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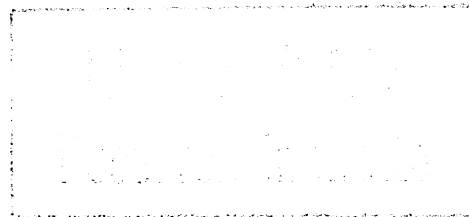
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**ORACIC MODEL IMPROVEMENTS
(PERIMENTAL TISSUE PROPERTIES)
VOLUME III LITERATURE SURVEY**

Contract No. DOT-HS-031-3-763

May 1975

Final Report



PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

WASHINGTON, D.C. 20590

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16. Abstract The general objective of this research program was to obtain mechanical properties, both stress, strain, and rupture strength, for various human tissues that are directly applicable to the thoracic injury problem as defined in the finite element model of the human thorax that is being developed by the Franklin Institute Research Laboratory (FIRL) under NHTSA Contract No. DOT-HS-243-2-424, "Thoracic Impact Injury Mechanism." The properties were determined at strain rates that can occur during fatal automobile accidents. The properties of Rhesus monkey tissues are also of interest in the modelling effort, and consideration was given to providing experimental data on selected Rhesus tissues as well as human tissues.					
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1.0 INTRODUCTION

This volume contains the results of an extensive literature survey carried out as part of a research project entitled, "Thoracic Model Improvements (Experimental Tissue Properties) conducted by the Biomechanics Department of the Highway Safety Research Institute of The University of Michigan.

2.0 LITERATURE SURVEY SUMMARY

A literature survey which concentrated on the areas of soft tissue testing and analytical representation of soft tissue mechanical behavior was implemented early in the program as an aid in guiding the experimental design and data analysis techniques. In addition, the literature survey was used to study mechanical properties data on thoracic tissues of primary interest to the project.

The list of journals that were surveyed includes the following:

American Journal of Physiology
 Journal of Applied Physiology
 Journal of General Physiology
 Physiological Reviews
 ASME Publications
 SAE Publications
 Applied Mechanics Reviews
 Journal of Biomechanics
 Biorheology
 Medical and Biological Engineering
 Biomedical Engineering
 Experimental Mechanics
 Advances in Bioengineering and Instrumentation
 American Journal of Physical Medicine

U.S. 6570 Aerospace Medical Research Laboratories Reports (Med. Library
RC1050 u.63)

NASA Scientific and Technical Aerospace Reports

Acta Orthopaedica Belgica

Acta Orthopaedica Scandinavica

Archives Physical Medicine

Clinical Orthopaedics

Journal of Bone and Joint Surgery

Rheumatology and Physical Medicine

Aerospace Medicine

Journal Sports Medicine/Physical Fitness

Journal of Trauma

Injury

Monatschrift Unfallheilkunde

Thorax

A bibliography based on the papers located by the literature survey
was compiled in the following manner:

1. Obtain the paper.
2. Code it using the scheme shown on the master card shown in Figure 1.
3. Abstract the article.
4. Type the information on a Keysort card, an example of which is shown
in Figure 2.
5. Punch the card according to the code.

Duplication of the Keysort card bibliography was done by Xeroxing the
cards on a dark background at a slight reduction in order to allow attaching
on the duplicate to a blank Keysort card for punching as indicated by the

Other	Other
Dried	Other
Solution	Other
Embedded	Other
Frozen and Thawed	Other
Refrigerated (unfrozen)	Other
Fresh	Other
Living Tissue (in vivo)	Other
Body Fluids (CSF, synovial, serum)	Other
Microstructural Components (cartilage, collagen, hair)	Other
Cardiovascular System & Lungs	Other
Nerves & Nervous Tissue	Other
Integument (skin and subcutaneous tissue)	Other
bone	Other
Ligaments & Tendon	Other
Muscle	Other
Cartilage	Other
Joints	Other
Viscera	Other
Torso (ribs, spine, pelvis)	Other
Shoulder	Other
Skull	Other
Upper Extremities	Other
Lower Extremities	Other
Other	Other
Polymers	Other
Fibrous (wood)	Other
Metals	Other
Cold Blooded Vertebrates (reptile, fish, amphibians)	Other
Birds (chicken, duck, fowl)	Other
Ungulates (horse, swine, cow, goat, deer, elephant)	Other
Ungulates (cat, dog, rabbit)	Other
Rodents (rat, mice, guinea pig)	Other
Primates (ape, monkey)	Other
Mean	Other

Recorded Parameters	
Age of Source	
Time after Death	
Specimen Geometry	
Temperature	
Moisture Content	
Density	
Viscosity	
Elasticity	
Hardness	
Ductility, extensibility	
Inhomogeneity	
Anisotropy	
Energy Absorption	
Strength	
Frequency	
Amplitude	
Rate of Variable Change	
Stress	
Strain	
Strain Rate	
Failure	
Other	
Radiation	
Wounds and Healing	
Velocity	
Electrical Properties	
Ionic Properties	

Specimen Origin	
Gold Blooded Vertebrates (reptile, fish, amphibians)	
Birds (chicken, duck, fowl)	
Ungulates (horse, swine, cow, goat, deer, elephant)	
Ungulates (cat, dog, rabbit)	
Rodents (rat, mice, guinea pig)	
Primates (ape, monkey)	
Mean	

AN	Author
BC	
CD	
DE	
EF	
FG	
GH	
IJ	
KL	
LM	
NZ	

Index	Rate
Creep - Stress Relaxation	
Quasi-static	
Impact	
High-Speed	
Cyclic	
Pulse	

On file, no punch for R2C indicates comment.
Statistical Validity
Property Correlation
Apparatus Description
Technique Description
Review
Pathological
Histological
Experimental Work
Theoretical Work

Electrical (Piezoresistance, etc.)
Acoustical
Optical (X-ray, photography, polaroid)
Chemical
Pressure
Combined Stress
Torsion, shear, tearing, puncture, penetration
Flexure
Compression
Tension

Hildebrandt, J.
Extension of Small-Strain Theory to Finite Deformation of Cylindrical Vessels by
Internal Over-Pressure
Angiologica 7: 257-272, 1970.

Abstract: Calculations of the pressure distention of closed cylindrical vessels using classical infinitesimal-strain theory predict that, for isotropic materials the length remains fixed while the diameter increases linearly with pressure. These predictions can be verified experimentally only if the radial deformation is less than 2-3%. This paper develops formulae applicable to deformations up to approximately 10 times the above, based on a modification of infinitesimal theory. The results predict significant lengthening of isotropic vessels, and ballooning or 'blow-out' above a certain pressure. It is shown that the classical stresses contain a common hydrostatic component which must be subtracted before the stresses can be integrated across the wall thickness to yield wall tensions. When the hydrostatic component is taken into account, Laplace's law is found to hold for thick-walled vessels as well as for thin-walled vessels.
key words: pressure distention; Elastic cylinders; infinitesimal theory; lengthening isotropic vessels

duplicate. The copies of these bibliography cards are contained in this report. A total of over 500 cards were prepared during the project. In addition, selected articles of particular pertinence to the program have been microfilmed in their entirety and supplied in microjacket form to the CTM.

