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Prof. B. Ramachandra Rao

"Ultrasonic propagation properties of mammalian tissues and organs: An epitome,"

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Prof. B. Ramachandra Rao

Biographical Sketch

Prof. B. Ramachandra Rao was born on 23rd November 1922, at Yellamanchili, in the Visakhapatnam District, Andhra Pradesh.

After schooling at the Mrs. A.V.N. College High School, he joined the B.Sc. (Hons.) Physics course in the Andhra University in 1941. He secured a first class and won the Sripathi Medal in 1944. He did M.Sc. by research during 1944-45, and also secured a first class. His thesis was adjudged the best for the year and he was awarded the coveted Metcalfe Medal. He later did research under the guidance of Prof. S. Bhagavantham in the field of Ultrasonics. The D.Sc., degree was awarded to him by the Andhra University in 1948 for his thesis entitled "Diffraction of Light by High Frequency Ultrasonic Waves".

Prof. Rao continued his work in Ultrasonics with vigour and developed a number of highly useful techniques and devices in the Ultrasonics Laboratory of the Andhra University. He published over 100 research papers on a wide range of topics including Diffraction of Light by Ultrasonic Waves, elastic constants of solids, velocity, dispersion, and absorption of ultrasonics in liquids, liquid mixtures, polymers, electrolytes and their solutions.

In 1951, Dr. Rao visited Australia as the first Commonwealth Senior Research Fellow and conducted research in ionosphere and Space Physics, under the guidance of Prof. D.F. Martin, F.R.S. This was a significant turning point in the scientific career of Dr. Rao. The ionosphere Space Research Laboratory established by Dr. Rao at the Andhra University is a reputed International Centre for research.

In 1953 he was elevated to Professorship at the University.

Prof. Ramachandra Rao succeeded Prof. S. Bhagavantham at Andhra University and further developed the Physics Department by starting new courses, research programmes, and training of teachers from affiliated colleges. He directed research programmes of a large number of scholars in the Physics Department of the Andhra University and produced 36 doctorates. He has published more than 300 research publications.

In recognition of his extraordinary research work, the highest National Honour, Shanti Swarup Bhatnagar Award of CSIR, for Physical Sciences was awarded to him in the year 1965.

Several research projects were planned and executed by Dr. Rao, with financial assistance from the UGC, CSIR and Defence Organisation and under the PL 480 Indo-US collaboration scheme.

Dr. Rao has been a great builder of institutions. He started the Acoustical Society of India, in the year 1971; and has been its Secretary & Treasurer for many years. He was its President during 1980-81. The Society has been publishing a Quarterly Journal entitled "The Journal of the Accustical Society of India".

Prof. Rao has intimate and fruitful association with many national and international bodies connected with Scientific Research and Science Education. Dr. Rao is a Fellow of the Indian Academy of Sciences, Founder Fellow of the Andhra Pradesh Academy of Sciences, Fellow of the British Institute of Radio Engineers, Fellow of the Physical Society of London and the Fellow of the Indian Geophysical Union. He has been a Member of the Indian Science Congress Association since 1954 and was the President of the Tirupati Session in the year 1983.

He was appointed Vice Chairman of University Grants Commission in 1976 and continued for two consecutive terms. Dr. Rao shaped and directed many innovative programmes for streamlining the system and bringing about qualitative improvement in Higher Education.

An important step taken by Prof. Rao was the sponsoring of the scheme for establishing University Service and Instrumentation Centres. Nearly 60 Universities in India are at present operating this scheme.

Prof. Ramachandra Rao has had close connections with several All India organisations in other areas of Science as well. Prof. Rao has always actively involved him self in the social, educational and cultural life of the society around him and to improve the conditions of the weaker sections of the community by providing benefits like better educational facilities to their children. He is currently Vice President, Association for Continuing Education, New Delhi.

With his entry in to the Rajya Sabha in 1982, Dr. Rao's Career has taken a new significant turn. He now has endless opportunities for translating his ideas and ideals into reality. He is a valuable source of strength to the Government of India in advancing science and technology for the progress of the Indian Society.

Dr. Rao is an eminent Scientist dedicated to the twin causes of knowledge and humanity. His life is an abiding source of inspiration to his students, colleagues and admirers.

The Accustical Society of India dedicate this issue of the Journal to Prof B. Ramachandra Rao.

Ultrasonic Propagation Properties of Mammalian Tissues and Organs : an Epitome

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ABSTRACT

A brief account is given of the ultrasonic wave speed, attenuation, absorption, and their dependencies upon freqcency, temperature and tissue composition. It emerges that the ultrasonic propagation properties of these tissues are governed, to some extent, by their biochemical compositions. Thus, characterization of these materials by determination of wave propagation parameters, at least for some tissue-specific states, is encouraged.

