Average velocity of ultrasound in the human female breast

George Kossoff  
*Commonwealth Acoustic Laboratory, Sydney, Australia*

Elizabeth Kelly Fry  
*Indiana University School of Medicine, Indianapolis, Indiana 46202*

Jack Jellins  
*Commonwealth Acoustic Laboratory, Sydney, Australia*  
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A technique for measuring the *in vivo* average velocity of ultrasound in the human female breast was developed and applied to determine the range of such values in the breast of normal subjects in the approximate age ranges 20 to 80 years and in subjects with selected breast pathologies. Reasonable correlation of the velocity values with breast tissue type, as determined by x-ray (mammography), was obtained, indicating that ultrasonic velocity data provide useful information on the main tissue constituents in the breast and that this technique should allow safe, long-term study of changes that may occur in the composition of such tissues.

Subject Classification: 16.2.

**INTRODUCTION**

The velocity of propagation of ultrasound is an important acoustic parameter dependent upon the density and elasticity of the transmitting medium. In an organ such as the breast, where the nature and distribution of the internal tissues vary, it is reasonable to expect that the average velocity through the breast will be related to the density and elasticity of the different tissues within the breast. This study was designed to determine the *in vivo* range of average acoustic velocity in the breast of normal subjects, and of patients of various ages with breast pathologies. The purpose of the study on normal subjects was to determine if such measurements could provide data which would (1) characterize the tissues present in the breast, and (2) show the range of variation of these tissues, both within each age group and across the age groups. The study on subjects with breast abnormalities was undertaken to ascertain whether a specific distribution in velocities exists in breasts containing benign or malignant changes.

**I. STRUCTURE OF THE BREAST**

The breast of the adult, premenopausal female is a modified secretory gland composed primarily of glandular, connective and adipose tissue.¹ ² The term "glandular tissue," used synonymously with the term "breast tissue," should not be interpreted as a reference to any of the fine structural units of the breast concerned with the specific function of milk secretion, such as the alveolus (*acinus*), but rather to the relatively gross conglomerate of tissue constituted from such individual units. Specifically, glandular tissue is an anatomical unit, the *corpus mammae*, composed of 15 to 20 lobes, each containing an excretory duct which opens to the nipple. If traced to their secretory origin, the terminal branches of these ducts end in a tubulo-saccular spherical or pyriform alveolus, the secretory organ. A number of alveoli (*acinus*) grouped together, bound with a delicate connective tissue structure and opening into a common branch of a duct, constitute a lobule. Each of the 15 to 20 lobes of the "breast tissue" is made up of multiple lobules. Encircling the outside of all ducts and alveoli is a loose fibrous connective tissue which can take part in certain physiological or pathological changes occurring in the breast. In addition, there is a dense fibrous connective tissue, which separates the lobules from each other and which is the main supporting tissue of the breast. This tissue does not take an active part in pathological changes. In the premenopausal subject, the above-described glandular tissue forms a conical mass, the apex of which is aligned toward the nipple while the base is loosely connected to the fascia of the underlying pectoralis muscle. Outside of the breast tissue is a layer of subcutaneous adipose tissue, usually more well developed on the ventral surface where it fills in between the irregularities caused by the lobes, and gives to the surface of the breast its smooth appearance. However the amount of subcutaneous fat varies considerably and in some instances may be essentially absent. The subcutaneous fat is interlaced by connective tissue strands, which attach to the skin, the so-called Cooper suspensory ligaments. There is little fat between the lobules in nulliparous (subjects who have never borne children) but much
more fat is present in such areas in multiparous (subjects who have borne three or more children in as many pregnancies). There is no fat immediately beneath the nipple and areola.

There is considerable variation in the amount of glandular tissue present in the premenopausal subjects; the number, size, and distribution of lobules is dependent on an interplay of various hormone controls. It should not be assumed that the secretory activity takes place only in pregnancy and lactation. The so-called "resting breast" (i.e., nonpregnant, nonlactating) has limited secretory activity, with secretions present in the alveoli and ducts. However, in the case of a pregnant subject, there may be an increase in the numbers of alveoli and ducts and there is distention of the alveoli due to an increase in the level of secretion. Further, as the pregnancy progresses and lactation finally takes place, fat tissue is absorbed allowing a continuing increase in size of lobules. During lactation the alveoli are dilated, being distended with liquid and are quite numerous; after lactation the alveoli regress, but the involution is never complete and the glandular tissue does not entirely disappear. During each menstrual cycle these structural changes are reproduced in miniature, with only a certain proportion of the lobules undergoing changes. Finally, during or following menopause, a so-called involution process takes place in which the glandular tissue shrinks leaving essentially only membranous connective tissue sheets, large ducts and, in many cases, large deposits of fat. Specifically, two primary changes are taking place in the period following onset of menopause: (1) Lobules are undergoing almost complete conversion to fibrous tissue in the area; (2) the dense interlobular connective tissue undergoes atrophy and may be replaced by fat. In addition, the small peripheral ducts involute and only the larger ducts remain. However, the extent, time of onset, and scale for completion of the involutional changes is variable from subject to subject.1