3.0 LITERATURE SURVEY ABSTRACTS

On the following pages of this section are the abstracts of articles surveyed in this study. They are reproduced in slightly reduced form to allow for mounting of the abstracts on Keysort cards. The abstracts are listed in alphabetical order by author as closely as possible (since the duplication was performed at different times during the project there are occasional conflicts in the ordering of pages).

ABRAHAMS, M.

The Mechanical Behaviour of Tendon Collagen Fibres under Tension in Vitro
7th Int. Conf. on Medical and Biological Engng., Stockholm, 38-6, 1967

Abstract: The mechanical behavior of tendon can be described in terms of a stress strain curve. This curve was obtained with a modified floor model Instron Testor. This test was carried out using a horse extensor tendon. The histological studies indicate that the initial extension can be associated with a straightening out of the collagen fibre wave formation while the approximate linear portion of the curve is a measure of the load extensor response of the collagen fibres themselves.

ABBOTT, B.C., & Wilkie, D.R.

The Relation Between Velocity of Shortening and the Tension-Length Curve of Skeletal Muscle
J. Physiol. 120: 214-223, 1953

Abstract:

AGOSTONI, Emilio
Mechanics of the Pleural Space
Physiol. Rev. 52:57-128, Jan.72

Abstract: (continued) pleural membranes.

Despite recent interest, the mechanics of the pleural space is an old subject, like most of the mechanics of breathing: the knowledge of its history and development is therefore essential to provide a perspective of the recent research.

AGOSTONI, Emilio
Mechanics of the Pleural Space
Physiol. Rev. 52:57-128, Jan.72

Abstract: The great progress in the mechanics of breathing that followed the classic studies of Rohrer and Henn, Otis, and Rahn reached a stage about 10 years ago in which a more systematic and a deeper insight into the mechanics of the pleural space appeared essential to the advancement of our knowledge, not only of the mechanics of breathing, but also of the pulmonary circulation and gas exchange. In 1961 Mead, in his basic review on the mechanical properties of the lung pointed out that "there is great need for better information as to the surface topography of lung pressure." During the last few years many efforts have been made to solve the theoretical and experimental problems encountered in obtaining this information. This concerns one aspect of the mechanics of the pleural space: namely, the interaction between the mechanics of the lung and of the chest wall. Since the mechanical properties of the lung were, and still are, better known than those of the chest wall, this study has been mainly undertaken through the mechanics of the lung. The mechanics of the chest wall, however, must be considered to the same extent. The other aspect of the mechanics of the pleural space concerns the nature of the coupling between the lung and the chest wall: i.e., the factors holding together these structures and providing the lubrication. This aspect involves a study of the contents of the pleural space as well as of the exchange through the

ADAMS, K.H.
Mechanical Equilibrium of Biological Membranes
Biophysical Journal, Vol.12, 123-30, Jan.1972

Abstract: The nature of mechanical and electrical forces on biological membranes in relation to mechanical equilibrium is examined. The presence of a double layer of electric charge is shown to give rise to an effective pressure drop across a curved membrane of finite thickness. For certain geometric shapes of a membrane, the magnitude of the pressure drop due to electrostatic forces may set a limit on the hydrostatic pressure drop that the membrane can support without buckling. The results are applied to the equilibrium shape of the red blood cell.

ALEXANDER, Robert S.

Contribution of Plastoelasticity to the Tone of the Cat Portal Vein
Circulation Research, 28, 461-468, 1971

Abstract: Isolated helical strips of cat portal vein were subjected to sudden stresses to produce immediate elastic extension followed by a slow plastoelastic extension or "creep." Recovery from this creep was evaluated by restretching with varying intervals between stretches. In appropriately stimulated vessels, significant creep recovery continues for periods in excess of 20 minutes. Both the rate and the ultimate magnitude of the creep recovery were substantially increased by contractile activity produced by norepinephrine or electrical stimulation. The rate and ultimate magnitude of creep recovery were decreased by dilator drugs, although some recovery persisted. The only factors found capable of blocking creep recovery were complete inactivation of the contractile machinery by removal of calcium from the system or maintenance of tension on the tissue during the recovery period. This behavior is explained by a model in which contracted elements are capable of slowly converting into a stable shortened configuration capable of passively maintaining venous tone until mechanical stress causes a plastoelastic extension to the longer configuration.

biomechanics, blood vessels, contraction of veins, creep of veins, rheology of venous tissue, smooth muscle tone

Anderson, Robert M., Fritz, James M., O'Hara, James E.
The Mechanical nature of the heart as a pump.
American Heart J. 73:1, 92-105, Jan 1967.

Abstract: A cardiac replacement pump which duplicates cardiac function in all physiologic states with no controls or adjustments has been used in 27 mongrel dogs.

The essential characteristics of the heart and also of this replacement pump have been demonstrated: (1) They are nonsucking pumps, (2) they have a pulsatile outflow, and (3) there is uninterrupted venous flow into them.

A new concept of basic hemodynamics is presented which gives better insight into the passive nature of the heart in the regulation of cardiac output and of blood volume between the lungs and systemic circuits.

The atria are found to have their physiologic benefit in allowing continuous venous flow to the heart in the presence of an intermittent pumping system.

Cardiac output (in the presence of a nonfailing heart) is shown to be determined completely by extracardiac factors.

Anliker, Max, Histan, Michael B. and Ogden, Eric
Dispersion and Attenuation of Small Artificial Pressure Waves in the Canine Aorta
Circulation Research, Vol. 23, pp. 539-551, 1968

ABSTRACT: A method was developed to determine the elastic behavior of large blood vessels in terms of their transmission characteristics for small sinusoidal pressure signals. The method is new insofar as it utilizes transient signals of the form of finite trains of sine waves that are superimposed on the naturally occurring pressure fluctuations and are generated by an electrically driven impactor or by a pump. Its application to the thoracic aortas of 18 mature mongrel dogs anesthetized with pentobarbital has shown that dispersion and attenuation data for frequencies between 40 and 200 cps can be obtained without requiring either Fourier transform computations or resolution of reflection interference. For the frequency range considered, the descending aorta is only mildly dispersive but exhibits strong attenuation that must be attributed primarily to dissipative mechanisms in the vessel wall. At normal blood pressure levels, the wave speed during diastole can have a value between 4 and 6 m/sec. For all frequencies tested the amplitude ratio of the waves exhibits the same exponential decay pattern with distance measured in wavelengths. A marked increase in wave speed observed from diastole to systole can be associated with an increase in mean flow and with a stiffening of the aortic wall due to the rise in pressure. This phenomenon implies that the aortas of anesthetized dogs

Anliker, Max, Histan, Michael B. and Ogden, Eric
Dispersion and Attenuation of Small Artificial Pressure Waves in the Canine Aorta
Circulation Research, Vol. 23, pp. 539-551, 1968

ABSTRACT (continued): should exhibit nonlinear properties with respect to large amplitude pulse waves such as those generated by the heart.

Anliker, M., Moritz, W.E. and Ogden, E.
Transmission Characteristics of Axial Waves in Blood Vessels
Jr. of Biomechanics. Vol. 1 No. 4, 235-246, 1968.

