EXPLICIT USE OF ULTRASONIC PROPAGATION PROPERTIES FOR TISSUE CHARACTERIZATION

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Abstract

It is suggested that enhanced 'contrast' can possibly be obtained, in the identification of some pathological states by ultrasonic techniques, wherein greater use is made of the available knowledge of tissue properties. An example, employing model materials and involving loss and time-of-flight measurements, illustrates the basic idea.

I. Introduction

In the identification of deviations from normality, as sought by an image-producing schemata, the deviant structures either must be significantly different in elementary properties to be clearly exhibited, or a processing of the signals may be perpetrated to enhance the contrast to a usable level. Both strategies are recognized in ultrasonic clinical diagnosis (i.e., some disorders are exhibited with relative ease as the impedance of the pathological state is sufficiently different from that of the normal tissue (Fields and Dunn, 1973) and a possible subfield has emerged, often referred to as 'tissue characterization', wherein processing of the received data is attempted in order to glean information in those situations for which deviations from normalcy could not otherwise be observed (WFUMB, 1982). 'Tissue Characterization' appears to have attracted attention, and some investigators with skills and instrumentation (largely associated with established signal processing methods) have attempted application to clinical diagnostic situations. Though some progress is being made (and more is certain to appear) it may be that not as much detail has been utilized, from basic ultrasonic tissue propagation properties, as is available, and that a more complete utilization could be beneficial.

This note describes, as an example only, a proposed utilization of elementary properties of biological media for enhancement (or exaggeration) of features which may, under appropriate circumstances, allow an otherwise non-outstanding pathological state to be identified clinically. It is considered that the data available is that from current clinical-type instruments, but that use is to be made, additionally, of available knowledge of the ultrasonic propagation properties of tissues for suggesting other data handling procedures. One such procedure is discussed briefly, but only as an example of a possibly much broader field of endeavour. Measurements on a kind of tissue model are presented to illustrate the ideas proposed.

II. Ultrasonic velocity and attenuation in tissues

It has been suggested (Goss et al., 1980b), and data compilations appear to support the view (Goss et al., 1978; 1980a), that the attenuation coefficients of tissues increase faster than linearly with total protein content, and with the fraction of protein that is collagen. This appears to be the case for the five groupings of tissues extending, teleologically, from vascular fluids to adipose tissues, to parenchymal tissues, to stromal tissues, and to structural framework tissues (Dunn, 1976). For example, at 1MHz, the attenuation coefficient approximately doubles from group to succeeding group in this series (lung may be the only tissue omitted in this discussion as its attenuation is much greater than any of the above, and originates from completely different mechanism (Dunn and Fry, 1961).

It has been suggested, and investigation appears to confirm (Goss et al., 1980b), that the speed of ultrasound in tissues also increases with globular and structural protein content. Thus, the product of velocity (speed) and attenuation should increase more rapidly than either of these two quantities considered alone, with, for example, increasing protein content.

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Further, the transition of a tissue or organ from the normal/healthy state to the diseased/pathological state often involves alterations in protein content. Examples are cirrhosis of the liver and infarction of cardiac muscle, wherein normal tissue becomes replaced by fibroid tissue having a relatively high collagen content. It has been reported that the speed of sound and the attenuation both increase with progression of these disorders, and this may be the case for all fibrocystic diseases (Omoto and Kobayashi, 1981). Alternatively, conditions in which solid tissues are infiltrated by fluid volumes dilute in protein content may, according to the above considerations, exhibit decreases in prevailing speed of sound and attenuation values (Omoto and Kobayashi, 1981).

Thus, the opportunity may exist to obtain a greater difference in a tissue parameter than that provided by the velocity or attenuation alone, by involving both simultaneously; provided these changes occur with some directivity.

III. Example of tissue property advantage

The following rather simple example may serve to illustrate the use of ultrasonic propagation properties of tissue to advantage in obtaining increased 'contrast' between normal and pathological states.

