FREQUENCY DEPENDENT ULTRASONIC ATTENUATION COEFFICIENT ASSESSMENT IN FRESH TISSUE

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Abstract

Ultrasonic attenuation coefficient measurements were made at 1.4, 4.2, 7.0 and 9.8 MHz using a phase insensitive, radiation force balance technique. Ultrasonic attenuation coefficient vs ultrasonic frequency relationships were determined for liver, spleen and pancreas of bovine, porcine and sheep using linear regression analysis techniques. All measurements were made at room temperature (24°C), in saline, within 5 1/2 hours of slaughter. Utilizing linear regression, the data shows that the frequency dependency of the ultrasonic attenuation coefficient ranges from $f^{0.78}$ to $f^{1.36}$ and its magnitude at 1 MHz ranges from 0.037 to 0.12cm^{-1}. This approach may be limited since, for most of the data, the frequency dependent attenuation coefficient must be described by a higher ordered function than a simple power fit. Also, hydroxyproline (a quantitative index for collagen concentration) was measured and no obvious trend emerged.

Introduction

With the emergence of diagnostic equipment and continuing research in acoustic imaging, there comes an increasing desire to characterize tissue quantitatively. Tissue attenuation, which is a measure of the total loss (due to heating, reflections, scattering, diffraction, and refraction) of an ultrasonic wave as it propagates through the tissue, provides one means of tissue characterization. This study attempts to determine the frequency dependency of the attenuation coefficient for six tissues using the radiation force balance technique. A total of 880 insertion loss measurements were made over the course of nine months in an attempt to build a large data base utilizing one well characterized measurement technique with well characterized tissue.

Acoustical Development

The radiation force balance technique for measuring ultrasonic attenuation follows from developments both in nonlinear acoustics and in experimental procedures for determining total acoustic power.

Nonlinear acoustic theory states that the Langevin radiation pressure on a perfectly absorbing target in an open vessel is

$$P_L = \langle E \rangle = \frac{I}{c_o} \qquad (1)$$

where <E> is the average acoustic energy density, I is the acoustic intensity and c_o is the speed of sound in the medium (1). Multiplying Langevin radiation pressure by the area of the sound beam yields the radiation force

$$F_L = A P_L = \frac{AI}{c_o} = \frac{W_A}{c_o} \qquad (2)$$

where Wa is the total (temporal average) acoustic power. Experimental procedures for measuring total acoustic power typically measure the force via a balance apparatus. Multiplying that force by the speed of sound yields total acoustic power. Attenuation measurements can be made similarly by using the insertion loss technique which will be described in the next section.

System Components and Data Acquisition

The system for making attenuation measurements in this study was established at the Bioacoustics Research Laboratory (2). A system block diagram appears in Figure 1.

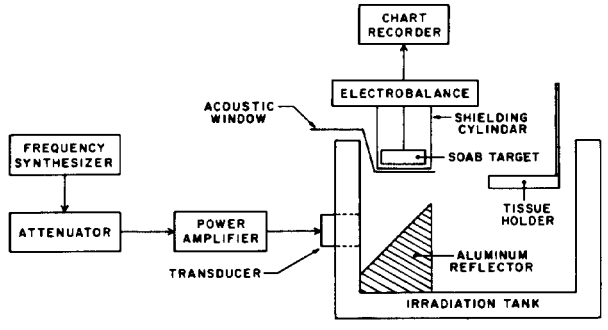

Figure 1. Radiation force balance system bock diagram.

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The output of the Hewlett Packard 8660B frequency synthesizer feeds into a Kay Elemetrics precision attenuator. The attenuator is used in two states, 0dB, which corresponds to full power, and 70dB, which corresponds to zero power. The output of the attenuator is connected to a power amplifier (Electronic Navigation Industries, model 310L) and then to the transducer. The 1.39 MHz fundamental frequency transducer focuses onto a 45° reflecting block which reflects the sound field up to a SOAB (B. F. Goodrich) target, which is suspended from one arm of the Cahn model RG electrobalance. In the absence of a sound field (zero power), the target rests at an equilibrium position, and an equilibrium position is established on the Houston Instruments model 2000 chart recorder. When the sound field is turned on (full power), the radiation force (Eq. 2) imparted onto the SOAB target is detected by the balance and chart recorder. Figure 2 schematically demonstrates the typical chart recorder record from which the insertion loss is determined.

To determine the insertion loss, IL, an initial value, D_o, is obtained by taking the difference between the full power and zero power deflections. Next, a specimen, of known thickness, is inserted between the reflecting block and the SOAB target and again, zero power and full power deflections, D_s, are determined. The insertion loss is then calculated by the equation

$$IL = 10 \log \frac{D_o}{D_s} \qquad (3)$$

Insertion loss values are plotted as a function of specimen thickness at each frequency. A linear regression analysis

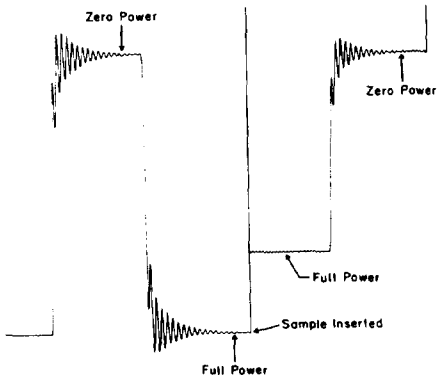

Figure 2. Chart recorder response for a typical insertion loss measurement.

is used to fit a straight line to these data. Ultrasonic attenuation coefficients are then determined from the slope of that line.