Abstract: The elastic behavior of blood vessels can be quantitatively examined by measuring the propagation characteristics of waves transmitted by them. In addition specific information regarding the viscoelastic properties of the vessel wall can be deduced by comparing the observed wave transmission data with theoretical predictions. The relevance of these deductions is directly dependent on the validity of the mathematical model for the mechanical behavior of blood vessels used in the theoretical analysis. Previous experimental investigations of waves in blood vessels have been restricted to pressure waves even though theoretical studies predict three types of waves with distinctly different transmission characteristics. These waves can be distinguished by the dominant displacement component of the vessel wall and are accordingly referred to as radial, axial and circumferential waves. The radial waves are also referred to as pressure waves since they exhibit pronounced pressure fluctuations. For a thorough evaluation of the mathematical models used in the analysis it is necessary to measure also the dispersion and attenuation of the axial and circumferential (torsion) waves.

To this end a method has been developed to determine the phase velocities and damping of sinusoidal axial waves in the carotid artery of anesthetized dogs with the aid of an electro-optical tracking system. For frequencies between 25 and 150 Hz the speed of the axial waves was between 20 and 40 m/sec and generally

Anliker, M., Moritz, W.E. and Ogden E.
Transmission Characteristics of Axial Waves in Blood Vessels
Jr. of Biomechanics, Vol.1 No.4, 235-246, 1968.

Abstract Continued: increased with frequency, while the natural pressure wave travelled at a speed of about 10 m/sec. On the basis of an isotropic wall model the axial wave speed should however be approximately 5 times higher than the pressure wave speed. This discrepancy can be interpreted as an indication for an anisotropic behavior of the carotid wall. The carotid artery appears to be more elastic in the axial than in the circumferential direction.

Annovazzi, Dott G.
Osservazioni Sulla Elasticita Dei Legamenti
Arch.Sci.Biol. 11:467-502, 1928

Abstract:

ANLIKER, M and Maxwell, J.A. (1966)
The dispersion of waves in blood vessels.
IN: Biomechanics, edited by Fung, pp.46-67, ASME, New York, 1966

Abstract: Dispersion phenomena associated with waves propagating in blood vessels are potential measures of the distensibility of the vessels and other cardiovascular parameters. In this investigation we assume the vessels to behave like thin-walled circular cylindrical shells filled with an inviscid compressible fluid. The vessel wall is assumed to have isotropic and homogeneous elastic properties. The waves are described by small three-dimensional displacements of the middle surface of the shell from an equilibrium configuration defined by a mean transmural pressure and an initial axial strain. The fluid motion associated with the waves is considered as irrotational. The linearized differential equations of motion are based on the shell equations by Flugge.

The results of a parametric analysis indicate that axisymmetric waves are only mildly dispersive while nonaxisymmetric waves are highly dispersive and exhibit cut-off phenomena. The transmural pressure and the initial axial stretch can have a marked effect on the phase velocities and cut-off frequencies. The effects of the compressibility of the blood are insignificant for waves with frequencies below 1000/cycles/sec. The nature and results of in-vivo experiments by Landowne are interpreted in the light of this analysis.

Apter, Julia T.

An Analysis of Aortic Pressure Curves Taking Into Account Visco Elastic Properties of the Aorta and Variations in Peripheral Resistance
Bull. Matn. Biophys., Vol. 27, pp. 27-52, 1965

ABSTRACT: The aortic pressure curve necessarily reveals the mechanical properties of the aorta and peripheral resistance as well as of the dynamics of blood flow. The present study uses a reasonable model of visco-elastic properties of the aorta, a reasonable form for variations in peripheral resistance and blood flow to predict an aortic pressure tracing. Numerical values of constants measured experimentally were available in the published literature. These were used in the nonlinear differential equations of motions of the system under analysis. The equations yielded to piece-wise solution, giving the aortic circumference and the aortic pressure as functions of time. The form of both curves resembles clinical tracings, but numerical values of circumference were higher and of pressure lower than in vivo. The discrepancies between predicted and clinical curves may reveal certain inadequacies in published measurements on visco-elastic constants. These measurements have been made on longitudinal rather than circumferential strips often containing dead rather than living muscle. The discrepancies, therefore, indicate specific gaps in our knowledge of aortic behavior in vitro. The suggested model of the system aided in the design of experiments which could supply data necessary to substantiate or to revise the model.

Apter, Julia T.

Correlation of Visco-elastic Properties of Large Arteries with Microscopic Structure
Circulation Research, Vol. 19, pp. 104-121, 1966

ABSTRACT: The media of 14 regions of the aorta and 3 regions of the pulmonary artery of dogs were subjected to a step-function circumferential stretch taking 20 msec to complete. The tension rose synchronously with the increase in circumference, then dropped exponentially to a reasonably steady state within 2 sec. A mathematical model, developed consistent with this stress-relaxation curve, showed how to use the tension curves to measure a viscous, a series-elastic and a parallel-elastic constant unique for a given curve. These constants were compared with the microscopic structure of the same or similar segments; collagen was determined as hydroxyproline in a water soluble fraction, elastin as hydroxyproline in the residue and from the width and number of elastic lamellae, and muscle from the nitrogen content of a nonfibrous fraction, from cell counts and from contractility. The constituents varied widely and independently enough to permit correlating viscous and elastic constants with microscopic structure. The viscous and series-elastic constants were higher where muscle content was high, and increased markedly when the muscle was tonically contracted. The parallel-elastic constant was high when elastin was high and in the presence of contracted muscle, but seemed independent of collagen content, at moderate tensions tested.

Apter, Julia T.

Correlation of Visco-Elastic Properties with Microscopic Structure of Large Arteries

Circulation Research, Vol. 21, pp. 901-918, 1967

ABSTRACT: The media of eight regions of the aorta and three of the pulmonary artery of dogs, as well as isolated elastin, collagen, and smooth muscle obtained from vascular and other sources, were subjected to a step-function circumferential stretch at a variety of temperatures between 0° and 70°C. The tension rose to a peak synchronously with the stretch and then fell along an essentially exponential course to a steady tension. Suitable use of the peak tension, the steady-state tension, and the time required to go from peak to steady state, supplied three temperature-dependent parameters (one viscous and two elastic) characteristic of the material. The two crystalline polymers, collagen and smooth muscle, had higher constants at low temperatures, and the amorphous polymer, elastin, had higher constants at high temperatures. Collagen differed from smooth muscle in its inertness to autonomic drugs and in its elastic modulus. Intact arteries stretched slightly (2% to 20%) in the presence of phenylephrine behaved like smooth muscle; arteries stretched more (20% to 70%) behaved like elastin. At both strain levels, the tensions developed were compatible with in vivo pressures. Arteries stretched even more (>100%) to tensions compatible with pressures of 300 Hg, behaved like collagen.

APTER, J.T.

Computer Solution of Non-Linear Differential Equations of Motion of the Aorta
7th Int. Conf. on Medical and Biological Engng., Stockholm, 27-2, 1967

ABSTRACT: The purpose of this paper is to show that a mathematical model based on the in vivo behavior of the aorta can generate aortic pressure curves closely resembling real ones. A secondary irregularity in the diastolic portion of the real curve was observed in the mathematical model.

APTER, Julia T. and Marquez, Elsa
A Relation Between Hysteresis and Other Viscoelastic Properties of Some
Biomaterials
Biomeology, Vol. 5, pp. 285-301, 1968

ABSTRACT: The behavior of linear visco-elastic materials may be approximated by differential equation of motion whose solution makes it possible to establish a relation between visco-elastic parameters obtained from stress relaxation studies and those obtained from oscillatory studies. Living tissues behave like linear visco-elastic materials under some conditions so that parameters may be determined from the two kinds of studies and compared with each other to establish the standard linear solid as a model. This study succeeds in showing the model to be suitable under a limited range of conditions for a variety of viable tissues tested in vitro.

