltrating carcinoma are frequently diminished, and this "shadowing" had been identified as an important sign of malignancy [6]. However, many cancers have no effect on distal echoes, and some even show enhancement of posterior echoes [10, 16]. A review of 33 pathologically proved cancers depicted with a hand-held sonographic unit found that 19 produced no effect on posterior echoes, eight resulted in distal echo enhancement, and only six caused distal shadowing [10]. Diminished echoes may also be seen posterior to some fibroadenomas [17, 18]. Diagnosis of carcinoma by sonography is further complicated by the fact that some carcinomas, probably fewer than 10–15%, have sonographic features similar to those usually associated with benign solid masses such as fibroadenomas (Fig. 2) [10, 19]. Therefore, it is important that biopsy of a palpable or mammographically detected solid mass not be deferred solely on the basis of "benign" sonographic features.

Another problem that has received less attention is overdiagnosis resulting from the depiction of large numbers of benign solid masses detected incidentally by sonography, leading to "unnecessary" biopsies [20]. As a result of the nonspecificity of sonography in the evaluation of solid breast masses, in many clinical practices biopsies are performed on all masses that are shown to be solid. However, the rate of cancer detection (number of cancers detected over total biopsies performed) resulting from the biopsy of nonpalpable well-circumscribed mammographically undetected masses by using sonography is unacceptably low [10, 11, 21].

Although sonography has been shown to have no role in screening, it is occasionally useful in the evaluation of selected patients with suspected carcinoma. For example, it may help in localizing a suspicious mass detected in only one mammographic projection [22]. However, this is usually accomplished more effectively with additional mammographic positioning [23]. Some radiologists use sonography for the evaluation of an asymmetric density identified by mammography; however, there is no evidence, other than anecdotal, to prove the efficacy of the use of sonography for this purpose and it is not currently recommended [24]. Not only is sonography ineffective in identifying nonpalpable carcinoma in these cases, but a normal-appearing sonogram does not exclude the possibility of carcinoma.

Sonography has been recommended as the primary imaging technique for women younger than 30 with breast problems [11, 25]. The rationale for this approach in younger women includes the lower prevalence of breast cancer, the greater likelihood that the breasts will be dense and poorly suited to mammography, and greater susceptibility to radiation-induced malignant tumors [26, 27]. When a simple cyst is identified at the site of a palpable abnormality, mammograms are not necessary. When sonography does not show a cyst, the mammographic workup in the woman under 30 is tailored to the clinical findings and usually begins with an oblique view of one breast [11]. In a review of 389 women under 35 who had undergone sonographic examinations, sonography, although useful in preventing excisional biopsies of simple cysts, was not reliable in differentiating benign from malignant solid masses [27].

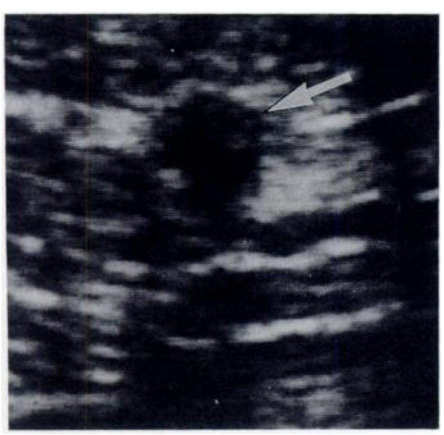


Fig. 1.—Sonogram of infiltrating ductal carcinoma. Mass (*arrow*) has an irregular border, inhomogeneous low-level interior echoes, and poorly defined posterior wall. Note attenuation of echoes posterior to tumor (shadowing).

Fig. 2.—Sonogram of well-circumscribed ductal carcinoma. Mass (*arrow*) has a relatively smooth border, homogeneous internal echoes, and well-defined posterior wall. Note accentuation of echoes posterior to tumor (enhancement).

