Ultrasonic Examination of the Breast
Edited by J. Jellins and T. Kobayashi

ULTRASONIC PROPAGATION PROPERTIES OF THE BREAST

J.C. Bamber

Institute of Cancer Research : Royal Marsden Hospital,
Sutton, Surrey, U.K.

INTRODUCTION AND REVIEW OF PREVIOUS DATA

Knowledge of the ultrasonic propagation properties - velocity (c), scattering coefficients, absorption coefficient and attenuation coefficient (α) - and their variation in different tissues with frequency, orientation, temperature, age, treatment, pathological state, etc., is of fundamental importance to our ability to make the most efficient use of ultrasonic techniques. Direct applications of such knowledge are: in suggesting the most potentially useful properties and variables on which to base future diagnostic techniques, aiding the correct interpretation of ultrasonic images and other information such as Doppler signals, optimizing the design of ultrasonic instrumentation, providing the necessary data for the construction of imaging phantoms and testing hypotheses concerning the mechanisms of interaction of ultrasound and tissue.

Only a very small portion of the data available on ultrasonic propagation properties of tissues arises from observations on human breast tissues (Goss et al, 1978; 1980) and none of these data provide values for scattering or absorption coefficients. For the present discussion it is useful to consider separately the properties of the various component tissues of the breast, as listed in table 1.

Figs. 1 and 2 summarize the data on sound velocity in terms of their dependence on temperature and age of patient. Values from both *in vivo* and fresh *in vitro* tissues have been included in these graphs, but good agreement and consistency in the data is seen in spite of this. The trends seen in these figures are consistent with, and can be explained in terms of, previously noted differences between fatty and non-fatty soft tissues in general (Bamber and Hill, 1979); i.e. non-fatty tissue has a relatively high velocity with a positive temperature coefficient whilst fat possesses a low velocity which has a negative temperature coefficient. The age dependence seen in Fig. 2, and other variations in the average sound velocity through normal breast that are apparent in Fig. 1, can be explained by the fact that the average velocity along a given path is a very strong function of the proportion of fat present, as revealed by X-ray mammography

(Kossoff et al, 1973). No significant age dependence was observed for velocity at room temperature for in vitro breast cancers (Greenleaf et al, 1977) but generally in vivo cancers in older fatty breasts possess a velocity in the range 1500-1540 ms^{-1} whereas the values for cancers in dense breast of patients less than 40 years old were between 1560 and 1590 ms^{-1}.

For the sake of clarity in Fig. 1 data for benign breast disease has been omitted. Velocity values from fibrocystic disease tend to overlap with those for both normal and malignant breast tissue . Room temperature values in excised breasts range from 1514 to 1562 ms^{-1} (Greenleaf et al, 1977). In vivo data ranges published are (approximately) 1536-1563 ms^{-1} (Glover 1977; 1979) and 1470-1588 (Greenleaf and Bahn, 1981). Sound velocity in fluid cysts appears to be in the range 1500-1525 ms^{-1} at body temperature (Glover, 1977; Greenleaf and Bahn, 1981).

In contrast with the situation for data on velocity, frequency is an important parameter in attenuation measurements. The poor agreement within the few data that exist is probably a reflection of the difficulty of making accurate measurements of the attenuation coefficient and of the wide variation in temperature and condition of the specimens chosen by different authors (Fig. 3). The large overlap of results from malignant, benign and normal breast tissues may be consistent with similar observations for relative estimates of local attenuation in vivo (Greenleaf and Bahn, 1981). Strong shadowing posterior to breast carcinomas in B-scans, suggestive of a high local attenuation coefficient, has been attributed to a high concentration of connective tissue within some tumours (Kobayashi, 1978).

A need for many more reliable measurements is apparent, even from this brief survey. The remainder of this paper reports the results of some preliminary measurements of velocity and attenuation coefficient in 7 fresh in vitro post-operative breast specimens. One aim at this stage of the work was to ascertain the nature of the temperature and frequency dependences of these propagation characteristics and to investigate the validity of the trends suggested by Figs. 1 and 3.