APTER, Julia T. and Marquez, Elsa
Correlation of Visco-Elastic Properties of Large Arteries with Microscopic
Structure-- V.Effects of Sinusoidal Forcings at Low and at Resonance Frequencies
Circulation Research, 22, 393-403, 1968

Abstract: Nine aortas from recently killed dogs were sectioned into 21 or more ring segments supported horizontally on two hooks in Ringer's solution.

Absolute dynamic modulus, storage modulus, loss modulus, phase shift, and loss angle measured from stress-strain loops compared favorably with similar measurements published for other visco-elastic materials and with viscous and elastic constants obtained from stress-relaxation experiments on aorta.

visco-elasticity, muscle, elastin, collagen, dog aorta, storage modulus, resonance

Apter, Julia T.
Dynamic Compliance of Living Lungs Before and After Perfusion
Journal of Biomechanics, Vol. 3, No. 1, pp. 77-85, 1970

Abstract: In situ lungs of living, anesthetized dogs were exposed to adequate ventilatory conditions between short exposures to test conditions for measuring some dynamic properties of the lungs. These properties include dynamic compliance as a function of respiratory cycle frequency and of stroke (or tidal) volume with the lung tissue in various stages of pre- and post-perfusion conditions. Between test exposures, ventilation was maintained with a respiratory rate of 0.4 Hz and a stroke volume of 399 ml. Test exposures for computing dynamic compliance as a function of frequency were a tidal volume of 100 ml and rates from 0.04 Hz to 0.9 Hz. At a tidal volume of 100 ml, the lungs behaved linearly, giving a sinusoidal pressure output to a sinusoidal volume input. Test exposures for finding the pressure-volume relationship were performed at a cycle frequency of 0.4 Hz with stroke volumes from 50 ml to 500 ml. Histologically verified pulmonary tissue changes followed steady (non-pulsatile) pulmonary artery perfusion with whole blood for two hours. The visco-elastic properties were a function of the condition of the living tissue.

Because the dynamic compliance was a function only of frequency or of volume or of condition of the lung, there was no hysteresis in these records.

Apter, Julia
Dynamic Compliance of Living Lungs Before and After Perfusion
Journal of Biomechanics, Vol. 3, No. 1, pp. 77-85, 1970

Abstract (continued): They were reversible, reproducible, responsive to verified changes in pulmonary tissue and were consistent with contemporary methods for testing other viscoelastic systems. The tests themselves did not endanger pulmonary tissue properties nor interfere with the gaseous exchange function of the lungs. Therefore, the tests could be adapted for clinical measurements of pulmonary mechanics.

Arnold, G. and Worthmann, W.
Mechanical Recovery Properties of Human Tendons
Experientia 28:455-6, April, 1972

Apter, J. T., and Graessley, W. W.,
A Physical Model for Muscular Behavior
Biophysics J. Vol. 10, 539-555, 1970

ABSTRACT: A model for muscular behavior has been developed by a generalization of the laws governing the viscoelastic behavior of polymeric materials. The model simulates events thought to take place during stretch loading, and stimulation of muscle, whether smooth or striated. The equations of motion were solved with an analog computer for several types of perturbation and stress, strain, and strain-rate curves were generated. Model parameters were selected by fitting experimental stress-relaxation data. The resulting equations predicted the frequency dependence of dynamic modulus and phase angle within experimental error. With appropriate boundary conditions and suitable values for model parameters, the computed results also closely resembled experimental curves of contraction velocity vs time, isometric tension development vs. time, force-velocity curves, and temperature-tension relationships. These results call attention to the relationship between the behavior of various kinds of muscle and open the way for quantifying muscular behavior in general.

APTER, Julia T. and Mason, Patricia
Dynamic Mechanical Properties of Mammalian Ureteral Muscle
Am. J. Physiol. 221(1): 266-272. 1971

Abstract: This study gives a description and measurements of the mechanical properties of ureters isolated from anesthetized dogs and calves, in particular the stress response to step-function and sinusoidally oscillating strains. A step-function extension strain of a strip of the ureter was accompanied by a sharp rise in stress which fell along an essentially exponential course (stress relaxation) to be followed by a single or by repeated recontractions, depending on temperature, ionic environment, and strain level. A sinusoidally oscillating strain was accompanied by an oscillating stress which sometimes led (as for inert viscoelastic material) and sometimes lagged (as for muscle) behind the strain, depending on the oscillation frequency. In addition, the stress, though oscillating, was nonlinear since it was not sinusoidal except for very small strains and at frequencies higher than .8 Hz. Quantification of these data as a physical system was accomplished by referring to a simplified, idealized system which responds to similar strains with similar stress behavior; that is, with recontraction, phase leads, phase lags, and nonlinearities, thus strongly resembling ureteral specimens.

viscoelasticity; smooth muscle; muscular properties

ATTINGER, Françoise M., Peterson, Lysle H. and Gooren, Louis
Geometry of the Main Distributing Arteries
Fed. Proc. 25, p.509, abstract #1800, 1965

ABSTRACT ONLY NO PAPER The objective of this study was to determine the *in vivo* geometry of the aorta and of the main distributing arteries. Such information is of importance for an adequate description of the physical properties of the arterial system as well as for the determination of the vascular impedance. In most of the recent mathematical models of the cardiovascular system it has been assumed that the relative thickness of the wall with respect to the radius remains constant in all the major arteries. In order to test this assumption the following vessels from 7 dogs were fixed in their *in vivo* geometry and measured for radius and wall thickness: aorta at 8 sites from the root to the bifurcation, carotid, superior mesenteric, renal and femoral arteries. It was found that in the aorta the radius to wall thickness ratio increases regularly from 5.39 at the root to 7.74 above the renal, then decreases to 6.24 at the bifurcation. The results for the carotid were 3.39, for the mesenteric 2.58, for the renal 2.23, and for the femoral 4.73.
(Supported by grants USPHS HE 07762 and N-ONR 551 (54))

Arndt, J. O. , Stegall, H. F. and H. J. Wicke
Mechanics of the Aorta in Vivo
Circulation Research, Vol. 28, pp. 693-703, 1971

ABSTRACT: The hydraulic properties of the unexposed thoracic aorta were studied in five cats by angiography. Repeated measurements of pressure and diameter were obtained at various distances from the aortic root, and it became obvious that the unexposed aorta in cats was more than twice as distensible as the exposed aorta. Diameter of the aortic root, for example, varied by about 20% over a physiologic pulse pressure (40 mm Hg); even in the lower thoracic aorta variations exceeded 15%. When plotted as a function of distance from the root, aortic diameter and distensibility both decreased, and the calculated impedance increased. Despite these changes, however, the calculated reflection coefficients were quite small. It was concluded that geometric and elastic inhomogeneities in the thoracic aorta tend to balance one another, keeping the reflection coefficient quite low and helping to "decouple" the oscillatory left ventricular pump from the static peripheral vasculature. Since the aortic pulse contour is reflection-free during the first 50 msec following the onset of ventricular ejection, it may reliably indicate left ventricular properties and their changes with stress. In several animals norepinephrine infusion was used to elevate the aortic pressure to hypertensive levels. When compared to hypertension induced by carotid reflex stimulation or mechanical occlusion of the aorta, however, aortic wall properties were essentially the same suggesting that this agent has no important direct effect on the aortic wall.

