



# The History of Breast Ultrasound

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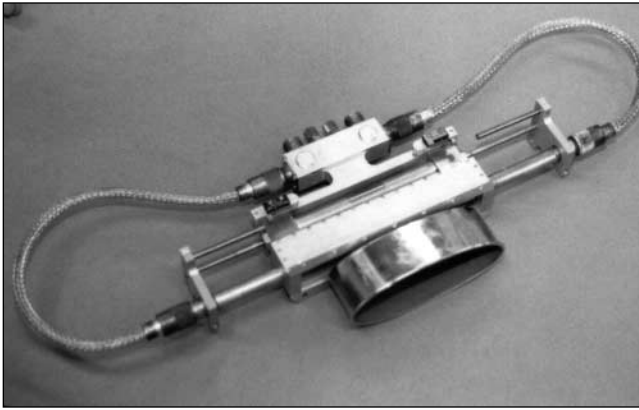
**R**emarkably, sonography of the breast has been performed both in vitro and clinically for 53 years. Initially little more than a curiosity, it became regarded as a possible means of distinguishing between benign and malignant lesions, a goal that many imaging methods have unsuccessfully tried to achieve over the years. Later in the evolution of breast ultrasound, iterations of “automated” devices, designed in theory to completely scan all the breast tissue, briefly generated hopes of a screening method that could replace x-ray mammography. Breast ultrasound has now come full circle to a method that is viewed as the most important adjunctive breast imaging method available and that also serves as the most common guidance system for percutaneous breast biopsy and preoperative localization. The history of this valuable breast-imaging method is important in framing an understanding of the key role it now holds.

## The Early Times

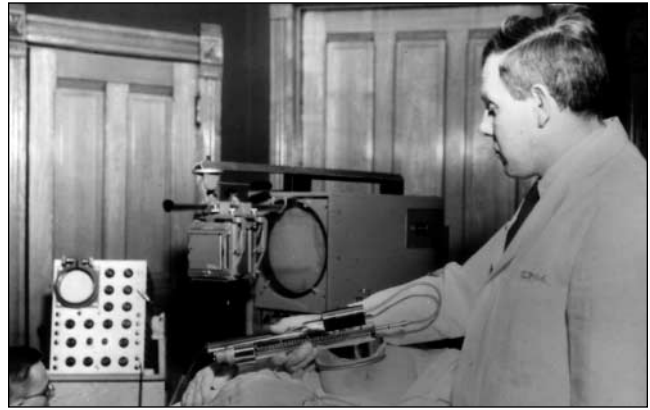
Originally a military modality used to detect metal flaws, the technology of high-frequency ultrasound was released for general use after World War II. In 1951, Wild and Neal<sup>1</sup> described the acoustic characteristics of 2 breast tumors, 1 benign and 1 malignant, in the intact, in vivo breast. Using a very rudimentary high-frequency (15-MHz) system producing an A-mode sonogram, 3 different acoustic signatures were described on the basis of the measured acoustic impedance for normal breast tissue, for benign tumors, and for malignant tumors. In 1952, Wild and Reid<sup>2</sup> published the results of ultrasound examinations in 21 breast tumors, 9 benign and 12 malignant. Two of those cases became the very first 2-dimensional echograms (B-mode sonograms) of breast tissue ever published.<sup>2</sup> The following year, Howry et al<sup>3</sup> published 2-dimensional images of in vitro breast tumors using a lower-frequency pulse echo scanner with focusing elements within it designed to reduce beam width. Both of these modifications produced images of better diagnostic quality (Figure 1, A and B).

The first clinical application of breast ultrasound was reported in 1954 by Wild and Reid.<sup>4</sup> The early research in sonographic breast imaging did not consider that this modality might be used as a screening tool. It was quite the opposite. Wild and Reid stated, “The investigation was not planned to detect tumors and was not necessarily intended to replace existing methods of diagnosis of breast lesions.”<sup>2</sup> The focus was, however, clearly on the goal of distinguishing between benign and malignant breast lesions, and the results were remarkably accurate in this regard. Wild and Reid were

