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Average velocity of ultrasound in the human female breast

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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 synonomously 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 tubulosaccular spherical or pyriform alveolus, the secretory organ. A number of alveoli (*acini*) 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 facia 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 nulliparae (subjects who have never borne children) but much more fat is present in such areas in multiparae (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.[1] 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 atrophies 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 absorption leaving dense 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 time 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 distilled water of identical path length. The measurement therefore represents the average value of the velocity through the traversed tissues.

The measurements were obtained using 1.5-cm-diam unfocused 2-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 1300 pps) and one as the receiver. The transducers were placed on opposite sides 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,

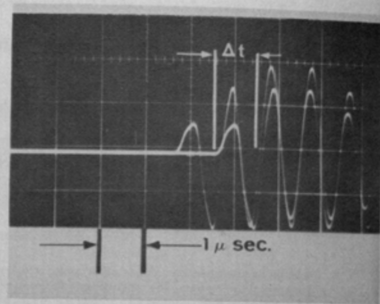

FIG. 1. Received waveforms of ultrasonic pulse transmitted through water and through breast tissue.

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 waveform in breast tissue and in water, the received waveform of the water path was superimposed on the same film trace 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

$$v_b = \frac{V_W}{1 \pm (\Delta t / t_w)},$$

where v_b is the velocity of ultrasound in the breast, v_w is the velocity of ultrasound in the water at 30°C, Δt is the time difference between the two waveforms and t_w is the total time taken for the ultrasonic pulse to travel the separation distance in water.

Measurements were performed on both breasts in the vertical, horizontal, and 45° skew planes 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 reorientation of the contact between 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.[3] The error in v_w can be limited to 0.17% by keeping the

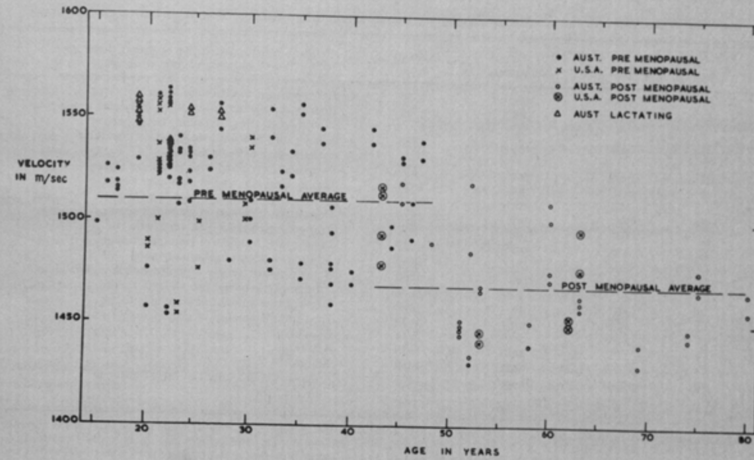

FIG. 2. Average velocity of ultrasound in normal subjects in the U.S.A. and in Australia.

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 t_w, with the oscilloscope trace at a time scale of 5 μsec/cm, is of the order of ±0.25 μsec. For a mean transmission time of 25 μsec the error is of the order of 1%. The time difference Δt was measured by comparing the times of the first negative peaks. Using a time scale of 1 μsec/cm (the oscilloscope calibrated beforehand by a time-mark generator), the reading error is of the order of ±0.025 μsec which, for a mean reading of 0.5 μsec represents an error of 5%. The error in $(\Delta t/t_w)$ is therefore of the order of 6%. This term, however, is small relative to 1 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 ±3 m/sec when the velocity in the breast lies in the 1460 and 1570 m/sec range and is as low as ±1 m/sec when the velocity lies near the 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 Δt and by using a more accurate delayed time base for measurement of t_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 25°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 1568 m/sec for pectoralis muscle.[4] As yet, no sufficiently large sample of *in vitro* glandular tissue has been available to the present authors for measurements purposes.

Measurements in the breast were taken at different depths and different planes 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 ±3 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 ±20 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,

TABLE I. Velocity in breasts of normal subjects.