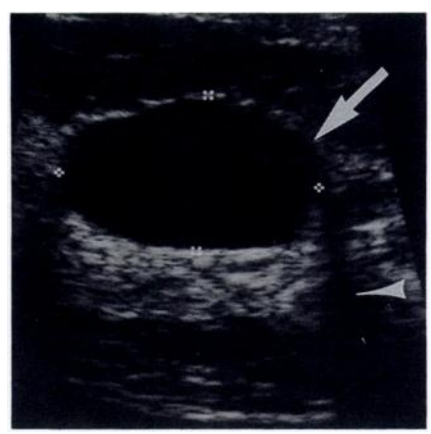


Fig. 3.—Sonogram of typical cyst. Oval mass (*arrow*) has well-defined anterior and posterior borders, anechoic interior, and enhanced through-transmission of sound distally. *Arrowhead* indicates refractive shadows distal to lateral wall of cyst.

Today, the primary role of sonography is in the cyst vs solid differentiation of palpable and mammographically detected masses. In the diagnosis of a simple cyst, sonography has a reported accuracy of 98–100% [21, 28, 29]. Typical features of cysts include round to oval shape, well-circumscribed margins, anechoic interior, and increased through-transmission of sound (Fig. 3). Additional features that may be seen include refractive shadowing posterior to the lateral margins of the cyst, compressibility, and the presence of septa within multiloculated cysts. Although the detection of solid masses smaller than 1 cm is unreliable, because the mass may have an echo intensity similar to that of surrounding breast tissues, cysts as small as 2 mm can be detected easily because the anechoic interior of a cyst provides high contrast with adjacent breast parenchyma [10]. In addition, the increased intensity of echoes distal to a cyst enhances its identification.

The sonographic demonstration that a mammographically detected mass is a simple cyst eliminates the need for any further workup, including aspiration, biopsy, or follow-up [29]. A simple cyst is defined as one with smooth margins, a well-defined posterior wall, enhanced sound transmission distally, and, most importantly, an echo-free interior when imaged with appropriate technical parameters (Fig. 3). By showing that a mammographically detected mass is a simple cyst, sonography can decrease the number of needle localizations and biopsies that need to be performed by 25% [29]. However, it is important to be certain that a mass demonstrated by sonography is the same mass as the mammographically detected one. This can be accomplished by placing a radiopaque marker over the location of the mass with sonographic guidance, and then repeating the mammogram with the marker in place [11].

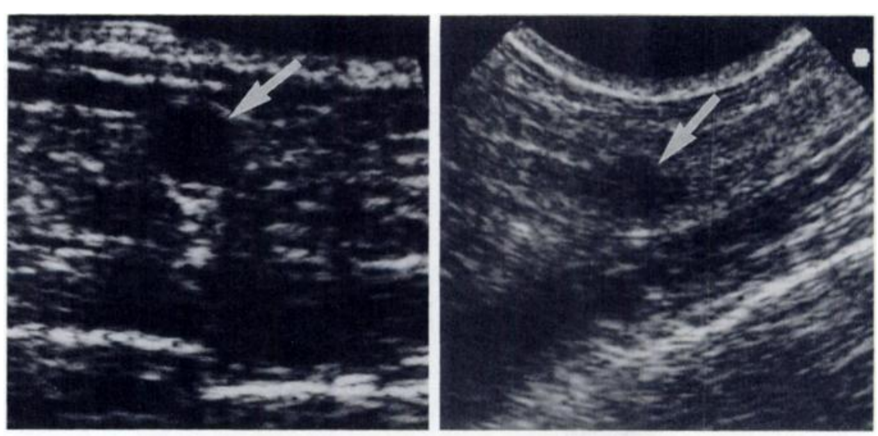
Technical Factors and Equipment

In order to use sonography effectively it is important to understand the technical factors that affect the images, and breast sonography presents several technical challenges. For example, breast tissue is heterogeneous, resulting in rapid diminution of the beam owing to reflection and scattering from the many impedance mismatches of tissue interfaces. Extensive refraction from curved breast tissue interfaces adds to beam defocusing [30]. These problems have resulted in the development of tightly focused, large-aperture, high-frequency transducers capable of depicting the smaller breast structures. Additional technical factors to be considered in breast sonography include imaging lesions in the focal zone of the transducer and selecting proper power, time-gain compensation, and gray-scale mapping.