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**A**



**B**

**Figure 1.** **A**, Dr Wild's clinical B-mode instrument, completed 1951, now in Wild's possession in Minneapolis. It is pictured here without its original attachments to electronic or mechanical systems. This instrument, like its predecessor, was fabricated entirely by Wild and Reid. [Photograph taken by Ramunas Kondratas, Smithsonian Institution, November 17, 1987, courtesy of Dr John J. Wild.] **B**, Dr Wild (right) applies the second incarnation of his and Reid's B-mode scanner to a patient's breast, as J. M. Reid works the controls (bottom left). This instrument, according to Dr Reid, was the world's first clinically operational real-time compound scanner. Photographs and legend reprinted with permission from *Medical Diagnostic Ultrasound: A Retrospective on Its 40th Anniversary*, published by the American Institute of Ultrasound in Medicine in collaboration with Eastman Kodak Company; 1988.

accurate in preoperatively characterizing 12 of 12 malignant tumors (11 ductal carcinomas and 1 sarcoma) and 9 of 9 benign tumors (Figure 2).<sup>2</sup>

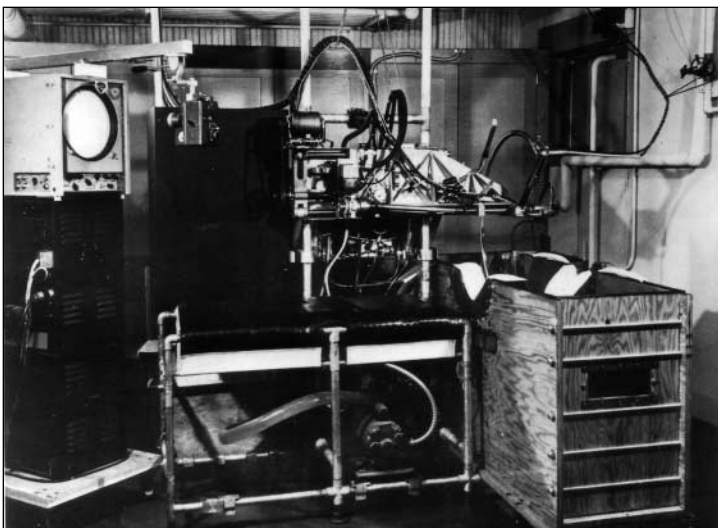
After these initially favorable studies, technical improvements began to be made in sonographic equipment. In 1969, DeLand<sup>5</sup> published an article in which he scanned a total of 19 breast cancers, 16 ductal and 3 medullary. He had made several

equipment modifications, which included a 2.5-MHz B-mode system with a 5-crystal array, 1 emitting and 4 receiving. The emitting crystal was unfocused, but with a collimator applied to the face, some control of the lateral resolution was achieved. In addition, DeLand used a supine, single-breast water path technique, resulting in no distortion of the skin contour. His results were quite accurate in characterizing the ductal carcinomas, correctly identifying 15 of the 16 preoperatively. All 3 of the medullary carcinomas, however, were missed. We now understand that the error resulted from the fact that medullary carcinoma, a homogeneous highly cellular type of tumor, usually exhibits through-transmission rather than shadowing. Medullary carcinoma again appeared as a characterization stumbling block in 1976, when Calderon et al<sup>6</sup> studied 18 breast tissue samples: 2 normal, 7 benign, and 9 malignant. Eight of the 9 carcinomas were correctly characterized, the single error being in the 1 medullary carcinoma.

### Development Around the World

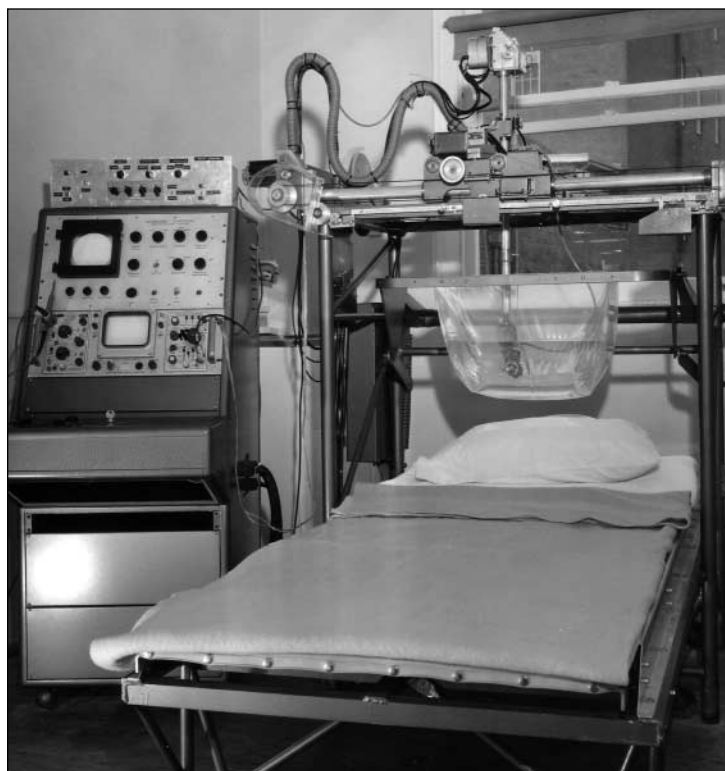
During the 1960s, continuing research work on breast ultrasound was centered in 3 main areas of the world: Australia, the United States, and Japan. In Australia, the first ultrasonic breast scanner was installed at the Royal North Shore Hospital in Sydney in 1966. It was a bistable machine capable

