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AN ULTRASONIC STUDY ON ELASTICITY OF ANIMAL SOFT TISSUES

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Abstract: The paper presents data on elastic constants of soft tissues such as muscle, heart, liver, kidney, spleen, tongue and brain of the animal – ox. Elastic constants are calculated from the knowledge of ultrasonic compressional and shear wave velocities. For this purpose, Ultrasonic pulse transmission technique has been employed. The recondite feature of the study is negative Poisson's ratio. The significant variations in elastic constant of soft tissues may be attributed to their water content, molecular architecture and cellular assembly.
Keywords: Soft tissues, Ox, Elastic constants, Ultrasonic pulse transmission technique, compressional wave velocity, shear wave velocity.

1. Introduction

The vertebrate body consists of soft and hard tissues which provide a means to support the body against the gravitational force. Most of the soft tissues are flexible and highly elastic. In general, their behavior is assumed to be visco-elastic. In contrast, hard tissues are more compact, rigid and less elastic and serve as endoskeleton and exoskeleton of the vertebrate body. It seems ultrasonic method is more convenient for the determination of elastic constants of soft tissues accurately with respect to size, inhomogenity and anisotropy of the sample.

Gopala Krishna et al [1, 2] reported the preliminary results of compressional wave velocity and elasticity of mammalian muscle tissues. Rama Rao [3] measured ultrasonic compressional and shear wave velocities in animal integuments at different physiological conditions using pulse transmission technique and calculated elastic constants. He used this data for the verification of values obtained from simple techniques developed at Biophysics laboratory, Nizam College, Hyderabad for the study of elasticity of integuments. Siddiq Mohiuddin [4] studied elastic constants of femur, scapula and rib bones of the animal ox at their different physiological conditions such as fresh, oven dried and decalcified using ultrasonic velocity (compressional & shear) data obtained from ultrasonic pulse transmission technique.

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Ultrasonic studies have been made in different fields to compute the elastic constants, where as in the field of ultrasonic biophysics these techniques have not been applied on muscle tissues for the determination of elasticity.

In view of this, an attempt has been made to determine the elastic constants of mammalian tissues by applying ultrasonic pulse transmission technique.

2. Materials and Methods

To determine the ultrasonic velocity (compressional and shear) and elastic constants, the following soft tissues of different systems of the animal (ox) have been chosen.

- Brain (Nervous system)
- Heart (Cardiac system)
- Muscle (Muscular system)
- Liver (Digestive system)
- Kidney (Renal system)
- Tongue (Digestive system)
- Spleen (Digestive system)

The samples of these animal tissues were purchased from slaughter house, located at a distance of about 5 km. from the Biophysics Research Laboratory, Nizam College, Hyderabad. Studies were made on the samples within 6-8 hours after their slaughter. Samples were cut in disc shape of size having diameter 3 cm and thickness about 2 cm from tissues along the fiber direction. Measurements of compressional wave velocity and shear wave velocity were made at frequency 1 MHz and temperature of 28^0C, using pulse transmission technique. The details of the technique and experimental procedures were mentioned elsewhere [3, 4].

In general, for unbounded solid objects, the propagation velocities, v_p (Compressional) and V_s (Shear or Transverse) waves are given by

$$V_p = \left[\frac{E\,(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}\right]^{1/2}$$

and

$$V_s = \left[\frac{\mu}{\rho}\right]^{1/2}$$

where E = longitudinal elastic modulus or young's modulus

μ = transverse deformation coefficient or shear modulus

ρ = density and

σ = Poission's ratio

But $$E = 2\mu\,[1 + \sigma]$$

On transformation, we get $$\sigma = \frac{a^2-2}{2\,(a^2-1)}$$

where, a is the ratio of velocities, (i.e. $a = \frac{V_p}{V_s}$), and $\frac{V_p}{V_s}$ is a measure of the index of refraction of acoustic energy. The bulk modulus (K) is evaluated from

$$K = \frac{\rho(3{V_p}^2 - 4\,{V_s}^2)}{3}$$

and $$\frac{1}{K} = \beta$$

where β is the compressibility.

Besides the rigidity of muscles (μ), the stiffness modulus of muscles (Y) is of academic interest and is given by

$$Y = \rho\,{V_p}^2$$
$$= \frac{E\,(1-\sigma)}{(1+\sigma)(1-2\sigma)}$$

The stiffness modulus (Y) varies as does the Young's modulus (E) and denotes the dynamic stress – strain characteristic of the body and change in Y is a sensitive indicator of structural changes.

3. Results and Discussion

Tables 1 to 7 reveal the data on elastic constants such as Young's modulus, rigidity modulus, bulk modulus and Poisson's ratio of the tissues of muscle, heart, liver, spleen, kidney, tongue and brain of the animal Ox. The elastic constants so presented here are computed from the knowledge of ultrasonic compressional and shear wave velocity. It can be noted from the tables that the values of Young's modulus, rigidity modulus and bulk modulus are significantly more in muscle, heart and tongue than in liver, spleen, kidney and brain. It is interesting to note that the elastic constant known as Poisson's ratio has negative value and more or less the same in all the tissue of the present investigation.

Table 1 - A comparison on Elastic Constants of tissues of the animal Ox

Parameter / Tissue	E ($\times 10^{11}$ dyne/cm^2)	μ ($\times 10^{11}$dyne/cm^2)	K ($\times 10^{11}$ dyne/cm^2)	σ
Muscle	0.308 ± 0.011	0.184 ± 0.010	0.068 ± 0.019	- 0.096 ± 0.029
Heart	0.309 ± 0.014	0.186 ± 0.005	0.067 ± 0.012	-0.104 ± 0.015
Liver	0.253 ± 0.009	0.158 ± 0.004	0.049 ± 0.011	-0.112 ± 0.010
Spleen	0.256 ± 0.002	0.160 ± 0.004	0.049 ± 0.006	-0.114 ± 0.006
Kidney	0.250 ± 0.002	0.169 ± 0.004	0.032 ± 0.006	-0.124 ± 0.010
Tongue	0.311 ± 0.015	0.195 ± 0.004	0.058 ± 0.015	- 0.114 ± 0.014
Brain	0.258 ± 0.012	0.176 ± 0.003	0.031 ± 0.013	- 0.120 ± 0.002

Among the tissues investigated, the values of elastic constants are high in fiber containing tissues (skeletal muscle, heart and tongue), compared to other tissues which do not contain the fibers (Liver, spleen, kidney and brain). In comparison with hard calcified tissues, soft tissues possess low values of elastic constants, which can be attributed to large quantity of water and less amount of inorganic material. The low values of elastic constants of different tissues of organs in different systems in the living body are more advantageous for the physiological adaptation to carry out life processes.

In living and non – living hard tissues and material, Poisson's ratio is *Positive.* The recondite feature of soft tissues understudy is they possess *Negative* Poisson's ratio. It is a moot point. The negative Poisson's ratio of soft tissues observed in the present investigation is in agreement with that reported by Hoppin et al [5] in the case of dog lung tissue. In conclusion, even though all biological materials, classified as visco-elastic, the classification of soft tissues as elastoplastic appears to be more appropriate, since the ATP acts as a plasticiser to maintain the tissue in a flexible and easily extensible state [6-10].

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