II. MEASUREMENT TECHNIQUE

The velocity was obtained by measuring the difference in the time of arrival of an ultrasonic pulse travelling through the breast and travelling through distances of identical path length. The measurement therefore represents the average value of the velocity through the traversed tissues.

The measurements were carried out using 1.5-cm diam 2.25 MHz ceramic transducers mounted on a rigid bar with adjustable separation. One transducer was used as the transmitter (average power output 0.2 mW/cm² for a pulse repetition rate of 1300pps) and as the receiver. The transducers were placed on the lateral aspect of the breast, facing each other, and the received waveform displayed on an expanded time base, on a CRT and photographed. As the transducers were removed from contact with the breast, the separation distance between the transmitter and receiver was fixed at the distance used when the sound pulse was transmitted across the breast. Without any change in this separation distance, the transducers were then immersed in water at 30°C (37°C distilled water used in the studies carried out in the United States), the transmitting transducer energized and the received waveform photographed. In order to simplify the determination of the difference in travel time, Δt, between the waves in breast tissue and in water, the received waveform of the water path was superimposed on the same film track used for recording the waveform of the breast tissue (Fig. 1). After determining the total time taken for the ultrasonic pulse to travel the separation distance in water, the velocity is calculated from

\[ v_w = \frac{d}{t_w} \]

where \( v_w \) is the velocity of ultrasound in water, \( v_b \) is the velocity of ultrasound in the breast, \( \Delta t \) is the time difference between the two waveforms, and \( t_w \) is the total time taken for the ultrasound pulse to travel the separation distance in water.

Measurements were performed on both breasts in the vertical, horizontal, and 45° skew places at different depths. Distortions in the received waveform were sometimes observed during measurements. The precise origin of this distortion is not known. However, in cases where such distortions were present, they were reduced to a minimum by repositioning of the contact surface (the breast surface and the transducer until an acceptable waveform was received.

The accuracy in the measurement of the velocity by this method is relatively high, as it is based on the accurately known velocity of propagation in water. The error in \( v_w \) can be limited to 0.17% by keeping the water temperature at 30°C±0.5°C. For the method outlined here, that is, measurement from a film trace, the accuracy of measurement of \( v_w \) with the oscilloscope traces at a time scale of 5 m/sec/cm, in the order of 0.25 m/sec. For a mean transcutaneous time of 25 usec, the error is of the order of 1%. The time difference \( \Delta t \) was measured by comparing the times of the first negative peaks. Using a time scale of 1 m/sec/cm (the oscilloscope calibrated beforehand by a time-mark generator), the reading error is of the order of 0.0013 usec which, for a mean reading of 0.5 usec represents an error of 4%. The term \( v_b/\Delta t \) is therefore of the order of 4%. This term, however, is small relative to 1 so that even when there is a large difference in velocities in the breast compared to water and the total error in the measurement of \( v_b \) is estimated to be ±0.3 m/sec when the velocity in the breast lies in the 1400 and 1570 m/sec range and is as low as ±1 m/sec when the velocity lies near 1510 m/sec value. This accuracy was considered adequate for the study. The accuracy can be improved by keeping the water temperature more constant, and by using a faster expanded time base for measurement of \( \Delta t \) and by using a more accurate delayed time base for measurement of \( v_w \).

III. RESULTS IN NORMAL BREASTS

The average value of the velocity through the breast is obviously dependent on the values of velocity in the traversed internal tissues. Velocity measurements were carried out, at 21°C, in subcutaneous fat, fibrous connective tissue, and pectoralis muscle from a breast which had been surgically excised 6 h previously and stored dry at an air temperature of 25°C. The values obtained were as follows: fat, 1470 m/sec; connective tissue, 1545 m/sec; pectoralis muscle (across the muscle fibers), 1545 m/sec. Frucht obtained a value of 1465 m/sec for excised human breast fat and 1506 m/sec for pectoralis muscle. As yet, no sufficiently large sample of excised glandular tissue has been available to the present authors for measurements purposes.