**Figure 2.** Equipment designed and constructed by Dr John Wild for mass screening for breast cancer. The water tank across which the patient was to be suspended is at left. [Photograph courtesy of Dr John J. Wild.] Photograph and legend reprinted with permission from *Medical Diagnostic Ultrasound: A Retrospective on Its 40th Anniversary*.



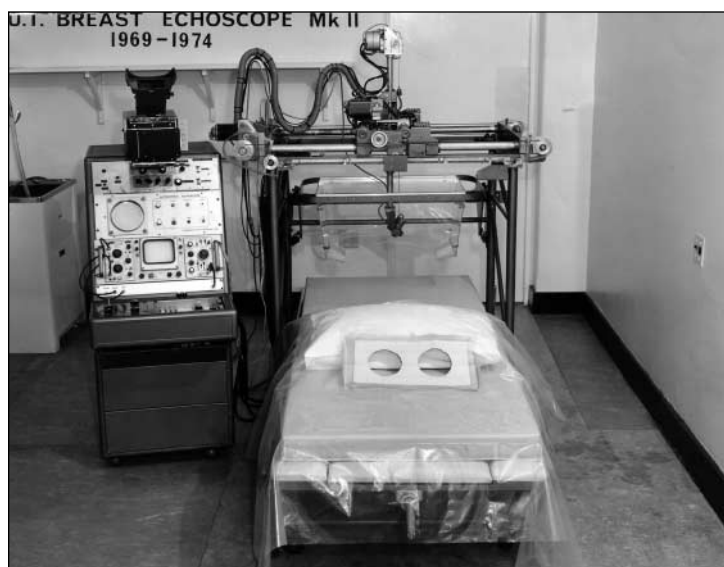
of imaging in linear, sector, and compound scanning modes. A major improvement occurred in 1969 with the introduction of gray scale imaging. Kossoff, Jellins, and their associates at the Commonwealth Acoustic Laboratories incorporated a gray scale technique and a focused array format and also described the principles of gray scale sonography for all soft tissues (Figures 3 and 4).<sup>7-10</sup> In the United States, Kelly-Fry et al,<sup>11,12</sup> in developing an online, computer-controlled system in the late 1960s, signaled a change in emphasis from tissue characterization of known masses to an effort toward the early detection of subclinical breast lesions. She and her associates were the first to examine the breast in asymptomatic women of different ages. They were able to identify the different structural elements of the mammary gland by the echogenic patterns generated in studies of patients in 3 different age groups. This was the first attempt made to study asymptomatic, healthy women with sonographic techniques, and it is considered the pioneer effort in the correlation of sonographic patterns with histopathologic findings in the breast.<sup>13</sup> The work of Kelly-Fry and Kossoff showed small differences in ultrasound velocity in the breasts of patients studied at different ages and in the presence of different pathologic processes.<sup>14</sup> This was duplicated by Calderon and his group in 1976, when in vitro measurements of acoustic attenuation were found to differ in various pathologic states, with malignant lesions exhibiting the highest attenuation values.<sup>6</sup>