Masses located in the superficial breast tissues may be distorted or missed because they are in the near field of the transducer [31–33]. The heterogeneous intensity pattern of the beam in the near field may cause echoes from surrounding tissues to appear within a cyst, suggesting that it is a solid mass (Fig. 4). For this reason, a satisfactory breast examination with a hand-held transducer requires either the use of a fluid offset (a degassed water-filled bag placed between the transducer and the breast or a commercially produced offset device) or a transducer with a built-in fluid offset [32, 33]. Transducers of automated whole-breast sonographic units are positioned within a water bath and separated from the surface of the breast, and imaging of the superficial tissues with these whole-breast units is less problematic than with a hand-held sonographic probe.

Masses deep in the breast may also be distorted owing to the diverging beam that degrades lateral resolution. This distortion may take the form of blurring of the margins of masses, filling-in of shadows behind small masses, and failure to resolve smaller masses. With a hand-held transducer, the focal zone can be repositioned for deeper breast tissues by moving the transducer to a closer breast surface, moving the patient, or by applying greater compression with the transducer. Transducers of automated scanners are moved closer to or farther from the breast within the water bath to position the focal zone.

Power, sometimes referred to as sonic intensity, output power, percent power, or dB, is the amount of voltage applied to the transducer to produce the ultrasound wave that enters the breast [34]. The amount of power determines the distance



A B

Fig. 4.—Sonograms of 0.5-cm superficial cyst (*arrows*) imaged with 7.5-MHz transducers with and without built-in fluid offsets.

***A*, Transducer with fluid offset shows anechoic interior of cyst.**

***B*, Transducer without fluid offset shows artifactual echoes throughout cyst.**

the wave travels before it is completely attenuated. A power setting that is too high results in (1) saturation of the amplifier, giving an excessively bright image without texture or variations in gray scale, and (2) amplification of all the dampened cycles in the short pulse of ultrasound emitted by the transducer so that resolution perpendicular to the transducer face (axial resolution) will be degraded. Thus, the operator should keep the power as low as possible, consistent with penetration to the chest wall.

Time-gain compensation, or depth-gain compensation, is an increase in amplification of waves returning from the deeper tissues to compensate for their greater attenuation. For breast imaging, the time-gain compensation is adjusted by the operator of hand-held units according to breast density and size; denser breasts require a time-gain compensation curve that is steeper than less dense breasts. The use of higher-frequency transducers results in greater beam attenuation and also requires a steeper time-gain compensation slope. When the time-gain compensation curve is too steep, the amplification capacity may be exhausted, resulting in inadequate depiction of the deep tissue. Furthermore, shadowing or enhancement behind masses may not be depicted.

Gray-scale mapping circuitry in the sonographic instrument converts received voltages into discrete shades of gray based on their amplitude. The relationship of the voltage to the assigned shade is the gray scale. Linear gray-scale maps assign the same relative number of gray levels to low- and high-amplitude reflections. Logarithmic, sometimes referred to as root, exponential, or quadratic gray-scale, maps assign more gray-level values to low-amplitude reflections, thus increasing image contrast. However, nonlinear gray-scale maps may fill in anechoic masses with artifactual echoes not seen when a linear map is used.