Consider a plane acoustic wave propagating in an extended homogeneous and isotropic fluid-like medium. If $p_1(x)$ is the sound pressure at the position x and $p(0)$ is the reference sound pressure at $x = 0$, the decrease in the sound pressure amplitude (i.e. the loss L_1 in the path $x = 0$ to $x = x$) is, by general usage and definition,

$$L_1 = 20 \log \frac{p_0}{p_1} .$$

A similar relation describes the loss in the path from $x = x_1$ to $x = x_2$, and so the decrease in the sound pressure of the wave in travelling from x_1 to x_2, the distance ℓ, is

$$A = 20 \log \frac{p_1}{p_2} .$$

The attenuation coefficient for the medium is computed from

$$\alpha = A/\ell .$$

Now, by definition of the speed of the wave process in the medium, $\ell = vt$, where v is the speed of travel of the wave from position x_1 to position x_2 over the distance ℓ, and t is the time interval required for this travel to occur. Thus,

$$\alpha = A/\ell = A/vt$$

and

$$v\alpha = A/t \text{ (dB/sec)},$$

and it appears that the product wave-speed x attenuation coefficient ('spedatt') can be determined by dividing the wave amplitude decrease in propagating between two positions along its path by the transit time between the same two positions. Ordinary A-scan data can possibly be processed directly to determine the parameter, which, if both v and α increase (or decrease) together, should provide a more sensitive indicator of the existence of a pathological state than either alone.

Table 1. Tissue model materials, properties and measured parameters.

Material	f (MHz)	Thickness (cm)	Loss (dB)	t (μs)	α (dB/cm)	v (m/s)	$v\alpha(=L/t)\times10^{-6}$ (dB/s)
Acrylic resin	5.5	0.503	3.90	1.825	7.75	2756	2.14
	6.0		4.25		8.45		2.33
	6.5		4.51		8.97		2.47
Bakelite	5.5	0.496	8.57	1.700	17.3	2918	5.04
	6.0		9.24		18.6		5.44
	6.5		9.81		19.8		5.77

IV. Tissue model measurements

Measurements were made with plates of acrylic resin and Bakelite to simulate normal and pathological states, respectively, of a tissue. Table 1 lists the materials used and their pertinent properties. The observed loss was determined from the spectral data of the echoes received, in response to a 1μs normal incidence pulse repeated at 1kHz, from the front and back flat, parallel surfaces. The transmission time was obtained from A-scan data.

Here it can be considered that the acrylic resin corresponds to a normal state and that, due to a pathological condition, it becomes altered to the properties exhibited by the Bakelite, viz., a substantial increase in attenuation but a lesser increase in the speed of sound. These changes correspond, at least in kind, to the changes occurring in tissues associated with collagen content-increase disorders. It is seen that the attenuation increase of approximately 120% is enhanced to 135% on utilization of the spedatt parameter A/t.

V. Discussion

The purpose herein has been to suggest that by making better use of what is known of ultrasonic propagation properties of tissues, an enhancement in 'contrast' between normal and pathological states may accrue. The example given, admittedly contrived, does, however, illustrate the point. Investigators will, no doubt, identify other examples.

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References

[1] Dunn, F., *Ultrasonic Attenuation, Absorption and Velocity in Tissues and Organs,* In *Ultrasonic Tissue Characterization* (NBS Publ. 453), ed. M. Linzer (U.S. Gov't Print Office, Washington, D.C. 1976), pp. 21-28.

[2] Dunn, F. and Fry, W.J., *Ultrasonic Absorption and Reflection by Lung Tissue, Phys. Med. Biol.* **5**, 401-410 (1961).

[3] Fields, S. and Dunn, F., *Correlation of Echographic Visualizability of Tissue with Biological Composition and Physiological State, J. Acoust. Soc. Am.* **53**, 809-812 (1973).

[4] Goss, S.A., Johnston, R.L. and Dunn, F., *Comprehensive Compilation of Empirical Ultrasonic Properties of Mammalian Tissues, J. Acoust. Soc. Am.* **64**, 423-457 (1978).

[5] Goss, S.A., Johnston, R.L. and Dunn, F., *Compilation of Empirical Ultrasonic Properties of Mammalian Tissues II, J. Acoust. Soc. Am.* **68**, 93-108 (1980a).

[6] Goss, S.A., Frizzell, L.A., Dunn, F. and Dines, K.A., *Dependence of the Ultrasonic Properties of Biological Tissue on Constituent Proteins, J. Acoust. Soc. Am* **67**, 1014-1044 (1980b).

[7] Omoto, R. and Kobayashi, M., *Atlas of Essential Ultrasound Imaging,* (Igaku-Shoin, Tokyo, 1981), pp. 1-311.

[8] WFUMB, *Abstracts for Fifth World Congress of Ultrasound in Medicine and Biology, Ultrasound Med. Biol.* **8**, Suppl. 1, 1-220 (1982), see as example.

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