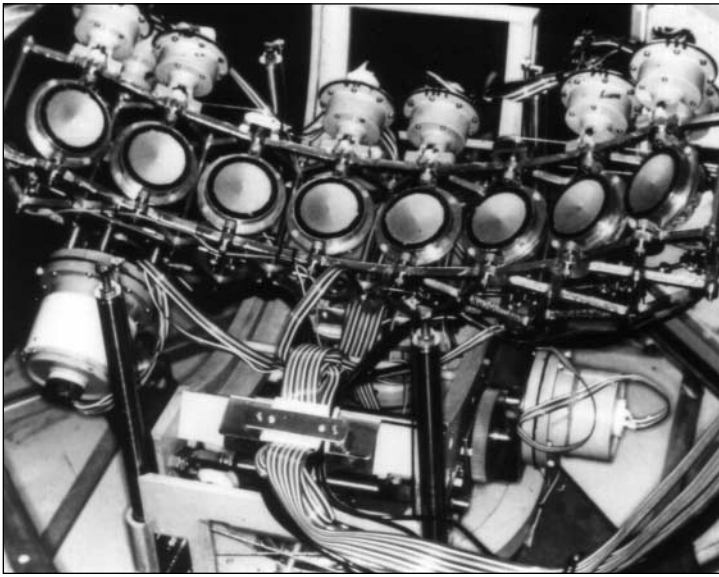
During the 1960s, Wells and his group in England constructed a machine, unique at the time, which used a prone scanning technique with the patient's breast suspended in a temperature-controlled water bath.<sup>15</sup> Only 1 published study emerged from this effort, however, but their design was incorporated in the Octoson scanner developed by Kossoff and Jellins in Australia (Figures 5-7) and in the automated scanners developed by the Life Imaging Corporation<sup>16-19</sup> and by Johnson & Johnson (New Brunswick, NJ) (subsequently by Technicare Corporation, Australia)<sup>20-22</sup> in the United States. All these were developed and marketed in the late 1970s. As a result of the continuing work done by Kelly-Fry in Indiana, a water-coupled commercial instrument in which the patient lay supine on the examining table was marketed by Labsonics (Australia) in the 1980s (Figures 8 and 9).



**Figure 3.** Jellins' first breast scanner, designed by Kossoff, Jellins, and the staff of Australia's Ultrasonics Institute, showing the enclosed water bath that was lowered across the patient's chest; the transducer mechanism is visible within the water bath. Photograph and legend reprinted with permission from *Medical Diagnostic Ultrasound: A Retrospective on Its 40th Anniversary*.

**Figure 4.** The second of the UI (Ultrasonics Institute) breast scanners used by Jellins. The breasts entered the water bath from below to assume buoyancy. The water bath housing is above the head of the bed-table; the lower segment of the housing, which sealed the tank and through which the breasts entered the water, is shown on the examining table. Photograph and legend reprinted with permission from *Medical Diagnostic Ultrasound: A Retrospective on Its 40th Anniversary*.

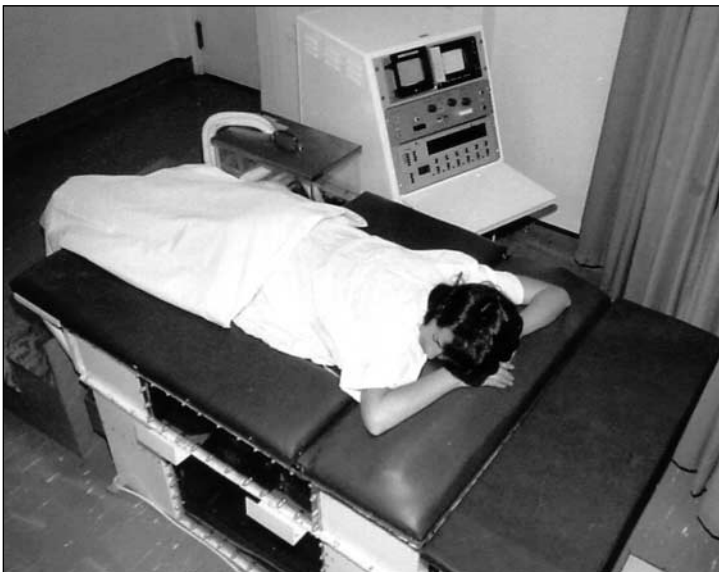




**Figure 5.** The eight transducers that were mounted within the Octoson's water bath. Photograph and legend reprinted with permission from *Medical Diagnostic Ultrasound: A Retrospective on Its 40th Anniversary*.