Selection of Equipment

Selection of equipment for breast sonography depends on many factors, including the number of examinations performed, financial limitations, space constraints, and personal preferences. Automated units produce whole-breast images in overlapping sequential slices that allow easy localization of abnormalities. However, an automated unit is likely to be more expensive and requires more space, a specially trained technologist, and more time for setup, performance, and review of the examination. It also may be more difficult to ensure that a palpable mass matches a sonographically depicted cyst. Currently, the only available automated instru-

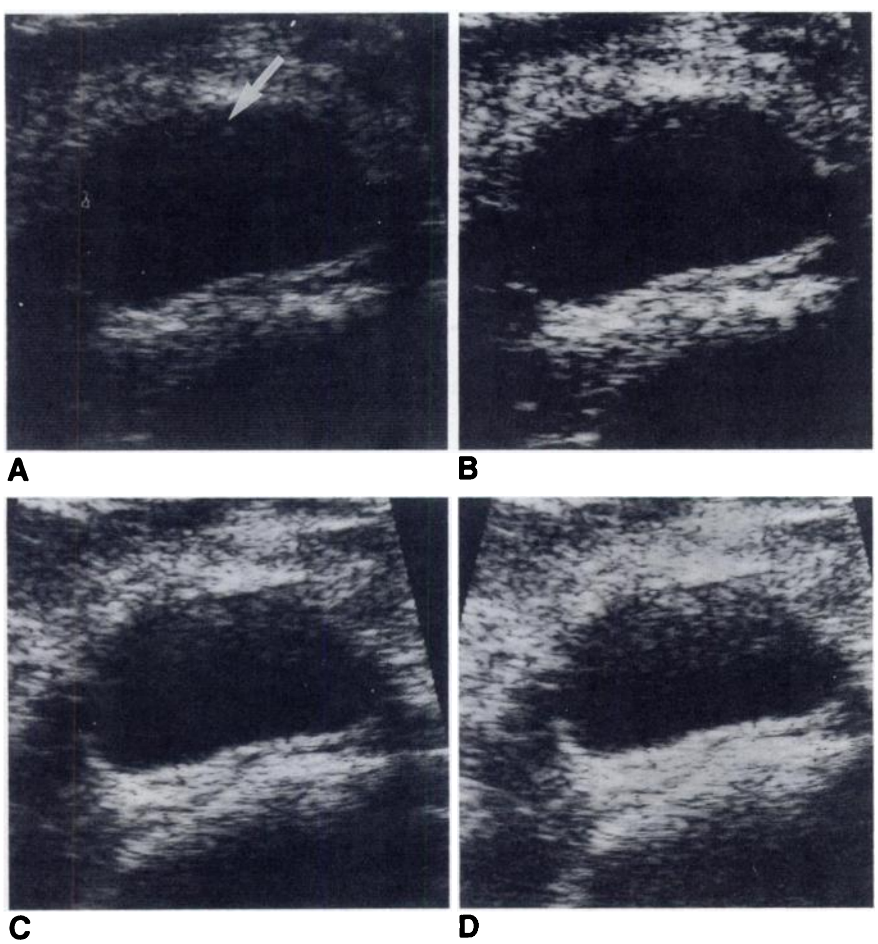


Fig. 5.—Sonograms of cyst. Effects of changing sonographic power and gray scale.

***A*, Cyst has an anechoic interior, except for reverberation echoes (*arrow*) in anterior portion.**

***B*, Same power setting as *A*, gray-scale map changed from linear to logarithmic. Echoes in anterior portion of cyst are more obvious. Overall brightness of image is increased.**

***C*, High-power setting, linear gray-scale map. Echoes fill in anterior half of cyst interior.**

***D*, Same power setting as in *C*, gray-scale map changed from linear to logarithmic. Echoes are visible throughout cyst, although they are brighter anteriorly.**

