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A COMBINED CLINICAL AND RESEARCH APPROACH TO THE PROBLEM OF ULTRASOUND VISUALIZATION OF BREAST

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The earlier investigations, initiated in 1968, on breast tissue visualization by the above first author and then associates was not a clinical study, although it was based on scanning human subjects.(1-6) Rather, it was an attempt to determine to what extent advanced, laboratory-based ultrasound instrumentation could provide new information that would be useful for early detection of breast carcinoma. The laboratory instrumentation available for the breast tissue investigations was a computer controlled, sector-mode, B-scanning visualization system which featured highly sensitive amplifiers, and an axial resolution and lateral resolution of 0.5 mm (provided by an adaptation of the focused, wide aperture, Hertz-Olofsson reflector type transducer system).(7) The improved resolution was not confined to a depth of tissue in the immediate area of the focus of the transducer, but could be made available for, essentially, the full depth of the breast tissue. This was accomplished with the aid of a digital computer which allowed segmental construction of echograms via program control of receiver gain as a function of range and echo strength. This segmental feature, in essence, was a method of accomplishing a multiple focus system. Recording was by means of Polaroid pictures of an oscilloscope display which provided reasonable grey scale.

Prior to the breast tissue investigations, this ultrasound instrumentation system had been applied to a study of liver tissue. The results obtained demonstrated not only that liver was not transonic, as indicated by the studies of earlier investigators, but that liver apparently could be characterized according to structure, by applying sufficiently sensitive ultrasound visualization techniques.(8-10) The success obtained by demonstrating the fine echo structures throughout liver tissue formed the basis of the approach to the study of breast tissue.[11] Experiments were designed to place primary emphasis on the characterization, by ultrasonic visualization methods, of the tissues of the normal breast, over the age range of young to old. It was felt that if such characterization could be accomplished, then recognition of deviations from the normal would form the basis of an early detection method. In that regard, studies were also initiated on the measurement of the average velocity of ultrasound for *in vivo*, normal breasts of various age ranges and for breasts with some abnormality.[4, 12] The visualization investigations also included the approach of using an adaptation of the above instrumentation to scan the breasts of volunteer patients with either benign or malignant breast tumors. In the later stages of the program, fundamental studies were carried out on visualization of excised breasts containing intact malignant tumors.[13, 14]

The authors wish to emphasize that in determining the approach to be taken in these investigations, that in addition to the above considerations, study was made of the results of the pioneering investigations of Wild and Reid and of Howry and associates during the 1950's and the subsequent work of individual investigators in various parts of the world during the 1960's, but, in particular, that of the investigations in Japan.[15-28] In the general period of 1960-1967, the most serious attempts to apply the ultrasound breast technique in a clinical environment seemed to be underway in Japan. The instrumentation applied to the breast studies in Japan during that period was primarily B-mode scanning using unfocused, narrow diameter transducers, and the water bag technique for coupling the output of the transducer to the breast. The approach of the bioacoustic scientist, Y. Kikuchi, in regard to a quantitative approach to ultrasound medical diagnosis, was an important aspect of the breast studies in Japan.[29]

In the initial planning of the research studies with the wide aperture transducer systems, the transducer coupling problem was approached from the viewpoint of having no distortion of either the outer or internal structures of the breasts. This could be best accomplished if the breasts were freely floating in a liquid which acted as the coupling medium for the ultrasound. From the viewpoint of the research data, (if the breasts were floating) the position of the patient, i.e., whether completely or partially prone, supine or sitting, was apparently not significant. However, simply because of the mechanical design of the above described laboratory instrumentation, it was convenient to have the subject in a supine position. A method of floating the breasts, for this supine position with no body regions other than the breast being subjected to the water bath, was developed.[1, 6] In later phases of the program, comparison studies were carried out on the echogram data obtained with such unimpeded and undistorted breasts and that obtained when the classical water bag technique was applied. It was found that information was lost with the water bag technique, particularly in the regions of the nipple and structures immediately underneath it.[4, 6] This information is significant to the present experimental approach of the above authors.