The issue of transducer design and beam characteristics became a paramount focus for the Canadian group headed by Foster and Hunt<sup>23-26</sup> and for the Indiana-based group of Kelly-Fry.<sup>11,12,27-29</sup> Both groups showed that resolution was not solely determined by frequency. Higher levels of resolution could be achieved without

**Figure 6.** The original Australian-developed Octoson breast scanner, 1975. [Photograph courtesy of Dr George Kossoff.]



changing the frequency but closely regulating lateral resolution, transducer diameter, and focal length.

A substantial amount of research in ultrasound took place in Japan in the 1950s and 1960s, and interest in breast cancer detection appeared in work from Kikuchi, et al.<sup>30</sup> They were later joined by J. Takada, H. Ito, H. Yokoi, K. Takahashi, S. Hayashi, and T. Kobayashi. In the early 1970s, most of the published work came from Japan and dealt with the ultrasonic characteristics of benign versus malignant breast disease. Articles by Kasumi et al<sup>31</sup> and Kobayashi et al<sup>32-35</sup> dealing with this topic reviewed and examined approximately 23 different diagnostic criteria for the possible differentiation of benign from malignant breast tumors. In these publications, the characteristic of acoustic shadowing became synonymous with malignancy, a concept later to be much more carefully refined. The emphasis from the Japanese literature was on the use of a single focused transducer designed to examine the supine patient using a water bag as a coupling agent. Examination of the breast in this manner used higher-frequency transducers than used previously ( $\approx 5$  MHz) and achieved resolution of approximately 2 mm.<sup>34</sup> During this time, Japanese investigators also developed color display systems and also began the regular clinical use of breast ultrasound.<sup>31,32,35</sup>

### The Digital Age and Technological Revolution

The early 1980s brought digital technology to the field of ultrasound in general and breast ultrasound in particular. Having a digital rather than an analog signal opened the door for numerous immediate improvements in resolution based on beam shaping as well as signal processing. Later, in the early 1990s, digital beam formers and broad-bandwidth capabilities led to developments such as tissue harmonics and real-time spatial compounding.

### Tissue Harmonics and Spatial Compounding

Two direct benefits of digital technology affecting breast imaging were the development of tissue harmonic scanning and spatial compounding. Each represented the 2 ends of the bell-shaped curve of signal processing. Tissue harmonic scan-

ning was devised as one way to compensate for ultrasound's multiple scattering artifacts, which then produces an image with reduced noise by narrowing the main beam and reducing side lobes.<sup>36</sup> It was originally developed as a different method of sonographic imaging to better detect blood flow when intravenous sonographic contrast agents were first introduced experimentally.<sup>37</sup>

Spatial compounding, conversely, actually uses multiple beams from multiple angles to produce an image with a smoothed appearance.<sup>38</sup> Those who scanned in the early days of clinical ultrasound in the early 1970s using bistable instruments will remember the so-called open shutter technique used with an open lens on a Polaroid camera, during which time multiple arclike sweeps were made with the transducer over the skin of the patient. This produced an image with a gray scale quality and essentially used the same principle mechanically that spatial compounding produces electronically using the capabilities of digital imaging.

### Doppler Development

The application of Doppler sonography to the study of breast nodules in theory provided a method by which the presence or absence of cancer neovascularity could be documented. Early work using Doppler sonography to study the breast was done in England by Burns and Wells and in Australia by Jellins and Kossoff. In 1983, Jellins et al<sup>39</sup> reported a series of 70 patients (23 malignancies) in which sensitivity of 95% for malignancies and 85% for benign lesions was achieved using continuous wave Doppler sonography. In England, Burns, Holliwel, and Wells concluded that the important Doppler signals detected in breast malignancies likely arose from the vessels in the region of, and not necessarily within, the tumor. The best differentiation between benign and malignant in their studies came from comparing the peak systolic frequencies of each. Last, they concluded that the most plausible model for the blood flow pattern in the region of breast malignancies was the "multiple feed artery" model. Further evolution of Doppler sonography was marked by the incorporation of color Doppler with gray scale imaging, which enabled further refinements in the interpretation of the basic Doppler data. More recently, the incorporation of both color Doppler and Power color Doppler analysis of the blood supply to