Measurements in the breast were taken at different depths and different places with usually eight measurements taken to obtain the mean value of each determination. Although, as already mentioned, the accuracy of the technique is better than ±1 m/sec, the mean standard deviation in reproducibility of measurements carried out at different times during the same day at the same position, as determined by a mark on the patient's skin, was found to be approximately ±5 m/sec. This difference is presumably due to difficulty in reproducing the same traversed path through the breast. In general, measurements taken at different depths varied no more than ±0.5 m/sec from the mean value, the velocity closer to the nipple being usually faster, probably because less of the slower fatty tissue was traversed by the beam. However, the measurements in the deeper tissue were more prone to distortions, presumably due to more variable internal velocity gradients and the greater distance of travel. In general,

\[ \text{FIG. 1. Received waveform of ultrasonic pulse transmitted through water and through breast tissue.} \]

\[ \text{FIG. 2. Average velocity of ultrasound in normal subjects in the U.S.A. and in Australia.} \]
The mean values of velocity in both breasts in the same subject were remarkably similar, usually agreeing within 30 m/sec.

Figure 2 shows the values of velocity in both breasts in an allegedly normal, pre- and postmenopausal population of subjects in the U.S.A. and in Australia. As illustrated, the average velocity in the premenopausal group is 1510 m/sec. Large deviations from this average are common with extreme values ranging from 1290 to 1750 m/sec.

The average velocity does not appear to be significantly related to age and extreme variations are seen in subjects in the same age group. The average velocity in the postmenopausal group in 1468 m/sec. Again large variations from the average are common, the extreme values being 1440 and 1530 m/sec, respectively.

Possible interpretation of the variations noted in both the pre- and postmenopausal groups is discussed in Sec. IV.

High values of velocity (in the 1530 m/sec range) were found to occur in lactating breasts and are illustrated by a triangle in Fig. 2. The velocity in human milk was measured as 1540 m/sec at 30°C. Since the lactating breast is reported to secrete milk from the system adventitiously, it can be assumed, therefore, that the velocity in glandular tissue is also in the 1530 m/sec range. This value would also correlate with the interpretations discussed below of mammogram data.

17. CORRELATION WITH MAMMOGRAPHY

A study was undertaken on 19 normal subjects (ranging in age from 19 to 83 yr), among whom a x-ray film of the breast (mammograms) were available, in order to determine possible correlations between acoustic velocity measurements and the primary type of tissue present in the breast, as determined by mammographic reading. This interpretation of the mammograms was performed by a radiologist who was not aware of the velocity values in the subject. As illustrated in Table I, all four subjects for whom mammograms indicated an appreciable amount of adipose tissue had velocities in the range 1450-1475 m/sec. Further, the remaining seven subjects with mammograms indicating a predominance of glandular tissue, exhibited velocity values ranging from 1500 to 1550, with an average value of 1546.

### TABLE I. Velocity in breasts of normal subjects.

<table>
<thead>
<tr>
<th>Age</th>
<th>Size*</th>
<th>Menopause</th>
<th>Velocity m/sec</th>
<th>Areal thickness of breast tissue Based on mammogram readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Large amount of glandular tissue</td>
</tr>
<tr>
<td>20</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breasts almost totally occupied by glandular tissue</td>
</tr>
<tr>
<td>21</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breasts almost totally occupied by glandular tissue</td>
</tr>
<tr>
<td>21</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breasts almost totally occupied by glandular tissue</td>
</tr>
<tr>
<td>22</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>22</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>23</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>23</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>24</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>24</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>25</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>25</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>26</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>26</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>27</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>27</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>28</td>
<td>34G</td>
<td>pre</td>
<td>1550</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
<tr>
<td>28</td>
<td>34G</td>
<td>pre</td>
<td>1530</td>
<td>Breast with a small amount of adipose tissue</td>
</tr>
</tbody>
</table>

* This notation is a clinical measurement. The letter code is the level at the level of the upper border of the breast, for the full circle of the observer, front to back. The letter designates the volume size of the breast, according to U.S. manufacturers' standard code. A: small volume, B: medium volume, C: large volume, and D: extra large volume.
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V. RESULTS IN BREASTS CONTAINING PATHOLOGICAL CHANGES