Tissue Handling

Fresh tissues were obtained from the University Meat Science Laboratory on campus. Upon slaughter the animals were bled, and the desired tissue was extracted. The extracted tissue was placed in degassed cat ringer at room temperature and transported to the Bioacoustics Research Laboratory. Measurements were completed as early as 68 minutes, or as late as 325 minutes after slaughter, with the average time being 182 minutes.

Data Handling

Five to seven sample thicknesses were measured for each tissue (liver, spleen and pancreas) of bovine, porcine and sheep. The measurements were made at 1.4, 4.2, 7.0, and 9.8 MHz. Five trials were performed for each sample thickness, at each frequency. The average value and standard deviation of insertion loss were calculated for each thickness. Insertion loss versus thickness was plotted for each tissue at each frequency. Four lines (one for each frequency) were determined using linear regression analysis (3) thereby obtaining the slope, intercept and correlation coefficient for each line at each frequency.

To assess the frequency dependency of the attenuation coefficient over the 1.4 to 9.8 MHz range, a best fit line was determined. The slope on a log-log plot is described by N, and the intercept (B) corresponds to the attenuation coefficient value at 1 MHz. Mathematically, the frequency dependency of ultrasonic attenuation is described by

$$A = Bf^N \qquad (4)$$

Results and Discussion

A summary of results from this study appears in Tables 1 and 2. The slopes and correlation coefficients calculated for the insertion loss versus thickness plots appear in Table 1. Table 2 contains calculated slopes and intercepts as described by equation 4. Four of the seven tissues investigated had a value of N which ranged from 0.9 to 1.1 while the remaining three were 0.780, 1.29 and 1.36. The attenuation coefficients at 1 MHz are typical of those for soft tissues (4).

Although the correlation coefficients seem to indicate a strong linear dependence (Table 2), it appears that in some cases (bovine spleen and pancreas, porcine spleen and liver and sheep liver), the attenuation coefficient could be more properly described by a higher ordered function. Perhaps this will limit this approach in the analysis of attenuation coefficient measurements.

The method appears to be repeatable, as Pohlhammer in 1981 (5) determined that for bovine liver, the frequeny dependency of attenuation was $A = 0.043f^{1.27}$, while here a relationship of $A = .038f^{1.36}$ resulted.

An examination of the collegan concentration, or more exactly, the hydroxyproline concentration, of each tissue was also undertaken. An automated amino acid analyzer determined the hydroxyproline concentration by measuring the amount of hydroxyproline present in a hydrolyzed tissue specimen. This technique is similar to a modified assay used to determine hydroxyproline in hydrolyzed tissue (6). This examination did not reveal any statistically significant trends between the hydroxyproline concentration of a tissue and its frequency dependent ultrasonic attenuation coefficient. Because all tissues examined had approximately the same hydroxyproline concentration, it appears that the correlation of this tissue property to the ultrasonic attenuation coefficient is limited for this application.

	FREQ. (MHZ)	1.4		4.2		7.0		9.8	
TISSUE	ANIMAL	SLOPE (NP/CM)	R	SLOPE (NP/CM)	R	SLOPE (NP/CM)	R	SLOPE (NP/CM)	R
LIVER	BOVINE	0.0597	0.395	0.258	0.885	0.533	0.940	0.868	0.971
	PORCINE	0.116	0.843	0.281	0.930	0.533	0.961	0.866	0.961
	SHEEP	0.122	0.724	0.285	0.951	0.497	0.989	0.755	0.995
SPLEEN	BOVINE	0.106	0.814	0.258	0.899	0.579	0.926	0.889	0.941
	PORCINE	0.0835	0.860	0.224	0.950	0.382	0.963	0.643	0.982
	SHEEP	0.0549	0.517	0.251	0.956	0.441	0.977	0.690	0.979
PANCREAS	BOVINE	0.167	0.834	0.308	0.959	0.515	0.983	0.814	0.989

R - CORRELATION COEFFICIENT

Table 1. Summary of results calculated from plots of insertion loss vs thickness.

TISSUE	ANIMAL	SLOPE OF LOG - LOG (N)	INTERCEPT AT 1 MHZ (B)	R
LIVER	BOVINE	1.36	0.0377	1.00
	PORCINE	1.00	0.0778	0.990
	SHEEP	0.916	0.0855	0.994
SPLEEN	BOVINE	1.08	0.0687	0.990
	PORCINE	1.01	0.0571	0.994
	SHEEP	1.29	0.0370	0.999
PANCREAS	BOVINE	0.780	0.119	0.979

Table 2. Summary of results calculated from log-log plots of attenuation vs frequency.

Conclusions

In conclusion, the technical measurement procedure and specimen handling procedures used to determine the frequency dependent ultrasonic attenuation coefficient appear to yield repeatable results, thus enabling intercomparisons. Each tissue measured resulted in distinct attenuation data. The attenuation coefficient of five tissues (bovine spleen and pancreas, porcine liver and spleen, and lamb liver) appears to obey a quadratic frequency dependence in the log-log coordinate system. Measurements at additional frequencies will help resolve this point. And finally, there does not appear to be any correlation between the frequency dependent ultrasonic attenuation coefficient and hydroxyproline concentation for these tissues.

Acknowledgements

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