MATERIALS AND METHODS

Whole breasts containing tumours were obtained following mastectomy and cooled to 4°C for 2 hours before slicing transversely at intervals of 8-12 mm. All of the patients were age 60 or more and possessed a primary breast carcinoma of diameter greater than 2.5 cm. The slice nearest to the centre of the tumour was then prepared as a parallel-sided specimen of thickness 7 ± 1 mm and, to remove air bubbles, was stored in saline at 4°C for a further 14 to 18 hours after manual manipulation and degassing under reduced pressure. The methods of measurement, which have been described previously (Bamber and Hill, 1979), rely on the transmission of a short pulse of sound through the tissue. The plane transducer used had a nominal centre frequency of 10 MHz, a bandwidth approaching 100% of this frequency and a beam width of 3.5 mm or less at the position of the specimen. An insertion technique was used to obtain c and α relative to the values for water, and an analogue spectrum analyser allowed α to be measured as a function of frequency.

RESULTS

Measurements were made only when it was apparent that the sound beam passed through only one of the kinds of breast tissue listed in table 1. An average value was then computed for each kind of tissue in each specimen. This was done at each of two temperatures, 20°C and 37°C. Figs 4 and 5 are examples of results from three kinds of tissue within a single specimen. These examples can not be said to be typical, however, since velocity in breast parenchyma, and attenuation in parenchyma or fat, displayed a variable temperature dependence. Figs. 6, 7 and 8 summarize all of the data for those measurement sites which included only normal breast fat or only the tumour.

DISCUSSION

These data provide confirmation of the trends suggested by data in the literature regarding average values for c and α in breast tissues, and their dependences on temperature and frequency. The very high values of α given in the references cited in Fig. 3 were, however, not confirmed.

The proportion of fat present in a given volume of tissue and the prevalence of fat/non-fat interfaces are the major determining factors for the local acoustic properties of breast tissue. Thus c is low and dc/dT (the temperature coefficient) negative for normal fatty breast tissue, high with dc/cT positive for breast carcinoma, and of intermediate value with a variable positive or negative dc/dT for normal dense breast parenchyma. Considerable variability and overlap exists in the values for α for tumour and normal breast, particularly at high frequencies and at body temperature. This is consistent with previous observations that the degree of attenuation or acoustic shadowing alone is not always a reliable sign of malignancy (Fields, 1980; Greenleaf and Bahn, 1981). This appears to be particularly so for larger lesions, such as were involved in this study (Jellins et al, 1978). For any frequency in an individual specimen $d\alpha/dT$ may be positive or negative for all types of breast tissue, although there is a tendency for this quantity to be small for tumours and positive for normal breast at frequencies above 4 MHz. The latter result is at variance with previous observations for pure fat (Bamber and Hill, 1979) and suggests that scattering of some kind may contribute strongly to attenuation in the breast, even in fatty areas. Some support for this is provided by qualitative observations at the time of measurement, that for fatty areas high values of α and a positive $d\alpha/dT$ tended to be associated with regions of greater structural heterogeneity and greater spatial variation of c. However, these comments are made here with some reservation since a uniformly thick specimen was not always easy to obtain.

Temperature is an important factor to be considered when performing ultrasonic studies on in vitro breast tissue, including studies where pulse-echo images of excised breasts are compared with gross histological structure. It seems likely that optimum conditions for velocity or pulse-echo imaging will be achieved by maximizing the breast temperature (Bamber and Hill, 1979), whereas optimum tumour:normal tissue contrast in attenuation coefficient may occur at low temperatures and low frequencies (see Fig. 7). Wagai (1982) has used ultrasonic and microwave heating to enhance the echographic appearance of breast tumours *in vivo*, and Kelly Fry et al (1981) feel that for purposes of differentiating benign and malignant lesions the acoustic shadow sign is better observed at a frequency of 2.25 MHz than at 5.0 MHz.

REFERENCES

Bamber, J.C. and Hill, C.R., 1979. Ultrasonic attenuation and propagation speed in mammalian tissues as a function of temperature. *Ultrasound Med. Biol.* *5*, 149-157.

Calderon, C., Vilkomerson, D., Mezrich, R., Etzold, K.F., Kingsley, B. and Haskin, M., 1976. Differences in the attenuation of ultrasound by normal, benign and malignant breast tissue. *J. Clin. Ultrasound*, *4*, 249-254.