The breast is subject to a number of pathological changes, some of which may be localized while others may be distributed throughout the breast. The velocity in breasts containing carcinoma, phlobocytic disease, fibroadenosis, and fibroadenoma is illustrated in Tables II to V. In all cases, the diagnosis of the specified condition was made from pathology tests on specimens of surgically excised tissue. The velocity measurements for the breast with pathological changes were made according to the same technique as that described for the normal breasts, except that whenever possible attempts were also made to obtain the velocity value in the region of the pathology. This value was averaged in with the measurements made in the other areas.

The mean value of velocity for subjects under the classification of breast carcinoma (Table II) primarily represents the value through tissue not containing palpable tumors, since for these specific cases, the malignant tumor present were generally small and localized. The majority of the patients in the carcinoma group are postmenopausal. The average velocity for this group (for the specific breasts diagnosed by pathology studies of excised tissue) is 1,465 m/sec, which is close in value to the 1,468 m/sec average velocity in the normal postmenopausal subjects and, presumably, simply representative of an adipose breast.

The average velocity of the phlobocytic group (for the specific breasts described by pathology studies of excised tissue) is 1,514 m/sec. Large deviations from this value are less common than in the normal, particularly in regard to the older patients where it might be expected that the velocities would be in the low range. This is consistent with the distributed nature of the disease, and in particular the presence of many liquid filled cysts which would tend to constrain the value of the velocity. Table III includes patients in whom large cysts, i.e., larger than 1 cm in diameter were detected by cross-sectional ultrasonic visualization methods.

The average velocity (again, for the specific breasts on which the diagnosis was made) for patients with fibroadenosis (description of fibrous tissue within the umbilical and fat for patients with fibroadenosis (a circumscribed, benign tumor) is the same, namely 1,529 m/sec. However, it should be noted that since two groups there is a higher proportion of premenopausal subjects and a more limited number of subjects compared to the other groups.

VI. DISCUSSION

The velocity of ultrasound for a variety of individual mammalian soft tissues, such as muscle and fat, and for a number of specific organs, including kidney, spleen, and brain shows a wide range of variation for each specific tissue and a relatively limited variability for each specific organ. In the human female breast, the variability and nature of the internal tissues yield a range of variations in the values of velocity that is unique. Conversely, accurate experimental determination of the range of velocity values in the normal breast, correlated with the knowledge of the individuals responsible for the specific velocity values, yields the required data for development of a technique in which velocity measurements may be used to obtain information on the internal tissues of the breast. In particular the techniques permit safe long-term study of changes that may occur in the composition of the breast, e.g., during and following pregnancy, in aging, and in response to medical treatment.

In the method described in this paper, the repetitability of the measurements is several times worse than the accuracy. Doubtlessly the repetitability may be improved by better positioning procedures and this will allow a following of smaller changes such as those that occur with the menstrual cycle.

The data presented also indicate that the technique might provide an effective method of measuring the velocity in a localized portion of the breast such as an encapsulated cyst or tumor, located in an accessible area. By comparing the velocity values when the beam propagates only through the presumed normal tissue and when it propagates through the pathological mass it may be possible to differentiate between various lesions (for example, fat necrosis) and malignant conditions, provided that the velocity values in such tissues are significantly different. Work is in progress to determine the extent of these variations. In this regard, Frucht found a value of 1,737 m/sec for excised breast carcinomas.

VI. SUMMARY

A simple but accurate method for measuring the in vivo average velocity in the human female breast is presented. The average velocity in the normal subject was found to vary from 1,400 to 1,500 m/sec, the mean value for the premenopausal group being 1,510 m/sec. The velocity in the postmenopausal group was found to range from 1,430 to 1,520 m/sec, the mean value being 1,468 m/sec. In both groups the velocity does not appear to be significantly related to age.

Good correlation was obtained between tissue classification from data obtained from mammography and velocity measurements. The distribution of velocities in the breasts containing carcinomas was found to be similar to that of normal subjects in the same age category. The velocity values in breasts of patients with fibroadenosis and fibroadenoma were also in the normal range but a rather

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M. C. Becker, T. A. Dosey, and J. W. Jull, "Human and Experimental Breast Cancer (Charles C Thomas, Springfield, Ill, 1965)."