Arntzenius, A. C., Koops, J., Rodrigo, F.A., Elsbach, H. and van Brummelen, A.G.W.
Circulatory Effects of Body Acceleration Given Synchronously with the Heart Beat (BASH)
Ballistocardiograph and Cardiovascular. 26:180-187, 1970

Abstract: The ballistocardiogram demonstrates that ejection of blood from the left ventricle into the ascending aorta produces a recoil displacement of the entire body in an opposite direction. It can be reasoned from this observation that by applying acceleration to the body at a propitious time in the heart cycle, one might actually enhance this flow of blood from the left ventricle to the aorta. Two series of experiments on the effects of Body acceleration given Synchronously with the Heart beat in circulation are described. The first series employed a mechanical hydrodynamic model, the second series of experiments were carried out with anesthetized piglets.

ATTINGER, F.M.
Some Problems Concerning the Analysis of the Mechanical Properties of the
Blood Vessel Wall
Doctoral Dissertation, University of Pennsylvania, 1964

Augenstein, D.C., Sinsky, A. J. and Wang, D.I.C.
Effect of Shear on the Death of Two Strains of Mammalian Tissue Cells
Biotechnology and Bioengineering, Vol 13, 409-418, 1971

Abstract: This study reports some findings on the death of mammalian cells occurring from fluid dynamic effects when they are pumped through capillaries. The cell strains used were human HeLaS3 and mouse L929, grown in monolayer culture. Cells were harvested and suspensions were pumped through various lengths and diameters of stainless steel capillary tubing. Viability of the cells was assayed by the dye exclusion test. Cells deaths occurred and could be correlated with either average wall shear or power dissipation within the capillary tube. L929 cells were found to be more sensitive than HeLaS3 cells at all shear rates tested.

ATTINGER, Françoise, M.L.
Two-Dimensional in-Vitro Studies of Femoral Arterial Walls of the Dog
Circulation Research, 22, 829 -840, 1968

Abstract: Analyses of the vascular system have characteristically been based on assumptions that the vessel wall is isotropic and that its properties and behavior can be linearized. To test the validity of these assumptions, excised arteries of dogs were submitted to stepwise strains tangentially and longitudinally during conditions of control, vasoconstriction, and inhibition of muscle metabolism. These strains were recorded simultaneously with the associated stress, and the relations between stress and strain were studied during both dynamic and steady-strain states. The vessels were anisotropic within most of the physiological ranges of tangential and longitudinal stress and strain. During control conditions the tangential modulus of elasticity was higher than the longitudinal; during vasoconstriction the situation was reversed for wall tensions corresponding to a blood pressure equal to or smaller than 190 mm Hg; however, above this value isotropic behavior prevailed. Vasoconstriction increased the nonlinearity of the stress-strain relation, and decreased the modulus of elasticity of the arterial wall. The viscoelastic properties of the femoral artery were found to be different tangentially and longitudinally, as evidenced by a much larger amount of stress relaxation in the former direction than in the latter.

BAUER, R.D. and Pasch, Th, Wetterer, E.
Theoretical Studies on the Human Arterial Pressure and Flow Pulse by Means of a Non-uniform Tube Model
J. Biomechanics, 6:3, 289-298, 1973.

Abstract: A theoretical model of the arterial system is described. It consists of three unbranched uniform tubes arranged in series. Using a digital computer (CD 3300), both pressure and flow pulses are computed at certain sites of the model on the basis of a primary pulse wave resembling the flow pulse in the ascending aorta. The calculations are performed assuming both undamped wave propagation and frequency-dependent damping. In each of these assumptions, real reflection coefficients is justified in frequency-dependent damping, are examined.

Computed and natural pulses correspond well, in particular with respect to the profiles of the pressure pulses. Therefore, the model permits us to clarify the genesis of the main characteristics of the contours of human arterial pulses. The influence of frequency-dependent damping on the pulse contours, as well as on the input impedance is demonstrated.

BAEZ, Silvio
Supporting Tissue Tension and Microvascular Reactions
Microvascular Research, 3, 95-103, 1971

Abstract: The effects of stretch of supporting tissue on resting vessel lumen size and of its response to standard amounts of norepinephrine were examined in striated (cremaster) muscle of the rat. Controlled amounts of stretch were imposed upon cremaster muscle using a microtensor device. The amount of stretch was determined by attaching the tissue via thin (10-0) nylon thread to the actuating pin of a calibrated (0-1000 mg) strain-gauge transducer. In rats lightly anesthetized with pentobarbital sodium (25 mg/kg), after control measurement of vessel lumen and its response to topical norepinephrine, the tissue tension was increased at 8-min intervals, and the measurement repeated at every newly achieved tissue tension. In 6 out of 10 arterioles in 10 rats, lumen expanded (av. 25%) with increasing tissue tension. The vessel response to norepinephrine increased in three of the expanded vessels, decreased in two, and remained unchanged in one. Two of the vessels showed no change in lumen but decrease in sensitivity, and two showed decrease in lumen size and increase in sensitivity to the drug stimuli. The results indicate that only overt stretch of supporting tissue >150 mg, will affect microvessel size and reactivity.

BANN, J.
Transverse impedance of arteries: animal experiments related to wave
transmission theory
Ph.D. thesis, Univ. of Pennsylvania, 1970

Barfred, T. roels
Experimental Rupture of the Achilles Tendon
Acta Orthop. Scandinav. 42:528-543, 1971

Berg, Solomon
Vesical Contractility 1. The Force-Velocity Relationship as an Index of Contractility
Invest Urol. Vol. 9, pp. 431-437, March 1972

ABSTRACT Force velocity relations were studied in vesical muscle isolated from the guinea pig. The influence of force (P) and initial muscle length (Lo) on the velocity of shortening (V) were observed. As seen in skeletal and cardiac muscle an inverse relationship exists between force and velocity. Increasing initial length enhanced all aspects of the force-velocity relationship leading to greater maximal velocity (Vmax), velocity at all levels of force, maximal force (Po), rate of development of force (dp/dt), peak power, peak work, and extent of shortening of muscle fibers (ΔL). The time required for the contraction to reach peak tension was not influenced by initial length. The significance of the force-velocity relationship as an index of contractility is discussed, as are its implications in the dynamics of micturition in humans.

Bergel, D.H.
Arterial Viscoelasticity
In Pulsatile Blood Flow, edited by E. O. Attinger. New York:McGraw, p275-292,1963

Abstract:

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

BERGEL, D. H.
The visco-elastic properties of the arterial wall.
Thesis. Univ. of London. 1960.

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Bergel, Kerek H., and Milnor William R.
Pulmonary Vascular Impedance in the Dog
Circulation Research, Vol. XVI, No. 5, pp. 401-415, 1965

ABSTRACT: The experiments reported in this paper were intended: (1) to measure pulmonary vascular impedance in the anesthetized dog, using Fourier analysis of phasic pressure and flow measurements, (2) to assess the linearity of the pulmonary bed by measuring impedance while the heart rate, and hence the pulsatile input to the bed, was varied, and (3) to determine the effect of pulmonary vasoconstriction on impedance, using 5-hydroxytryptamine (serotonin) as the vasoconstrictor. Pulmonary vascular hydraulic input impedance was measured in 13 anesthetized open-chest dogs with normal sinus rhythm, and 2 dogs with surgically induced atrio-ventricular block, by means of electromagnetic flowmeters and strain gauge manometers of known frequency response. The linearity of the pulmonary bed was evaluated by measuring impedance while the heart rate, and hence the pulsatile input to the bed, was varied.