Fields, S.I., 1980. Ultrasound mammographic-histopathologic correlation. *Ultrasonic Imaging*, *2*, 150-161.

Foster, S.F. and Hunt, J.W., 1979. Transmission of ultrasound beams through human tissue - focussing and attenuation studies. *Ultrasound Med. Biol.*, *5*, 257-268.

Frucht, A.H., 1953. Die Schallgeschwindigkeit in Menschlichen und Tierischen Geweben. *Z. Gesamte Exptl. Med.* *120*, 526-557.

Glover, G.H., 1977. Computerised time-of-flight ultrasonic tomography for breast examination. *Ultrasound Med. Biol.* *3*, 117-127.

Glover, G.H., 1979. Characterization of *in vivo* breast tissue by ultrasonic time-of-flight computer tomography. in *Ultrasonic Tissue Characterization II* (Ed. Linzer, M.) NBS Spec. Publ. 525, U.S. Govnt. Printing Office, Washington D.C., 221-225.

Goss, S.A., Johnston, R.L. and Dunn, F., 1978. Comprehensive compilation of empirical ultrasonic properties of mammalian tissues. *J. Acoust. Soc. Amer.* *64*, 423-457.

Goss, S.A., Johnston, R.L. and Dunn, F., 1980. Compilation of empirical ultrasonic properties of mammalian tissues, II. *J. Acoust. Soc. Amer.* *68*, 93-108.

Greenleaf, J.F., Johnson, S.A., Bahn, R.C. and Rajagopalan, B., 1977. Quantitative cross-sectional imaging of ultrasound parameters. *1977 Ultrasonics Symp. Proc.*, IEEE Cat.No. 77CH1264-ISU, 989-994.

Greenleaf, J.F. and Bahn, R.C., 1981. Clinical imaging with transmissive ultrasonic computerized tomography. *IEEE Trans. Biomed. Eng. BME-28*, No. 2, 177-185.

Jellins, J., Kossoff, G., Barraclough, B.H. and Reeve, T.S., 1978. Comparative study of breast imaging by echography and xerography. in *Recent Advances in Ultrasound Diagnosis* (Ed. Kurjak, A.) Excerpta Medica, Amsterdam-Oxford, 299-304.

Kelly Fry, E., Sanghvi, N.T., Fry, F.J. and Gallager, H.S., 1979. Frequency dependent attenuation of malignant breast tumors studied by the fast Fourier transform technique. in *Ultrasonic Tissue Characterization II* (Ed. Linzer, M.) NBS Spec.Publ. 525, U.S. Govnt Printing Office, Washington D.C., 85-91.

Kelly Fry, E., Harper, P. and Gardner, G.W., 1981. Possible misdiagnosis of sound attenuating masses as detected by ultrasound visualization techniques and solutions to this problem. *Proc. of the 26th Ann. Meeting of the Amer. Inst. Ultrasound in Med.* August 1981, San Francisco, California, p.129 (abstract).

Kobayashi, T., 1978. Ultrasonic tissue characterization of breast cancer: correlation of attenuation and echo-pattern. in Recent Advances in Ultrasound Diagnosis (Ed. Kurjak, A.) Excerpta Medica, Amsterdam-Oxford, 281-291.

Kossoff, G., Kelly Fry, E. and Jellins, J., 1973. Average velocity of ultrasound in the human female breast. J. Acoust. Soc. Amer. 53, 1730-1736.

Laffey, P. et al., 1976. New techniques for ultrasonic imaging. Radiology, 120, 385-388.

Lang, J., Zana, R., Gairard, B., Dale, G. and Gros, Ch.M., 1978. Ultrasonic absorption in the human breast cyst liquids. Ultrasound Med. Biol. 4, 125-130.

Le Croissette, D.H., Heyser, R.C., Gammell, P.M. and Wilson, R.L., 1978. Final Report: Tissue identification by ultrasound, JPL report for the NSF, California Institute of Technology, Pasadena, California.

McDaniel, G.A., 1977. Ultrasonic attenuation measurements on excised breast carcinoma at frequencies from 6 to 10 MHz. 1977 Ultrasonics Symp. Proc. IEEE Cat.No. 77CH1264-1SU, 234-236.

Nakaima, N., Aoyama, H. and Oka, M.J., 1976. Supplementary study on the ultrasonic absorption of human soft tissues. J. Wakayama Med. Soc. 27, 107-115.