Age	Size[a]	Menopause	Velocity m/sec	Radiologist's description of breast tissue based on mammogram reading
19	34A	pre	1550	Large amount of glandular tissue
20	34B	pre	1500	Breasts completely occupied by glandular tissue with small rim of fat along outer part
21	34A	pre	1550	Breasts almost totally occupied by glandular tissue with little or no fat
21	34B	pre	1550	Breast entirely filled with glandular tissue
21	34C	pre	1525	Dense; large amount of glandular tissue
21	34B	pre	1525	Dense; large amount of glandular tissue
21	38C	pre	1525	Dense; good amount of glandular tissue
22	34A	pre	1550	Primarily glandular with very little fat
22	34B	pre	1525	Dense; good amount of glandular tissue
23	36D	pre	1450	Adipose; moderate glandular tissue
25	32A	pre	1500	Breasts almost totally occupied by glandular tissue, little or not fat
29	32C	pre	1550	Dense; large amount of glandular tissue
30	34A	pre	1550	Dense; large amount of glandular tissue
43	34A	pre	1525	Glandular
53	34B	post	1450	Adipose
62	38C	post	1450	Adipose
63	34B	post	1475	Adipose; small amount of breast tissue in areola area

[a] This notation refers to brassiere size. The first number is the total chest measurement (in inches) made at the level of the superior border of the breast, for the full circle of the chest, front to back. The letter designates the volume size of the breast, according to U.S. manufacturers' standard code. Such sizes range from AAA to F; the A sizes represent small breasts, B to C medium, and D and above, large.

the mean values of velocity in both breasts in the same subject were remarkably similar, usually agreeing within 10 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 1450 to 1570 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 is 1468 m/sec. Again large deviations from the average are common, the extreme values being 1430 and 1520 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 1550 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 comprised chiefly of glandular tissue, with milk secretions filling the system from alveoli to excretory ducts, it can be assumed, therefore, that the velocity in glandular tissue is also in the 1550 m/sec range. This value would also correlate with the interpretations discussed below of mammogram data.

Seventeen subjects ranging from 17 to 46 years in age, six of whom were taking oral hormone contraceptives, were examined for six weeks every three or four days to determine the variations in velocity which might occur with the menstrual cycle. Although the velocities showed variations as great as ±15 m/sec, with a mean standard deviation of 6.5 m/sec, no obvious relationship could be determined indicating that the variations in velocity which occur with the menstrual cycle are less than the variations caused by repeatability errors.

IV. CORRELATION WITH MAMMOGRAPHY

A study was undertaken on 19 normal subjects (ranging in age from 19 to 63), for whom x-ray films 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 mammogram 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 1450–1475 m/sec range. Further, the remaining thirteen subjects, all of whom were premenopausal, with mammogram readings indicating a preponderance of glandular tissue, exhibited velocity values ranging from 1500 to 1550, with an average value of 1546.

TABLE II. Velocity in breasts with diagnosis of carcinoma.

Velocity Left	Velocity Right	Age	Menopause	Type
1489[a]	1477[a]	34	pre	Disseminated
1547[a]	···	42	pre	Scirrhous
1517	1518[a]	26	pre	Duct
1498	···	48	post	Disseminated
1459[a]	1473	49	pre	Scirrhous
1459	1444[a]	52	post	Scirrhous
1475[a]	1475	53	post	Scirrhous
1494	···	55	post	Anaplastic
1485[a]	1481	56	post	Scirrhous
1437[a]	···	59	post	Anaplastic
1458[a]	1475	64	post	Scirrhous
1463[a]	1470	67	post	Scirrhous
1488[a]	1490	68	post	Scirrhous
1485	1482[a]	70	post	Invasive
1461[a]	1459	74	post	Scirrhous
1452[a]	1455	74	post	Scirrhous
1460[a]	1478	75	post	Scirrhous
···	1456[a]	75	post	Scirrhous

[a] Diagnosed breast.

It is of interest to consider these results in conjunction with the data shown in Fig. 2 on the variation of velocity values with age and menopausal status. First, the large variation in velocity values for the *young subject* can be explained, on the basis of the mammogram velocity results, as a function of the relative amounts of adipose and glandular tissue present within the breast. Secondly, the average reduction of 42 m/sec in the velocity, with menopause, can be assumed to be due to the fact that a proliferation of fat occurs as the glandular tissue deteriorates during and following menopause. Note that in Fig. 2, for the postmenopausal age ranges, there are no cases with velocity readings of the order of 1550 m/sec, in contrast to the large number of young subjects with such readings; most of the postmenopausal subjects have velocity readings below 1500 m/sec. The tissue composition of the breasts of the postmenopausal subjects with velocity values in the range of 1470 to 1500 most likely consists of a proliferation of connective tissue with some distributed fat or this same combination is present with additional isolated segments of glandular tissue.[1]

Although a large content of fatty tissue may be considered normal for the postmenopausal group, a preponderance of fat in a young breast, under certain specific circumstances, may prove to be diagnostically significant. The differentiation between a *young glandular* breast, and a *young adipose* breast can easily be made by the ultrasonic-velocity method. Further, this technique may prove of value in elucidation of changes taking place during the transition period of menopause or possible changes brought about, in both the young and older subject, as a result of hormone therapy. In fact, this technique may be of particular

TABLE III. Velocity in breasts with diagnosis of fibrocystic disease.

