Attenuation and speed of ultrasound in lung

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The frequency dependence of the ultrasonic propagation properties of canine lung inflated to a density of 0.4 g/cm^3 are reported. The attenuation increases exponentially with frequency, and the speed of propagation increases linearly with frequency.

Subject Classification: 80.20.

An earlier study established that the attenuation of ultrasound in freshly excised dog lung at 1 MHz was unusually high, viz., more than an order of magnitude greater than air and greatly in excess of that exhibited by other soft tissues.[1] The opportunity to conduct such measurements as a function of frequency has since become available and the following is an initial reporting of this investigation.

The experimental methods employed were much the same as those previously reported. Briefly, a lobe of the freshly excised lung was ligated at the bronchial tube to retain such residual air that the density of the specimen was maintained at 0.4 g/cm^3, obtained from determinations of weight and volume. The preparation was suspended in the physiological saline transmitting medium between the sound source and a castor-oil absorption chamber provided to eliminate standing waves beyond the lung. The temperature was maintained at 35.0° ± 0.5 °C. The transient thermoelectric method[2] was utilized to investigate the acoustic field between the specimen and the source, to determine the axial standing wave pattern, and, between the specimen and the absorption chamber, to determine the wave amplitude transmitted beyond the lung. In this way, quantitative information was obtained from which the attenuation and apparent speed of sound in the lung could be obtained, assuming that infinitesimal wave acoustics prevailed and that the attenuation was sufficiently great that multiple reflections within the specimen need not be considered. The results are tabulated in Table I. Figure 1 shows the frequency dependence of the attenuation coefficient α defined by $I_l = I_0 \exp(-2\alpha l)$, where I_0 and I_l are, respectively, the acoustic intensities at the lung–saline interfaces nearest to and farthest from the source and l is the thickness of the lung sample. The error bars identify the range of experimental values obtained with 24 specimens, while the plotted points are the results obtained at all three frequencies for a single specimen where $l = 0.5$ cm. Figure 2 shows the apparent speed of sound in lung as a function of frequency for the specimen whose plotted points appear in Fig. 1. The uncertainty in the speed of sound determination, for all specimens, was less than 10^3 cm/sec.

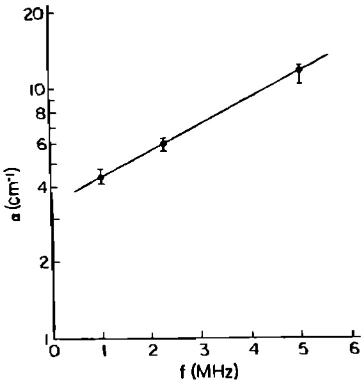

FIG. 1. Ultrasonic attenuation per unit path length in lung ($\rho = 0.4$ g/cm^3).

TABLE I. Tabulation of experimental results.

f (MHz)	α (cm^{-1})	$v \times 10^{-5}$ (cm/sec)
1	4.3	0.658
2.25	5.9	0.812
5	11.6	1.18

These results agree well with those of the earlier study, though the theory previously proposed to account for the unusually high attenuation, viz., radiation of acoustic energy by the pulsating gaseous structures of the lung tissue, is not supported. The theory predicted that the dominant loss mechanism would decrease with increasing frequency and that the attenuation would exhibit a minimum as its magnitude fell below that characteristic of other soft tissues, for which the absorption

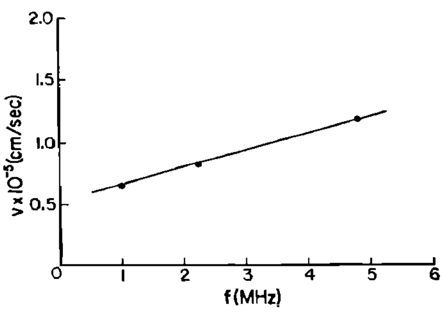

FIG. 2. Speed of sound in lung ($\rho = 0.4$ g/cm^3).

coefficient increases with frequency. It is clear from the data presented herein that, as the absorption for other tissues is only about 5% that of lung, minima cannot be expected to occur, at least within the frequency range of these observations. These findings are in general agreement with those of Bauld and Schwan.[3]

ACKNOWLEDGMENT

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[3]T. J. Bauld and H. P. Schwan, "Attenuation and Reflection of Ultrasound in Canine Lung Tissue," J. Acoust. Soc. Am. 56, 1630–1637 (1974).