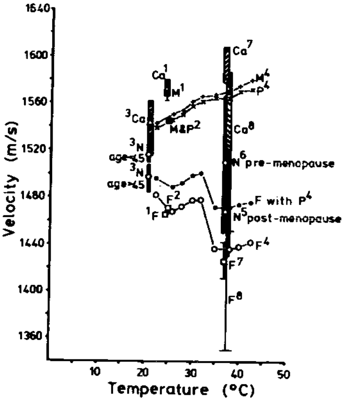
Oka, M., 1977. Progress in studies of the potential use of medical ultrasonics. Wakayama Med. Rep. 20, 1-50.

Rajagopalan, B., Greenleaf, J.F., Thomas, P.J., Johnson, S.A. and Bahn, R.C., 1979. Variation of acoustic speed with temperature in various excised human tissues studied by ultrasound computerized tomography. in Ultrasonic Tissue Characterization II (Ed. Linzer M.) NBS Spec.Publ. 525, U.S. Govnt. Printing Office, Washington D.C. 227-233.

Wagai, T., 1982. Echographic differentiation of histological structure of breast cancer and enhancement of breast cancer images by ultrasound irradiation. Ultrasound Med. Biol. 8, 440 (abstract).

Symbol	Tissue
S	Skin
N	Normal breast average value (may include skin if present)
F	Normal breast fat (subcutaneous or retromammary)
P	Parenchyma, glandular tissue, connective tissue (including intraglandular fat, ducts, ligaments, etc.)
M	Muscle
Ca	Primary breast carcinoma (all types)
FC	Fibrocystic disease
CL	Cyst liquid

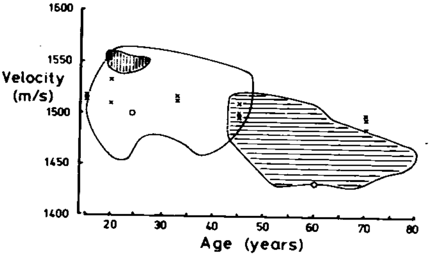
TABLE 1. Definition of symbols used to represent the component tissues and pathological structures of the breast.



KEY:

Number	Frequ. (MHz)	Temp. (°C)	No. of specimens	Reference
1	1·8	24	?	Frucht (1953)
2	2	25	1	Kossoff et al (1973)
3	?	room	12	Greenleaf et al (1977)
4	?	various	1	Rajagopalan et al (1979)
5	2	in-vivo	18	Kossoff et al (1973)
6	"	"	14	"
7	5	"	?	Glover (1977;1979)
8	8		18	Greenleaf and Bahn (1981)

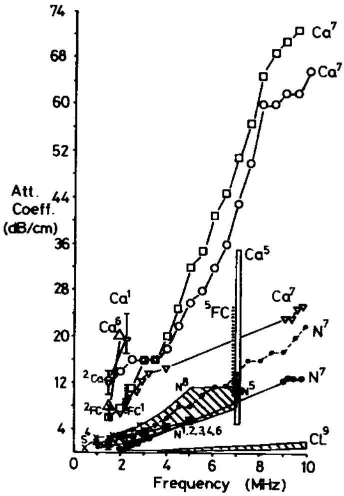
Fig. 1. Compilation of data on sound velocity in normal and diseased human breast tissues at various temperatures (*in vivo* and fresh *in vitro* specimens). Symbols as in Table 1.



KEY:

Symbol	Temp.	Frequ. (MHz)	Remarks	Reference
⬭	in-vivo	2	Boundary of 104 data points (pre-menopause).	Kossoff et al (1973)
▤	"	2	Boundary of 40 data points (post-menopause).	"
▥	"	2	Boundary of 10 data points (lactating breasts).	"
×	room	?	12-48 hrs after excision, stored in refrigerator.	Greenleaf et al (1977)
○	in-vivo	?	Averages along central lines though ultrasonic computed tomograms, assuming an average water bath temp of 34°C	Glover (1977)

Fig. 2. Compilation of data on average sound velocity through normal human breasts at various ages (*in vivo* and fresh *in vitro* specimens).