The pulmonary bed behaved as a quasi-linear system within the limits of the experiment. The pattern of the impedance spectrum suggested that reflections originating from arteries 1.0 mm and ten in diameter play a large role in determining input impedance and its variations with frequency. Vasoconstriction caused by any means increased wave reflection.

Blanton, Patricia L. and Biggs, Norman L.
Ultimate Tensile Strength of Fetal and Adult Human Tendons
Journal of Biomechanics, Vol. 3, No. 2, pp. 181-189, 1970

Abstract: Ultimate tensile strengths of human tendons were determined with an evaluation of the following criteria: adult or fetal; embalmed or unembalmed; from superior limb or inferior limb; and associated with extensor muscle or flexor muscle. A rather wide range of tensile strengths resulted for all categories of tendons in this study with considerable overlapping among several categories.

The tensile strength for human tendon from both adult and fetal sources was found to be enhanced by embalming. No significant difference was observed between the tensile strengths of tendons from the superior limb and the inferior limb. No significant difference was observed between the tensile strengths of tendons associated with flexor muscles and extensor muscles in the fetus. A somewhat greater difference in tensile strengths of tendons of these two categories was observed in the adult, those tendons associated with extensor muscles demonstrating the greater tensile strength.

The tensile strength of fetal tendons appeared to be somewhat less than that of adult tendons.

Berkley, David A.
Influence of Intraocular Pressure on Corneal Fluid Pressure, Tissue Stress and Thickness
Exp. Eye Res., Vol. 11, pp. 132-139, 1971

ABSTRACT: In this paper a simple idealized model is defined for the mechanical structure of the cornea of a mammalian eye. The model consists of thin anterior (epithelium and Bowman's zone) and posterior (Descemet's membrane and endothelium) layers, which form the front and back boundaries, respectively, of the main body - the stroma. The thin boundaries are assumed to be essentially force-free while the stroma, which is considered as a mixture of fluid and tissue is able to take up forces (fluid pressure, tissue stress across the cornea and tension along the cornea). From this model the elastic state of the cornea is studied for varying intraocular pressure. A simple equation is derived that relates the intraocular pressure, the corneal fluid pressure and the thickness of the cornea. It is shown that, under certain conditions, an increased intraocular pressure leads to tissue compression on the posterior side of the stroma and tissue expansion of the anterior side. This may be related to observations showing increased scattering from only the anterior half of the rabbit stroma under increased intraocular pressure. If the high intraocular pressure persists for a long time the theory predicts an increase of the corneal thickness. This prediction seems to be supported by recent clinical experiments.

BERTHOZ, A. ROBERTS, W.J. AND ROSENTHAL, N.P.
Dynamic Characteristics of Stretch Relax Using Force Inputs
J. Neurophysiol 34:612-9, Jul 1971

Abstract:(Summary) Sinusoidal changes in length and tension were applied to the gastrocnemius muscles of decerebrate cats to compare the transfer characteristics between muscle length and tension obtained with both types of input. The reflex behavior was studied as well as that of the muscle tissue after interruption of the reflex. It was found that within the limit of mean muscle tension used and with the range of modulation frequencies explored there is no obvious difference between force and length inputs. The nonlinearities are discussed.

Bing, Oscar H. L., Matsushita, Satoru, Fanburg, Barry L. and Levine, Herbert J.
Mechanical Properties of Rat Cardiac Muscle during Experimental Hypertrophy
Circulation Research, Vol. 28, pp. 234-245, 1971

ABSTRACT: The mechanical properties of trabecular muscles from the hearts of 77 rats subjected to aortic arch constriction were compared with those from 77 unoperated and sham-operated control animals at 1,3,7,14 and 28 days after operation. Significant hypertrophy, as evidenced by an increase in left ventricle to body weight ratio, was first seen at three days ($P < 0.02$), reached a maximum of 30 to 40% by seven days ($P < 0.001$), and remained relatively constant throughout the remainder of the experiment. Depression of isotonic shortening velocity and maximum isometric force of trabecular muscles from hypertrophied hearts was first seen at seven days. These changes persisted at 14 and 28 days. When alterations in muscle mechanics due to changes in muscle thickness were taken into consideration, muscles from hypertrophied hearts demonstrated a depressed maximum velocity of shortening ($P < 0.001$), while development of isometric tension was unaltered. The latter appeared to be maintained at least in part by a prolonged contraction time as reflected by increases in the time to peak isometric tension ($P < 0.05$) and the time to peak "unloaded" isotonic shortening ($P < 0.001$). Resting tension was increased in trabecular muscles from hypertrophied hearts. Tissue hydroxyproline concentration was elevated with hypertrophy. The observed depression in muscle shortening velocity at light loads may be explained by altered contractile state or by increased stiffness of the parallel elastic element.

BIRO, E., Rusnakova, M. Rusnak, J.
A Device for Measuring Isometric Contractions Mechanoelectrically
Physiol. Bohemoslov. 15:391-4, 1966

Abstract: An apparatus and compensating method for measuring isometric contractions is described. Transducer RCA 5734 with a moving anode was used. The compensating force was obtained from a moving coil of a small electrodynamic reproducer.

BLATZ, Paul J., Chu, Billie Mae, and Wayland, Harold
On the Mechanical Behavior of Elastic Animal Tissue
Transactions of the Society of Rheology 13:1, 83-102, 1969

Abstract: In this paper there is introduced a strain energy function which describes a class of materials that includes elastic animal tissue as well as other highly distensible materials. The functional form of this representation is general enough to suggest other forms that may encompass additional classes of material. The theoretical stress-strain curves are shown to correlate well with experimental data obtained upon loading (as distinguished from unloading) different animal tissues such as frog's striated muscle, human papillary muscle, and cat's and rabbit's mesentery, as well as synthetic materials such as latex rubber. There is also developed a thinness theory which can be used to calculate the deformation field in the case of applied plane stress for the more complicated geometry of a wedge-shaped (arcuate) specimen. This thinness theory has been applied to a fan-shaped specimen with tangential and radial loading.

Blumenthal, B. and Boren, H.
Lung structure in three dimensions after inflation and fume fixation.
Am. Rev. Tuberculosis 79: 764-772, 1959

ABSTRACT: A method of fume fixation of lung is described which provides an inflated, rigid specimen and allows structure of whole lungs to be surveyed. Revisions of conventional cutting, staining, and mounting procedures provide large thick specimens which allow the application of a wide variety of staining techniques. Three-dimensional structure of either the stained or unstained specimen is demonstrated by stereoscopic microscopy so that relationships present during life are more closely approximated.

Boerth, Robert C. and Covell, James W.
Mechanical Performance and Efficiency of the Left Ventricle During Ventricular Stimulation
Am. J. of Physiology 221(6): 1686-1691, 1971.