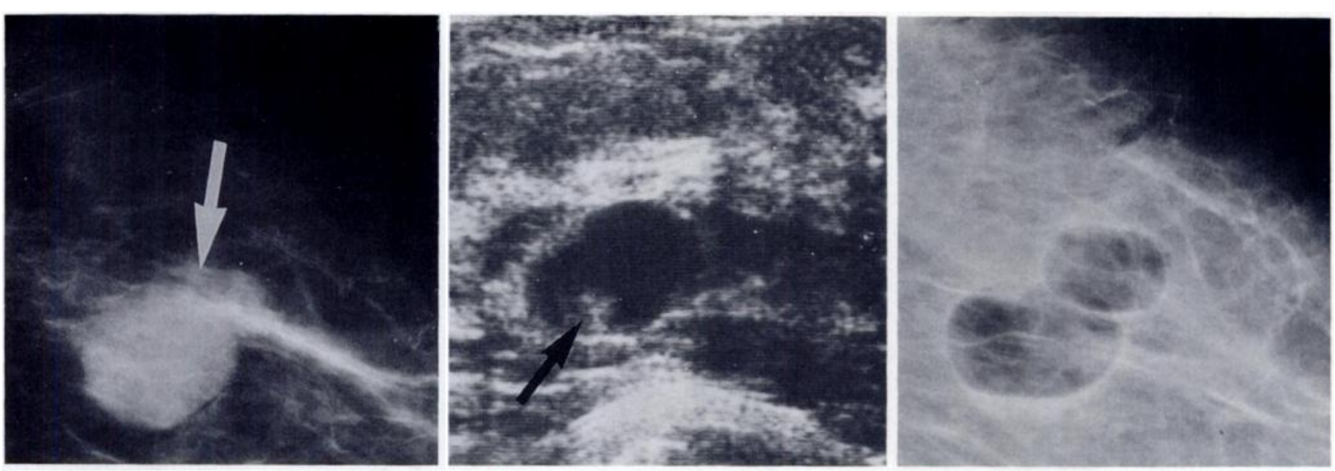
ment is the Labsonics dedicated water-path breast unit (Labsonics Inc, Mooresville, IN). With this automated scanner, examinations can be limited to a localized area of the breast.

Because the major indication for sonography is cyst vs solid differentiation of a palpable or mammographically detected lesion, most breast sonography is performed currently with hand-held units applied directly over the area of interest [35]. The advantages of hand-held units are that they are usually less expensive, smaller, portable, faster, and adaptable for sonographically guided needle aspiration or prebiopsy hookwire localization. The radiologist may elect either to have a small inexpensive hand-held unit permanently located near or in the mammography room or to transport the patient to an area where general sonographic examinations are performed. In either case, the instrument used for breast examinations should be a small-parts (high-frequency) unit with adequate power and time-gain compensation to penetrate 5 cm of breast tissue. Sonographic examinations can be performed by the radiologist or a technologist under the radiologist's direct supervision. If mammography technologists perform the examination, they should receive special training, including correct scanning techniques and basic understanding of the physics of sonography and how it affects breast imaging. Although multipurpose sonographic equipment can cost more than $100,000, small units appropriate for breast imaging are available for $30,000 to $40,000. A multiformat camera, rather than a Polaroid camera, which has limited gray-scale range, is also needed. Several linear- and phased-array units are suitable for breast sonography, as long as they are equipped with a 5.0- or 7.5-MHz transducer, and a 1-cm offset is available for imaging superficial tissues. Mechanical transducers for breast imaging should have a 7.5- to 10.0-MHz transducer, a fluid offset, and a soft membrane separating the standoff fluid and the patient to avoid reverberations in the near field. Annular arrays are excellent for breast imaging, but should be 5 MHz or higher. The annular array is a hybrid transducer, combining the variable focusing property of a phased-array with the mechanical sweep and fluid offset of a mechanical transducer.

Fig. 6.—Section from automated whole-breast sonographic examination shows a cyst 2 weeks after several unsuccessful attempts at needle aspiration. Gravity-dependent debris (*arrow*), believed to be due to trauma of attempted aspirations, is layered at bottom of cyst.