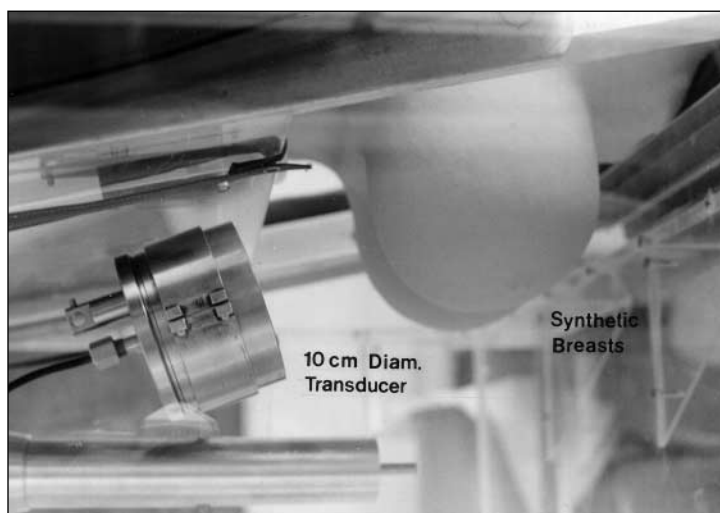
**Figure 7.** Left to right, from Australia, Dr George Kossoff, Dr Tom Reeve, and Dr Jack Jellins taken about 1975. [Photograph courtesy of Dr George Kossoff.]

breast tumors has clearly increased the specificity of clinical breast ultrasound but still falls short of the goal of 100% specificity in differentiating benign from malignant entities.<sup>40,41</sup>

### The Clinical Revolution

Although early clinical articles focused on the simple differentiation of cyst from solid, the

**Figure 8.** Dr Elizabeth Kelly-Fry's laboratory system for investigating ultrasound breast imaging with direct water coupling, Indiana University, 1974. The transducer is in the housing at left; the synthetic breasts are exact models of in vivo breasts. [Photograph courtesy of Dr E. Kelly-Fry.] Photograph and legend reprinted with permission from *Medical Diagnostic Ultrasound: A Retrospective on Its 40th Anniversary*.





**Figure 9.** The commercially produced Labsonics water-coupled breast scanner, which was the result of the research and development done by Dr Elizabeth Kelly-Fry in Indiana. [Photograph courtesy of Dr Valerie Jackson, Indiana University School of Medicine.]

1990s brought the clinical impact of breast ultrasound far beyond this initial stage. In 1987, Fornage et al<sup>42</sup> compared sonography with clinical examination and mammography in accurately determining the size of breast cancers preoperatively. They showed that sonographic measurement had the highest correlation coefficient with the lowest residual SD.<sup>42</sup> This also pointed the way to ultrasound's use in measuring tumor response to neoadjuvant chemotherapy. When handheld, real-time breast sonography became commonplace, it became the most widely used method for guidance during both core biopsy and fine-needle aspiration sampling of breast tissue. Because of its ease of use, its real-time capability, and its cost-effectiveness, breast sonography quickly became the preferred method for needle biopsy guidance. One of the first articles to show the capability of ultrasound to accurately guide the sampling of small lesions was published by Fornage et al<sup>43</sup> in 1990, in which they documented the results of sonographically guided biopsies in 49 breast carcinomas smaller than 1 cm<sup>3</sup>.

### Benign Versus Malignant: The Goal of Lesion Characterization

Since the first articles on breast ultrasound were published in the early 1950s, one of the principle goals of its use has been the attempt to distinguish benign from malignant tumors using a variety of sonographic criteria. A recent article frequently cited regarding tissue characterization was published in 1995 by Stavros.<sup>44</sup> On the basis

of a large volume of data derived from the study of 750 breast nodules, the acoustic characteristics of benign and malignant lesions were enumerated and described in detail. Although the ultimate reference standard for the distinction between benign and malignant lesions remains a histologic one, this article helped decrease the “gray areas” in interpretation.

### Lexicon

While assimilating the impact that this expanded role of breast ultrasound was playing and underscoring the integral role breast ultrasound plays in evaluating clinical breast problems, a lexicon for reporting breast ultrasound findings was developed to correlate exactly with that used for several years in x-ray mammography. This will provide a unified method to report all breast imaging findings in a way that will highlight for clinicians the overall impression of the study as well as give a clear indication of the clinical management recommended.

### Summary

What began as a laboratory-based spin-off of military technology has matured over the past 50 years into an integral part of the breast imaging armamentarium. It has revolutionized the evaluation of breast abnormalities and has provided a rapid, cost-effective, and accurate guidance method for a wide range of interventional techniques. Subsequent improvements in technology will only serve to further enhance its pivotal clinical role.

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