Abstract: The effects of electrical stimulation of the right atrium and right ventricular outflow tract on left ventricular performance and efficiency were compared in dogs in the isovolumic left ventricle in which end-diastolic volume was constant. During right ventricular outflow-tract pacing there were significant decreases in peak left ventricular pressure, peak left ventricular wall stress, and peak left ventricular dP/dt . Despite these decreases, myocardial contractility did not appear to be changed by right ventricular stimulation since there was no downward shift of the stress-velocity relationship at low stresses. During right ventricular outflow-tract stimulation myocardial oxygen consumption (MVO_2) was unchanged, and the efficiency of the isovolumically contracting left ventricle was decreased. It is concluded that electrical stimulation of the right ventricular outflow tract produces an abnormal pattern of contraction which depresses the function and efficiency of the left ventricle. The mechanism of this may be through altered synchronism of fiber contraction without an alteration of myocardial inotropic state.

BOREN, Hollis G.
The Development of a Molecular Model of Lung
Arch Intern Med., Vol. 126, 491-495, 1970

Abstract: Many different types of lung models, such as mathematical, anatomic, or physiologic, have been used in experimental studies. When animal models are used, the lung is observed under the conditions of controlled, integrated cellular activity. By adding the label tritiated thymidine and using autoradiography, observed changes can be related to pulmonary cellular kinetics. The observations are a necessary prerequisite to understanding the control mechanisms of pulmonary cells. By using multiple-labeling techniques and by measuring the effects of blockade of cellular control systems, a molecular model of the lung can be developed.

BOIS, Richard M.
The Organization of the Contractile Apparatus of Vertebrate Smooth Muscle
Anatomical Record, 177, pp 61-78, 1973

Abstract: Smooth muscle of the small intestine of the rat was fixed by vascular perfusion employing aldehydes in a balanced salt solution, followed by immersion fixation in aldehydes and post-osmication. In such tissue preparations thick filaments approximating 140 A in diameter are observed in virtually all the smooth muscle cells. The thick filaments are rather uniformly distributed among the more numerous thin filaments. The nearest neighbor distances between the thick filaments range from 400 to 700 A. The thick to thin filaments ratio is found to approximate 1:12. Only thin filaments are observed in the most distal segment of terminal processes of muscle cells and the tips of the these processes appear to be lined by attachment plaques. A clear segregation of the thick filaments from both dense bodies and attachment plaques is seen. Distally along the tapering extremities of muscle cells progressively more of the plasma membrane is found lined by attachment plaques. These observations are interpreted as strong evidence that the contractile apparatus of the vertebrate smooth muscle cell consists of interdigitating arrays of thick and thin filaments collated into contractile units by the anchoring of the thin filaments in dense bodies and attachment plaques.

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Boom, H. B., Van der Rijst, E., Ten Have, J. P.
Active Elasticity of the Isolated Rabbit Heart
Pflugger Arch. Vol. 314, pp. 163-4, 1970

ABSTRACT: In order to evaluate the quantitative effects of the series elastic component of heart muscle in the intact isolated rabbit heart, quick volume releases were effected by means of a small pump, which was driven electrically. The pump was connected to the isolated heart by means of a rigid cannula, ligated in the mitral opening, after dissection of the atria. When the piston was driven from the heart, which could be effected in 2 msec, the ventricular volume was suddenly decreased. The time of piston movement was derived from the time of artificial stimulation of the heart, after a delay which could be controlled. In this way it was possible to examine the whole systolic phase on a repetitive basis, the piston being driven back during diastole. Pressure alterations were recorded during the systolic volume alterations.

Pressure-volume curves were derived from the measured relationships between volume decreases and the related pressure drops. Unlike results found for papillary muscle, it appears that these pressure volume curves markedly depend on the relative moment in systole, at which they were measured. At a higher systolic pressure the series elastic stiffness of the ventricle seems to be increased.

Since series elastic stiffness also appears to be dependent of the preload,

Boom, H. B., Van der Rijst, E., Ten Have, J. P.
Active Elasticity of the Isolated Rabbit Heart
Pflueger Arch. Vol. 314, pp. 163-4, 1970

ABSTRACT: we examined pressure volume relations for different end-diastolic pressure. It was concluded that systolic stiffness decreases with increasing diastolic pressure or volume, which is the reverse as would be expected from isolated muscle experiments.

Boone, Alex W. and Albert G. Smith
The Elastic Properties of Normal Ureter
J.Urology, 73:3, 481-486, 1955

Abstract: Physiologic demands upon the ureter extend beyond passive conduction of urine from kidney to bladder. While the characteristics of ureteral tone, peristalsis, and innervation derangements have been extensively studied, the functional significance of ureteral elasticity has not been investigated. We are aware of the role played by blood vessel elasticity in hemodynamics, but the place of elasticity in ureteral physiology is not clear. This study was designed to evaluate the normal range of ureteral elasticity and correlate the physical characteristics with the microscopic structure.

(SUMMARY) Ureteral tissue acts as a biologic elastometer.

The histologic characteristics of ureteral elastic tissue have been described. Ureteral elasticity diminishes with age, but elastic fibers alone do not account for this change.

There is no correlation between age, sex or race and the amount of elastic tissue identified by histologic techniques.

BOUHUYS, Arend and Karel P. van de Woestijne
Mechanical consequences of airway smooth muscle relaxation
J. Appl. physiol. 30(5): 670-676, 1971

Abstract: We measured lung volumes, airway conductance (Gaw), maximum expiratory flow-volume (MEFV) curves, isovolume pressure-flow (IVPF) curves, and static lung recoil curves in healthy volunteers before and after inhalation of a bronchodilator drug. On the average, Gaw at 50% VC increased 34.7%, Gaw/TGV ratio increased 33.9%, maximum expiratory flow at 50% VC 9.0%, and FEV₁ 3.6%. TLC, VC, peak expiratory flow, and static lung recoil pressure did not change significantly. In a few subjects maximum flows on IVPF curves decreased slightly after bronchodilation. These results fit the hypothesis that bronchodilation renders large airways more compressible in man in vivo. This limits flow increase during forced expiration and may even result in decreased flows. The increased Gaw during panting reflects increased airway caliber which results from relaxation of tone when transmural stresses are low. Our results suggest that normal airway smooth muscle tone in man may help large airways to withstand dynamic compression during forced expirations.

Boorstin, J.B., Hayes, J.R. and Goldman, D.E.
Injury mechanism of internal organs of animals exposed to sinusoidal vibration.
Aerospace Medicine 37: 22-28, 1966

ABSTRACT: High speed X-ray cinematography has been used to determine organ motion in vibrated cats. Data processing with a motion analyzer and a computer permits rapid analysis of X-ray photographs. Results of experiments at several amplitudes and frequencies are compared to show wave distortions due to heart-lung-chest wall interactions and frequency response characteristics associated with the means of restraint of the animal and the way in which the vibratory motion is impressed. Gross and microscopic pathological studies as well as some chemical determinations provide correlation of mechanical response and tissue damage.

BOTWIN, M.R.
Determination of Viscoelastic Moduli of Arteries
J. of Biomechanics, 6:6 711-718, 1973

ABSTRACT: A model for the arterial wall, motivated by wave propagation findings, is developed. The wall is taken to be a viscoelastic, orthotropic, prestressed shell which is materially characterized at any prestress level by ten incremental moduli. By using the momentum equations and the wave propagation characteristics for three axisymmetric modes, the ten moduli are found in terms of the three wave speeds, the three attenuation coefficients and the prestresses.