Problems in Cyst/Solid Differentiation

The presence of artifactual or real echoes within cysts is one of the most frequent dilemmas encountered when performing breast sonography. Frequently this dilemma can be resolved by adjusting technical factors affecting the image, patient positioning maneuvers, or correlation of the sonographic results with mammographic findings and clinical data.



A B C

Fig. 7.—Loculated cyst.

***A*, Lateral mammogram shows lobulated mass (*arrow*).**

***B*, Sonogram reveals anechoic center and a small nodule (*arrow*) projecting from wall, suggesting intracystic tumor.**

***C*, Pneumocystogram, cyst aspiration followed by insufflation with air, shows a multiloculated cyst containing septa, responsible for apparent nodule seen in *B*.**

In the near field of the transducer, irregularity of the ultrasound wavelets may cause apparent echoes within a cyst (Fig. 4). In addition, because the beam is wider than in the focal zone, the edge of the beam may strike a random scatterer outside of the cyst, and these echoes may be displayed as coming from within the interior of the cyst. Phased-array transducer elements are rectangular, with the long dimension parallel to the slice thickness; the thickness of the slice of the image plane contributes information to the image. Unlike lateral resolution, which can be varied electronically in a phased array, slice thickness resolution is controlled by a fixed-focus lens. Phased-array probes almost always image superficial masses improperly unless a transducer offset device is used to bring the mass into the slice thickness focus. When using mechanical-sector transducers, near-field reverberations may be severe if hard plastic is used to separate a built-in fluid offset from the breast. Thus, a soft membrane should be used to separate the transducer from the breast surface. For similar reasons, artifactual echoes can also be seen when a cyst is imaged in the far field of the transducer.

One of the most common causes of artifactual echoes is the use of an inappropriately high power or time-gain compensation (Fig. 5). In general, increased power or time-gain compensation will fill in the anterior portion of a cyst first, and the posterior boundary of the cyst will continue to be well defined. Changing the gray scale or gray-scale dynamic range in order to increase contrast will also cause the center or all of the interior of a cyst to be filled in with fine textured noise.

A faulty electrical board can also result in artifactual echoes in a cyst, and equipment failure should be suspected when several consecutive masses expected to be cysts show an internal echo structure.

Echoes in a cyst can represent debris. The diagnosis of a cyst is still tenable if these echoes can be seen to move within the cyst fluid during continuous hand-held real-time scanning while the patient's breast is moved. Gravity-dependent debris may be observed layered at the bottom of the cyst.

Patients may be referred for sonography after unsuccessful attempts at needle aspiration. Unfortunately, repeated attempts at aspiration can result in considerable distortion in the breast parenchyma and may cause echoes to appear within a cyst [31]. It may be necessary to repeat the sonography 2–3 weeks later to show resolution of traumatically induced echoes in a cyst, or layering of blood or debris (Fig. 6). Preferably, mammography and sonography should be performed before attempted aspiration of masses that are not readily palpable.

Septa within multiloculated cysts are usually recognized as thin linear bands crossing the cyst interior. Occasionally, a septum will appear to be a nodule in the cyst wall (Fig. 7). Again, repeated real-time scanning while repositioning the transducer in the planes of the cyst may resolve this problem by showing the septum in a plane that makes it recognizable.

The sonographic demonstration of an echogenic mass projecting from the wall of a cyst should raise the possibility of intracystic carcinoma (Fig. 8). Breast carcinoma arising in the wall of a cyst is rare, representing only about 0.5% of all breast cancers [36, 37], but cystic degeneration of previously noncystic carcinoma can have a similar appearance. Because they are freely movable on physical examination, well circumscribed on mammography, and contain fluid on sonography, they may be dismissed as benign masses. Intracystic carcinomas are usually larger than 3 cm when biopsy is performed. To avoid delaying the biopsy of an intracystic carcinoma, or a well-circumscribed carcinoma with only a few visible internal echoes, it is important that strict criteria be used to make the diagnosis of a simple cyst. If a benign cause, such as technical factors, debris, or a septum, cannot be determined to explain echoes in a cystic mass, aspiration [38], pneumocystography (Fig. 7C) [39], or excisional biopsy should be performed.