I. Introduction

The propagation of an acoustic signal in biological media is characterized by variations in the physical variables that describe the state of the tissue. Changes can occur, for example, in the wave amplitude, temperature, density, and pathology. Since not all these quantities are measurable, at least not with usable accuracy and precision, compromises and accomodations must be reached and understood in order that the available data can be employed sensibly for biophysical and medical purposes. The "ultrasonic propagation properties" of a tissue include the speed at which the ultrasonic signal travels in a tissue, the attenuation/absorption of the wave energy by the tissue, and the features of the tissue responsible for reflection and scattering, phenomena generally embodied in the concept of impedance. Herein, the ultrasonic properties are briefly examined in terms of the reportings of measurements (1,2, and discussed concisely according to the above listing as categories. Generalizations are then attempted in order to characterize tissues from these categorical suggestions.

II. Speed of Sound

Data for the speed of ultrasound in tissues and organs come almost entirely for measurements of excised tissues (1,2). Examination of these data, in the temperature range 20-40°C (Table I), shows that there is an appreciable range in the reported values which is believed to result from the use of different measuring methods, from different specimen temperatures during the measurements, from different methods of specimen preparations, and from diffrent examples of specimens having been chosen. The range of the data standard deviations extends from less than 2% for brain, liver and kidney to approximately 7% for skin. The mean ultrasonic velocity for 21 tissues for which data have been reported, is 1581± 66m/sec. Note that the entries in Table I are listed according to increasing total protein content. A listing according to total collagen content would be similar, but not identical.

III. Attenuation

Because mammalian tissues and organs generally exhibit speeds of sound approximately the same as that of water, it has become customary to consider the soft tissues as being liquid-like media having densities and compressibilities much like water but with significantly different attenuation and absorption behavior, viz., much greater magnitudes and nearly linear, rather than quadratic, dependence upon frequency.

The published literature (1,2) exhibits a very appreciable range of reported values apparently reflecting the greater difficulty in making such measurements and in interpreting the resulting data (3,4), though it must be noted that measurement methods and specimen prepration have improved with time and experience as published values have decreased (5).

Though the reported attenuation range is more than 100% in some cases, the data can be described by

$$A = aF^b \qquad (1)$$

Where A is the attenuation coefficient in nepers/centimeter, F is the frequency in megahertz, and a b are constants determined from the published *in vivo* and *in vitro* data. Table II exhibits the values of these parameters for several tissues, or which sufficient data are available, in the frequency range approximately 1-10 MHz and in the temperature range 20-40°C. The parameter R is a measure of the goodness of fit of the data to eq. 1, with $R=1$ indicating a perfect fit.

These data show that the frequency dependence of attenuation is nearly linear for these four rather distinct tissues, over the 1-10 MHz frequency range. The magnitude of the attenuation coefficient, however, appears to be somewhat more dependent upon tissue type, with muscle and fat exhibiting attenuation magnitudes roughly twice that reported for brain (in the lower end of this frequency range). As the macrostructural characterstics of tissue affect the degree to which scattering losses at a given frequency contribute to the overall attenuation loss, increased attenuation in heterogeneous tissue might be expected to occur over those of more homogeneous structural features.

IV. Absorption

Few methods are available for direct measurement of ultrasonic absorption in tissues (4). The transient thermoelectric method has been used recently for measurements in freshly excised tissues as a function of frequency (6). For a description of the ultrasonic absorption coefficient similar to that for the attenuation coefficient, viz , eq. 1, the exponents on frequency, i.e. the parameter b, are found to vary from 1.02 to 1.08 among testis, kidney, heart, brain, liver and tendon, even though these tissues represent substantial differences in chemical and structural compositions. A pronounced difference in the magnitudes of the absorption are, however, extant as tendon exhibits an absorption that is approximately four times greater than that of liver, brain, heart or kidney, which in turn are about twice that of testis.

It should be noted as well that heart, brain and kidney have approximately 16-18% protein, of which 1-2% is collagen, and about 71-76% water. Tendon, on the other hand, has a total protein content of 35-43%, of which 30% is callagen, but with a water content of only 63%. Testis, which has among the very highest water contents, viz, more than 80%, has very little collagen and a protein content of about 12%.

The ultrasonic absorption, for the single organ liver from beef, pig, cat and mouse, in the frequency range 0.5-7 MHz, all at 37°C, has been found to exhibit little, possibly negligible, difference among these species.

Comparison of these absorption values with average values for attenuation taken from the literature (Table II) yields interesting contrasts (6), viz., that there is little difference in the frequency dependence of absorption and of attenuation in the frequency range 0.5-7 MHz, but that their magnitudes are greatly different, with attenuation being substantially greater than absorption.