Velocity Left	Velocity Right	Age	Menopause	Large cysts present
1568	1561[a]	23	pre	Yes
1554	1553[a]	26	pre	No
1505[a]	1515[a]	33	pre	Yes
1501[a]	1516	46	During	No
1520[a]	1524	34	pre	Yes
1495[a]	···	37	pre	No
1513[a]	1514	40	pre	Yes
1531[a]	1530	43	pre	No
1496	1500[a]	44	During	Yes
1531[a]	1531[a]	44	During	Yes
1503[a]	1511	44	During	No
1551[a]	···	46	During	No
1489[a]	···	46	During	No
1515[a]	···	47	pre	Yes
1507[a]	1510	47	pre	No
1541[a]	1542	47	pre	No
1477	1500[a]	47	post	No
1466[a]	···	48	During	No
1516[a]	···	49	pre	No
1547[a]	1530	50	pre	No
1485[a]	···	50	pre	Yes
1509[a]	1501	50	pre	Yes
···	1529[a]	50	pre	No
1496[a]	1510[a]	51	post	Yes
1467	1469[a]	52	pre	Yes
1516	···	53	post	Yes

[a] Diagnosed breast.

TABLE IV. Velocity in breasts with diagnosis of fibroadenosis.

Velocity Left	Velocity Right	Age	Menopause
1520[a]	1524	18	pre
1529[a]	1534	20	pre
1566[a]	1570	30	pre
1550	1554[a]	40	pre
1482[a]	1484	41	pre
1511	1527	42	pre
1503	1495	51	pre
1496	1520[a]	54	post

[a] Diagnosed breast.

TABLE V. Velocity in breasts with diagnosis of fibroadenoma.

Velocity Left	Velocity Right	Age	Menopause
1510	1522[a]	32	pre
1518	1527[a]	34	pre
1518	1527	34	pre
1520	1516[a]	38	Surgical
1556[a]	1553[a]	44	pre
···	1502[a]	46	Surgical

[a] Diagnosed breast.

value in characterizing the breast of the postmenopausal subject on long-term hormone therapy.

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 tissue. The velocity in breasts containing carcinoma, fibrocystic 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 tumors 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 1463 m/sec, which is close in value to the 1468 m/sec average velocity in the normal postmenopausal subjects and, presumably, simply representative of an adipose breast.

The average velocity of the fibrocystic group (for the specific breasts diagnosed by pathology studies of excised tissue) is 1514 m/sec. Large deviations from this value are less common than in the normal, particularly in regard to the older patient 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 diagnosis was made) for patients with fibroadenosis (proliferation of fibrous tissue within the lobule, the pathological tissue is firm but not circumscribed) and for patients with fibroadenoma (a circumscribed, benign tumor) is the same, namely 1529 m/sec. However, it should be noted that in these 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 reasonable constancy for each specific tissue and a relatively limited variability for each specific organ.[5–9] In the human female breast, however, the variable nature of the internal tissues yields 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 knowledge of the individual tissues 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 technique permits safe long-term study of changes that may occur in the composition of the tissues, e.g., during and following pregnancy, in aging, and in response to medical treatment.[10–12] In the method described in this paper, the repeatability of the measurements is several times worse than the accuracy. Undoubtedly the repeatability may be improved by better positioning procedures and this will allow a followup 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 in an encapsulated cyst or tumor, located in an accessible area. By comparing the velocity values when the beam propagates only through the presumed normal tissues and when it propagates through the pathological mass, it may be possible to differentiate between various benign (for example, fat necrosis) and malignant conditions, provided that the velocity values in such tumors are significantly different. Work is in progress to determine the extent of these variations. In this regard, Frucht found a value of 1573 m/sec ±7 for excised breast carcinoma.[4]

VII. 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 1450 to 1570 m/sec, the mean value for the premenopausal group being 1510 m/sec. The velocity in the postmenopausal group was found to range from 1430 to 1520 m/sec, the mean value being 1468 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 carcinoma 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 limited number of patients in these categories were available for study. Patients with fibrocystic disease had velocity values in the normal range but had less deviation from the mean, possibly because the distributed nature of the disease keeps the velocity closer to a constant value.

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