The results of these investigations showed the advantages of a quantitative approach to tissue visualization, when applied with the assistance of wide aperture, focused transducers combined with sensitive amplifier systems providing good resolution and high sensitivity. Included in the results was the demonstration of the precise location and identification of various sizes of cystic structures; the recognition of benign tumors, such as fibroadenomas, by the fine echo pattern from within the tumor; the attenuation characteristics of some malignant tumors; and the detection of certain disseminated conditions, such as fibrosing adenosis by a quantitative approach which compared the overall echo patterns of such conditions (under predetermined instrumentation settings), with that of normal subjects of the same general age range (for the same instrumentation values).[2-6] The excised breast experiments showed that such preparations can provide good experimental data which is directly applicable to the *in vivo* breast.[13, 14] An additional result of these detailed, basic studies was increased understanding of the complexity of the problem of: (1) differentiating between *solid* tumors which are malignant and those which are benign, by means of the fundamental characteristics of the tumor, rather than differences in its architectural features, such as wall structure, and (2) defining a breast malignancy in the very early stages of its development or in the premalignant stage. It should be understood, however, although it was recognized that the problem was complex, it was also evident that given sufficient time for adequate instrumentation development and research investigations, that ultrasound techniques had unique potential for providing fundamental data necessary for definitive identification of pathologic structures within the breast.

The approach of the present studies is based not only on these outlined results but on the findings of other investigators who carried out studies in the period after 1967.[30-36] Unfortunately, despite the serious need for ultrasound, breast cancer detection instruments and despite the research advances which indicate that such instruments could provide valuable diagnostic information, there has been very limited clinical application, in the United States, of ultrasound methods for breast cancer detection. The present investigations are based on a concept of combining bioacoustics research studies, and practical clinical investigations of both physicians and bioacoustics scientists within the same clinical environment in the hope of encouraging further medical applications of ultrasonic techniques. Current studies are concerned with (1) a computer based research instrument designed for both compatibility with the clinical environment and for capability of applying more advanced bio-

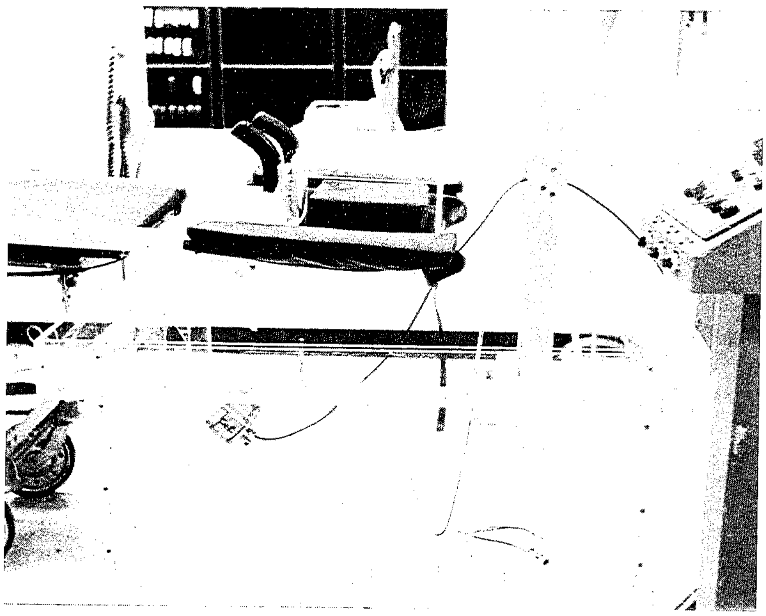

Fig. 1. Computer based system for study of breast pathologies by ultrasound visualization techniques and by determination of acoustic parameters of the tissue. The subject is prone, with breasts immersed in the water filled tank and head and arms resting on the support table. The transducers can be initially oriented in any one of several directions or angles in respect to the breast tissue surface; the subsequent scanning motions are under computer control. (PDP 11/45 digital computer evident in background; additional manual control system in foreground).

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acoustics techniques in an attempt to determine what are the critical acoustic parameters necessary for early detection of breast pathologies by ultrasonic techniques, and (2) a relatively simple clinical instrument which incorporates some of the instrumentation features found of value in previous studies. The general instrumentation system (in use or planned) for both of these approaches includes pulsers with PRF ranging from 500 to 1000/sec., wide diameter, spherical focused transducers (2.5 MHz to 10 MHz), a variable gain attenuator, a logarithmic amplifier, a PDP 11/45 computer system, high speed digitizer (Biomation 8100) and associated display system consisting of a PEP 400 scan converter, a 17" GBC monitor and a small dedicated monitor and videotape recorder. In addition to the video stored echograms, selected 35 mm film recordings of the dedicated monitor will be taken and a limited number of Polaroid pictures of selected echograms as displayed on a CRT.

