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FREQUENCY DEPENDENT ULTRASONIC ATTENUATION COEFFICIENT ASSESSMENT IN FRESH TISSUE

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INTRODUCTION

It is yet difficult to evaluate properly the mechanisms responsible for the propagation of ultrasound through tissue. This is due, in part, to the available data base. There does not yet exist a well documented and reproducible data basis which can be used to intercompare the ultrasonic propagation properties among various tissues.

If one considers the role collagen plays in terms of the ultrasonic attenuation coefficient, it is possible to group biological tissues, save bone and lung, into three general catagories. The low attenuating materials consist of virtually no collagen, the high attenuating materials consist of high amounts of collagen and the balance of materials fall between these two catagories. This latter group generally involves the parenchymal tissues of brain, liver, spleen, kidney, muscle, heart, etc. This observation has

been presented elsewhere (O'Brien, 1977) and showed that while a general trend existed between ultrasonic attenuation and collagen concentration, it was not evident whether any such trends were evident within this middle group.

This preliminary report discusses the frequency dependent ultrasonic attenuation coefficient for fresh liver from bovine, porcine and lamb, fresh spleen from bovine, porcine and lamb and fresh pancreas from bovine and further discusses the role of these attenuation coefficients in terms of their collagen, actually hydroxyproline, concentration. The unique features of this report are that the same tissue handling procedure, the same ultrasonic attenuation coefficient technique and the same hydroxproline analysis procedure were employed for all seven tissues, therefore providing a basis for comparison. The work reported herein is drawn from the thesis of Segal (1983).

METHODS

The tissue specimens were obtained from the University of Illinois slaughter house and transported to the Bioacoustics Research Laboratory in normal saline at room temperature. The specific specimen under investigation was then prepared for the radiation force balance technique, a phase insensitive procedure which determines the ultrasonic insertion loss of the specimen (of a known thickness) at the ultrasonic frequencies of 1.39, 4.21 7.02 and 9.82 MHz. The specimen handling procedure and the radiation force balance technique are the same as described previously (Pohlhammer et al, 1981) in which fresh bovine liver tissue was studied. All measurements were made in saline at a temperature of 22°C within three and one half hours of slaughter.

The ultrasonic attenuation coefficient was determined via a linear regression technique from the slope of the insertion loss versus specimen thickness data at each frequency. At least six tissue measurements were made for each thickness

and there were at least six thicknesses which ranged from 5 to 18 mm for each attenuation coefficient analysis.

A linear regression analysis procedure was then applied to the attenuation coefficient versus ultrasonic frequency data to yield a, the amplitude value at 1MHz, and b, the frequency exponent in the expression

$$A = af^b \tag{1}$$

Hydroxyproline concentration, a measure of the collagen concentration in tissue, was determined by hydrolyzing the specimen and measuring the amount of hydroxyproline in an automated amino acid analyzer by a technique similar to that described by Edwards and O'Brien (1980).

RESULTS AND DISCUSSION

The ultrasonic attenuation coefficient data obtained in this study for fresh bovine liver compares favorably with that obtained from a previous study (Pohlhammer et al, 1981) under identical experimental conditions but with different individuals conducting the actual experimental work. Previously, a least squares fit of the attenuation coefficient (Np/cm) versus frequency (MHz) to the 1-100MHz data base yielded

$$A = 0.043\ f^{1.270} \tag{2}$$

whereas this study yielded (to the 1-10MHz data base)

$$A = 0.038\ f^{1.36} \tag{3}$$

This supports the view that the experimental procedure is reproducible. In both of these studies, a straight line fit to the log-log data base was quite sufficient to describe the results over the measured frequency range.

In addition to the bovine liver, a straight line adequately described the log-log relationship of the frequency dependent attenuation coefficient for lamb spleen in which

$$A = 0.037\ f^{1.29} \tag{4}$$

So, for both bovine liver and lamb spleen, the amplitude value a and the frequency exponent b are sufficient to describe these tissues' attenuation coefficient as a function of frequency.

However, for the other five tissues examined, the simple power relationship of equation 1 does not appear to be adequate for describing the frequency dependency of the attenuation coefficient. While it has not been done for this preliminary report, an examination of the date suggests that a quadratic fit to the log-log data base would be more adequate. For these five tissues (bovine spleen and pancreas, porcine liver and spleen and lamb liver), the frequency dependent nature of the attenuation coefficient suggests that as the frequency increases, the actual attenuation coefficient values increase at a much greater rate than that of a linear fit. Thus, without this more complete analysis, it could be misleading to provide only a linear power fit equation to describe these data.

A brief examination of the attenuation coefficient data at 1.39MHz and 9.82MHz does not suggest any obvious trends between type of tissue or between source of tissue. In increasing order of the attenuation coefficient (in Np/cm) at 1.39MHz is lamb spleen (0.055), bovine liver (0.060), porcine spleen (0.084), bovine spleen (0.11), porcine liver (0.12), lamb liver (0.12) and

bovine pancreas (0.17). The 9.82MHz attenuation coefficient data in increasing values yields porcine spleen (0.64), lamb spleen (0.69), lamb liver (0.76), bovine pancreas (0.81), porcine liver (0.87), bovine liver (0.87) and bovine spleen (0.89). In both cases the order is quite different.

An examination of the ultrasonic attenuation coefficient as a function of the hydroxyproline concentration at each ultrasonic frequency did not reveal any statistically significant trends. Only at 9.82MHz was there even the slightest hint that the attenuation coefficient decreased as the hydroxyproline concentration increased, just opposite in trend to that of previous observations (O'Brien, 1977). In must be kept in mind, however, that all of these tissues had approximately the same collagen concentration and thus this tissue property may not (and indeed appears not to) be the best or even the proper one to correlate with the ultrasonic attenuation coefficient. It must be obvious that the comparison of the attenuation coefficient data to a single tissue property is somewhat simplified. A more complete comparison to a combination of tissue properties would appear to be more reasonable and is being done.

In conclusion, the following observations can be made from this preliminary data analysis. The technical procedures of specimen handling and data gathering are reproducible and thus provide the basis for intercomparison. The attenuation data for these seven tissues are each distinct in their own way. Describing the frequency dependency of the attenuation coefficient by a single number, usually the frequency exponent, may not be proper for many tissues. A higher order power fit appears to be necessary. And finally, there does not appear to be any correlation between the attenuation coefficient and collagen concentration for these tissues.

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