V. Temperature Dependence

Measurements of the temperature dependence of attenuation of excised tissues generally yield a decreasing dependence with temperature, as is expected when dealing with a fluid viscosity mechanism However, the situation for *in vivo* absorption, which is the more pertinent quantity, may be considerably different. As it is very difficult to conduct observations as a function of temperature with an ordinary mammal, because of their superior temperature-controlling apparatus, measurements have been made using young mice approximately 24 hrs after birth, which are essentially poikilothermic animals (7,8), The general demeanor of these studies are that the frequency-free absorption α/f^2 *vs* temperature comprises a family of curves whose maxima decrease and move toward ever increasing temperatures, as a function of increasing frequency. Thus, depending upon animal temperature and ultrasonic frequency, an increasing or a decreasing temperature dependence, or even no temperature dependence, of the ultrasonic absorption may be obtained.

VI. Dependence upon Constituent Macromolecules

The absorption of ultrasound in tissues is largely determined by the protein constituents and, because of this, aqueous solutions of proteins have been studied as model systems for which the tissue architecture becomes associated with the remaining portion of the attenuation (S). Such studies have involved both the globular proteins (9), which carry out the biochemical events in the physiological processes of the various organs, and the structural proteins (10) (largely collagen), which provide a framework for maintaining tissue structure integrity.

It has been observed that tissues comprised mainly of the structural proteins, mostly collagen, have much different elastic properties than do tissues having little collagen or those tissues predominately comprised of globular proteins (11). The speeds of sound of solutions of globular proteins and suspensions structural proteins are linear functions of the total protein content, with the structural proteins yielding the greater slop. When the speeds of sound of the various tissues are plotted on such a graph, it is found that they fall between these two curves, with those tissues predominately comprised of globular protein appearing near the globular protein (collagen-free) curve. Similarly, the collagenous tissues, such as tendon, where a substantial fraction of the protein is in the form of collagen, appear well above the globular protein curve and near the structural protein curve. It thus appears that the ultrasonic velocity in tissues in governed, in some way, by the ultrasonic properties of the individual macromolecular constituents comprising them.

Ultrasonic absorption appears to be governed by similar relationships. The absorption of collagen suspensions, as a function of the concentration C, is given approximately by $\alpha_c = 1.8 \times 10^{-3} c^{1.2}$ in the concentration range 0.07% to 3.7% collagen content, while that for globular protein solutions is given by $\alpha g = 5.3 \times 10^{-4}\ C^{1.2}$ in the conentration range 5% to 40%, all at 1 MHz. The absorption coefficients of tissues for which sufficient data are available for comparison, viz., brain, heart, kidney, liver, tendon and testis, fall between α_g and the α_c (extended) curves.

It thus appears the absorption in tissues may be considered a linear superposition of the absorption properties of their protein constituents, and may further apper, at least to a first approximation, as composite materials whose ultrasonic properties are governed by the individual ultrasonic properties of their structural and globular protein contents.

VII. Summary

From the foregoing, it appears that the ultrasonic propagation properties of tissues are determined, to possibly an appreciable extent, by their biochemical compositions. The paucity of available data from the measurements of the veary small number of tissues that have been studied does not provide for further generalizations. Perhaps future detailed measurements will allow assignment of resolvably singular values to each tissue structure, including usefully differentiable values for pathologcal states, so that attenuation, velocity and imedance values, as functions of state and acoustic parameters, should specify uniquely tissues for diagnostic purposes. An encouraging example is that of normal tissues, should be easily identified clinically, and it is. Contrariwise, metastases of, say nerve tissue neoplasm in liver are probably not identifiable, at least in the early stages before cirrhosis of the liver tissue begins, as suggested by the contents of Table II. A current major problem of prediction is the lack of data on abnormal tissues.

VIII. Acknowledgement

The author acknowledges gratefully partial support, for portions of the activities described herein, by grants from the National Institutes of Health.

TABLE I

Ultrasonic propagation speed in some mammalian tissues, in order of increassing table protein content.

Tissue	Speed of Sound (m/sec)
Fat	1412-1510
Brain	1530-1578
Testis	1596
Heart	1569-1602
Kidney	1565-1582
Muscle	1532-1622
Liver	1574-1613
Spleen	1549-1616
Uterus	1625-1634
Cornea	1559-1639
Sclera	1609-1718
Skin	1493-1734
Lens	1596-1616
Tendon	1730-1754

TABLE II

Ultrasonic attenuation coefficient in *in vivo* and fresh *in vitro* mammalian liver, brain, muscle and fat specimens in the temperature range 20-40°C, as a function of frequency. (See text for further explanation)

Tissue	a	b	R
Liver	0.0995	1.05	0.89
Brain	0.070	1.14	0.82
Muscle	0.140	0.926	0.75
Fat	0.126	1.09	0.75

$A = aF^b$; R, goodness of fit.

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