Insofar as the computer based instrument is concerned, the transducer coupling problem has been considered from the viewpoint of the absolute necessity of not distorting the breast tissue while carrying out detailed visualization scans to determine structural characteristics of tumors or when obtaining fundamental acoustic parameter measurements. However, it is also important to provide an examination system which is comfortable and only requires a minimum preparation time for the patient. To fulfill both needs an immersion tank has been constructed which consists of a see-through (to aid in alignment of breasts and transducers) frame, 43" x 43", and 18" in depth, with a built-in head and arm rest, and with a detachable surgical table which has a control both in respect to height and tilt (see Fig. 1). The tank is filled with body temperature, distilled water or saline solution; the patient lies prone with the undraped breasts immersed in the water and with both arms and head comfortably supported in an outstretched position. The table is then brought to best height and angle of tilt, which is dependent on the size of the breasts and the particular transducer being used. Wells, et al. used the prone position, water immersion technique to obtain compound sector B-scans of the breast but the technique proposed here will differ from that of Wells' in a number of respects.[30] In addition to maintaining the transducer normal to the anterior surface of the breast to provide horizontal scans (Fig. 2), provision is made for orienting the transducer normal to the outer lateral face of the breasts (Fig. 3), and for orienting the transducer so that it directly faces the area of the breast superior to the nipple. In other words, with the subject prone, and the breasts hanging freely, it is possible to scan (linear or sector) the breasts from three mutually perpendicular orientations. There may be unique advantages to visualizing breast tissue structures (particularly malignant tumors) from these three separate orientations. In addition to the visualization studies, experiments are planned to determine the value of significant acoustic parameters such as velocity, absorption and impedance, for both the in vivo and the excised breast, with this computer based research instrument.

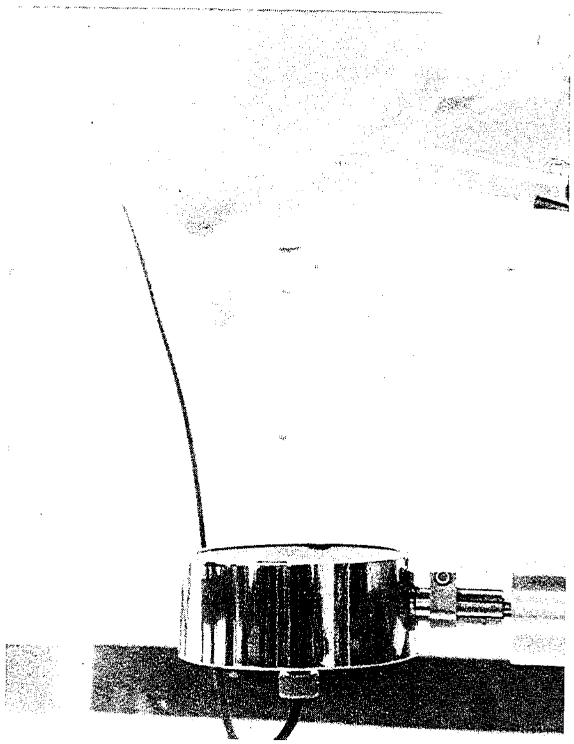

Fig. 2. View of 10 cm. diameter, focused transceiver and of breasts in water filled tank shown in Fig. 1. Note the undistorted contour of the breasts in the water medium.

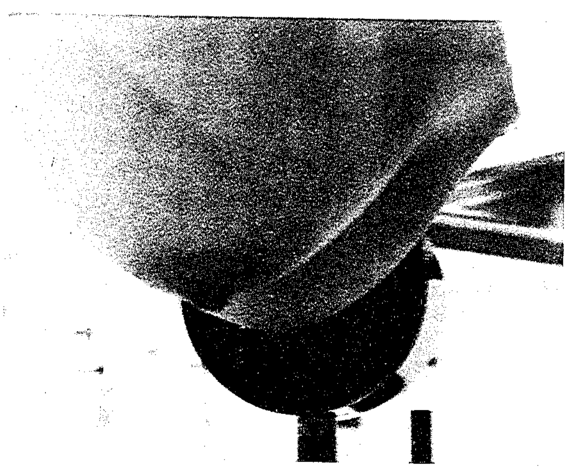

Fig. 3. Same as Fig. 2, but transducer facing lateral surface of breast.