KEY:

Number	Temp. (°C)	Number of specimens	Age (years)	Condition	Reference
1*	35	13 (N) 8 (Ca) 7 (FC)	?	Fixed	Calderon et al (1976)
2	35	7	?	Fixed	Laffey et al (1976)
3	40	?	?	Fresh	Oka (1977)
4	40	?	?	Refrigerated	Nakaima et al (1976)
5	23 or 37	?	?	Fixed	McDaniel (1977)
6	23	1	49	Fixed	Kelly Fry et al (1979)
7	37	2	>35	Fresh	Le Croissette et al (1978)
8	25 & 37	6	54-74	Fresh	Foster and Hunt (1979)
9	25 or 37	6	?	Fresh	Lang et al (1978)

* These values were calculated from information given in the reference, assuming an average frequency of 2·25 MHz. A single carcinoma, additional to the set of 8, gave $\alpha = 6{\cdot}7$ dB/cm.

Fig. 3. Compilation of data on sound attenuation coefficient for normal and diseased human breast tissues at various frequencies (fresh or formalin fixed *in vitro* specimens at temperatures in the range 23 - 40 °C). Symbols as in Table 1.

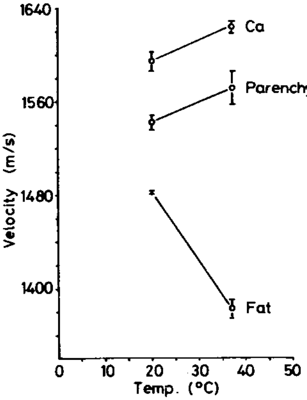


Fig. 4. Mean and range of 4 measurements of sound velocity through each of 3 kinds of tissue within a single breast. Symbols as in Table 1.

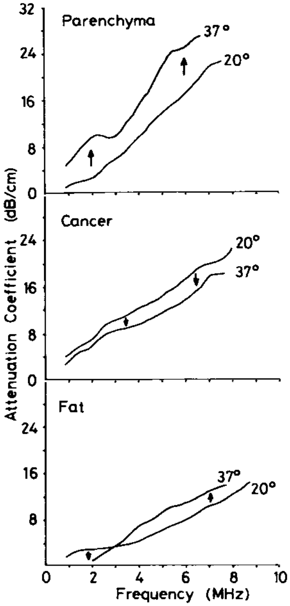


Fig. 5. Variation of mean attenuation coefficient with frequency and temperature for the same specimen as fig. 4.

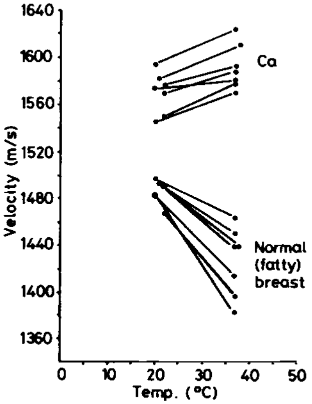


Fig. 6. Velocity of sound at room and body temperature in 7 breast specimens (each data point represents an average over 3 - 5 positions). Symbols as in Table 1.

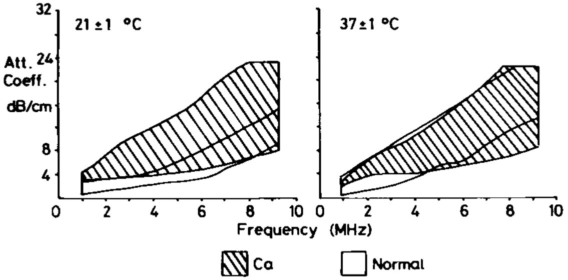


Fig. 7. Range of mean attenuation coefficients of breast cancer and normal (fatty) breast in 7 specimens; 56 positions, 3 to 5 positions per average. Symbols as in Table 1.

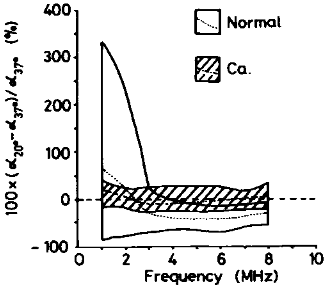


Fig. 8. Range of mean values per specimen, and overall mean values, for the percentage difference between the attenuation coefficients at room and body temperatures. Other details as for fig. 7. Symbols as in Table 1.