Posterior enhancement, considered to be a hallmark of cysts, may not be visible on all scans. Hilton et al. [29] showed posterior enhancement to be present to a variable degree in 78 of 80 cysts. However, in 25% of these cases posterior enhancement was not seen on all images. Slight changes in

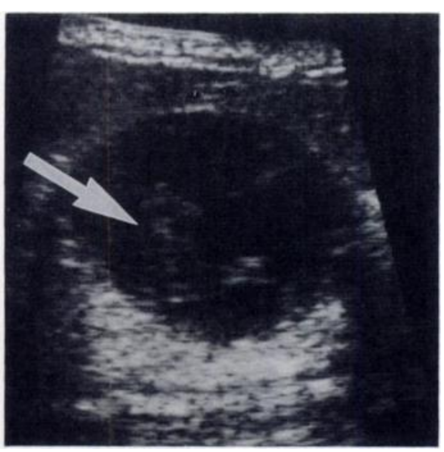
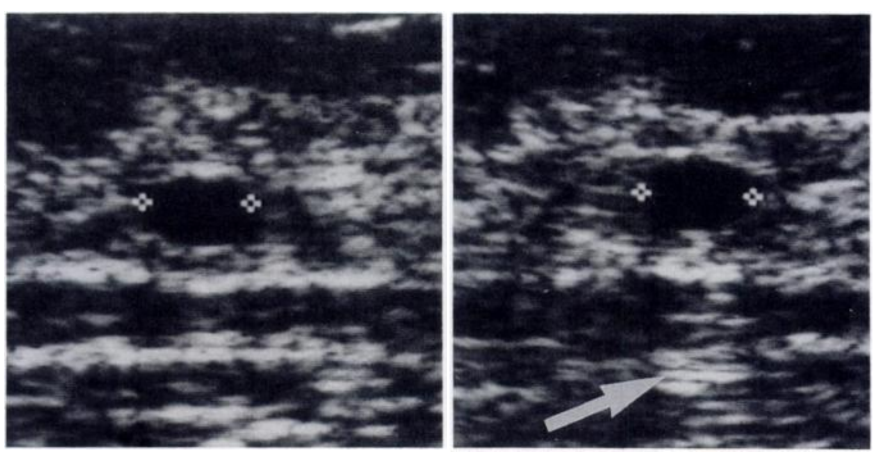


Fig. 8.—Sonogram of intracystic carcinoma. Echogenic tumor (*arrow*) is growing in wall of cyst.



A B

Fig. 9.—Sonograms of 0.5-cm cyst showing variable distal echo enhancement.
A, **Cyst (*between cursors*) interior is clearly anechoic, but distal echo enhancement is not seen.**
B, **Same cyst, imaged with slightly less transducer compression and a slight change in direction of ultrasound beam. Distal echo enhancement (*arrow*) is demonstrated.**

transducer positioning may affect the depiction of enhancement of echoes distal to a cyst (Fig. 9).

The Future of Breast Sonography

Although sonography is limited to cyst/solid differentiation in most radiologic practices today, improvements in equipment and greater experience in the evaluation of combined mammographic-sonographic examinations may eventually expand the specificity of sonography for the evaluation of solid masses, further reducing the need for excisional biopsies (Fig. 4) [40, 41]. The use of breast sonography to guide cyst aspiration, prebiopsy needle localization, and fine-needle aspiration biopsy is increasing [42, 43]. For these procedures, a hand-held 7.5-MHz or higher-frequency transducer should be used, preferably with a biopsy guide [38]. However, at this time, mammographic localization techniques are more reliable and sonographically guided procedures are usually limited to cases in which the lesion is not visible mammographically [44].

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