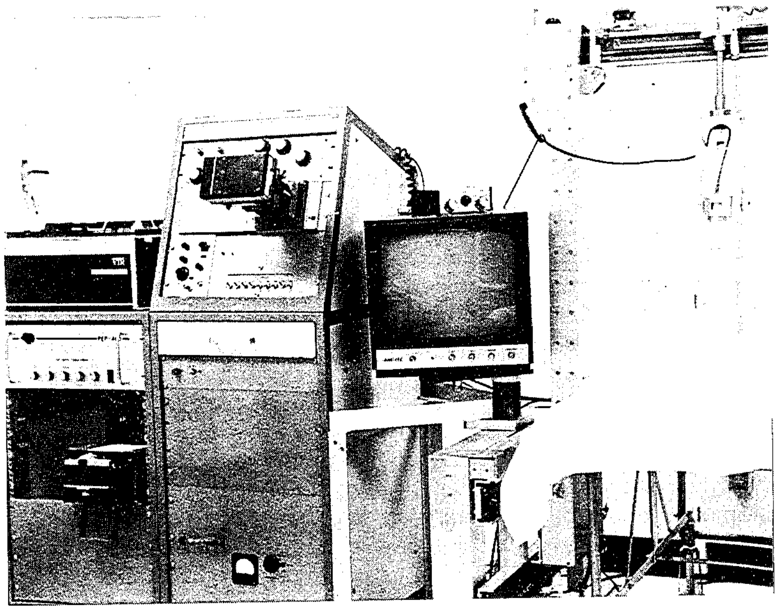

Fig. 4. Instrumentation used in non-computerized, breast visualization scanning system. On the right is the patient carrier and the water coupling scanning tube (see text); the large screen is a video display, the video recorder is in the upper left; the 35 mm camera in the lower left records from a small dedicated video monitor. The Polaroid camera provides immediate records of the echograms presented on the CRT.

The impedance investigations will include application of various tissue interrogation techniques.[37] Transmission studies of both excised and intact breasts, using the combination of the random acoustic signal method and the high sensitivity, wide aperture transducer systems are also in the planning stage.[38] The combination of the availability of the computer, the non-distortion of the breasts and the flexibility of the immersion tank in regard to placement of different types of transducer systems is a critical feature of all of the above approaches.

The coupling problem in regard to the non-computer, practical clinical instrument has been considered in terms of evolving a fast and simple coupling method for a portable scanning instrument, which will allow examination of the general tumor region of the breast without undue distortion. In addition, however, this coupling method was considered from the viewpoint of (1) attempting to view tumors from the three mutually perpendicular directions, as previously mentioned, not only for the purpose of investigating the characteristics of malignant tumors but also from the practical viewpoint of taking into account the variability in size and physical characteristics of the breasts of different subjects. In some cases, the physical characteristics are the basis of the inability to locate a tumor. In such cases it may be an advantage to scan the breast from a lateral or top plane as opposed to a simple horizontal scan. The water coupling tube shown on the end of the scanning arm in Fig. 4 consists of a solid, water filled sleeve which houses the transducer and allows for variable vertical movement of the transducer within the water bath. The bottom, closed end of this sleeve consists of a soft, flexible plastic. When this tube is used in conjunction with a water bag, only a small amount of water is required in the bag, thus decreasing the problem of distortion due to the weight of the water. Studies are underway on applying this water coupling sleeve and associated water bag as a transducer coupling technique for the clinical breast subjects. It is hoped that the minimum amount of water in the bag will make it practical to scan the breasts from the three planes previously described; the lateral scan can be achieved by having the patient lie on her side; the horizontal scan with the patient on her back and the top scan by sitting the patient beneath the scanning arm. Preliminary work is also underway on investigating the application of this water coupling tube as a direct contact scanner. Successful development of wide diameter, focused direct contact scanners would provide a means of obtaining good clinical data with relatively simple instrumentation and would encourage further use of ultrasonic methods for breast cancer detection. In using both of these clinical instruments, various diagnostic criteria, such as those outlined by Kobayashi, et al., as well as the criteria used in previous studies of the authors, will be applied.[37] However, emphasis will be placed on: (a) comparison of the echogram pattern from the interior of solid benign tumors with that of malignant tumors and correlation of these echogram patterns with known information regarding the tumor and the surrounding tissue structure, as determined by the radiologist and the pathologist, and (b) the attenuation characteristics of malignant tumors and the correlation of this attenuation phenomena with the classification of the tumor, with the type of tissue structures present in and surrounding the tumor, and with the size of the tumor. Particular attention will be given to the layered aspects of the tumor structure, especially the presence or absence of a necrotic core and the relation of this core to the attenuation phenomena. Echogram data will be correlated, to the extent this is possible, with Xeroradiogram information.

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