BRUTSAERT, Dirk L., Claes, Victor A. and Donders, Jan J.H.
Effects of Controlling the Velocity of Shortening on Force-Velocity-Length and Time Relations in Cat Papillary Muscle--Velocity Clamping
Circulation Research, 30, 310-315, 1972

Abstract: A new technique--velocity clamping--was used to study the effects of a constant total velocity of shortening on the interrelation between force, velocity, length, and time in cat papillary muscle. With decreasing values of clamped total velocity, the duration of the contraction increased but never exceeded the duration of an isometric contraction. Hence these findings confirm that the mode of contraction--isometric or isotonic--has a marked effect on the duration of the contraction. The active state can be prolonged when less shortening of the muscle. The data were also plotted on a three-dimensional graph and compared with velocity-length tracings of afterloaded contractions. The force-length trajectories of the muscle during velocity clamping did not fall on the surface described by the force-velocity-length relations as derived from afterloaded isotonic contractions. This finding could be ascribed to the masking effect of the series elastic component due to the continuous adjusting of the load.

series elastic element; contractile element; active state; myocardium; contractility

BRADY, A. J.
Active State in Cardiac Muscle
Physiol.Rev. 48:570-600, 1968

Abstract: A quick stretch was a substitute for allowing a muscle to shorten slowly against the rising tension of its series elastic component. It showed how very early the active state reaches its full intensity after a stimulus. This started a spate of experiments and speculations on the "active state", not always well considered; in the end one begins to wonder whether the term has any exact meaning!

BRAAKMAN, R. and Penning, L.
Mechanisms of Injury to the Cervical Cord.
Paraplegia 10:314-320, 1973

Abstract: (

Brady, A.J.
Mechanical Analysis of Cardiac Contractility.
UCLA Forum, Med.Sci. 10:139-47, 1970.

BRADY, A. J.
Length-Tension Relations in Cardiac Muscle
Am. Zoologist 7:603-610, 1967

Abstract: The distinguishing mechanical characteristics of cardiac muscle are (1) the presence of a significant and sometimes labile resting tension at functional lengths. Certain invertebrate skeletal muscles also possess this property, but the structural basis seems to be different. (2) Force-velocity characteristics of heart muscle are labile and constitute a mechanism for regulating cardiac performance. (3) Data on quick-stretch and release show that the active state in heart muscle is slow in its onset, probably preceding the development of isometric tension by only a short time. The onset of the active state is labile also, and probably forms the basis of the regulatory function of the force-velocity relation. Measurements of heat show a slow rate of increase of heat during a twitch consistent with the onset of contractility.

Brandi, Giorgio
Theoretical Considerations on the Response of Lung Tissue to the Acceleration of Gravity
Respiration Physiology. Vol. 9, pp. 356-370, 1970

ABSTRACT: Krueger et. al.'s hypothesis that the response of the lungs to acceleration is a) similar to that of a fluid, b) having the same mean density, was discussed considering separately the physical basis of a) and b). The validity of a) is sustained by the fact that lungs (which by themselves have some finite rigidity) are enclosed by the far more rigid chest wall; in this condition "shear" supporting forces may be negligible as they are in fluids. The part b) of the hypothesis is theoretically untenable and was substituted with the assumption that the density of any horizontal layer of lung is related with the corresponding recoil, (or the local transpulmonary pressure, P) in the same fashion as it is in whole lungs. If the lung density increases with vertical distance (h) from the top of the lung, the P-h relationships become curvilinear, convex towards the pressure axis. The experimental P-h curves are too different from each other to allow conclusions; apart from its validity the scheme presented has the merit of relating pressure, expansion and density of the lung with height coherently with the assumptions used. These concern the physical properties of the chest wall and the pleural boundary as well as those of the lung.

BRADY, Allan J.
Time and displacement dependence of cardiac contractility: problems in defining the active state and force-velocity relations
Fedr.Proc. 24:6, 1410-20, 1965.

Bright, E.F. and Beck, C.S.
Nonpenetrating Wounds of the Heart, A clinical and experimental study
Am. Heart J. 10: 293-321, 1935.

Braunwald, E.
Myocardial Function--1972,
Anesth. Analg. (Clev) 51:489-501, Jul-Aug. 1972

Buchthal, F. and Kaiser, E.
The rheology of the cross striated muscle fibre with particular reference to isotonic conditions.
Copenhagen: Det Kongelige Danske Videnskernes Selskab.
Dan. Biol. Medd. 21(7) 1951

BUCHER, K.
Besonderheiten des Herzens als Pumpe (II. Mitteilung) (Ger)
Helv. Physiol. Acta 24: 77-88, 1966

ABSTRACT: The starting point of the present investigations were the findings--in isolated heart preparations of cats--that a) one-sided increase of the aortic resistance by consecutively increasing the aortic pressure causes an increase in the minute output of the opposite side, i.e., right heart, whereas b) onesided increase of the resistance of the A. pulmonalis by consecutively increasing the pressure in the A.pulmonalis causes a decrease in the minute output of the opposite side, i.e., left heart.

By systematic variation of the different parameters it could be shown that the above findings are not the results of the experimental set up but, rather, must be due to intrinsic principles of the heart itself. (the summary article in German)

Burch, G.E. and Giles, T.D.

Angle of traction of the papillary muscle in normal and dilated hearts: A theoretic analysis of its importance in mitral valve dynamics.

Am. Heart J. 84:141-4, Jul. 1972

BULLER, A.J. and Lewis, D. M.

The Rate of Tension Development in Isometric Tetanic Contractions of Mammalian Fast and Slow Skeletal Muscle

J. Physiol. 176, pp.337-354, 1965

Abstract: (summary) The responses of soleus (slow) and flexor hallucis longus (fast) muscles of the cat have been examined following both repetitive and double stimulation through the motor nerves.

The maximum rate of rise of tension during tetanic stimulation increases with increase of stimulation frequency to approximately 300 pulses/sec in soleus and 600 pulses/sec in F.H.L.

Two-stimuli experiments show that the earliest observable separation of the mechanical response following two stimuli from that following one stimulus occurs at approximately 3.5 msec after the beginning of contraction in soleus and approximately 2 msec in F.H.L.

These results suggest that if a plateau of active state is reached in sarcomeres following a single stimulus its duration is shorter than 3.5 msec in soleus and 2 msec in F.H.L.

Brutsaert, Dirk L. and Sonnenblick, Edmund H.
Force-Velocity-Length Relations of the Contractile Elements in Heart Muscle
of the Cat
Circulation Research, Vol. XXIV, No. 2, pp. 137-149, 1969

ABSTRACT: The instantaneous force-velocity-length relations of the contractile elements of the cat papillary muscle have been obtained by determining the phase-plane trajectories of velocity of shortening relative to length during isometric contractions and correcting these measurements for the series elastic extension during the isometric phase of contraction. The load-extension curve of the series elastic component was obtained by quick release. The velocity-length relations for a given load were independent of initial muscle length and largely independent of the time after stimulation. Velocity-length traces at varying lengths diverged only late in contraction because of a fall in the intensity of the active state. Thus the surface created by the instantaneous force-velocity-length relations serves to define a given contractile state for the contractile element of heart muscle. Further, the linear length-tension relations observed for the contractile element permits an estimation of the maximum development of isometric force with the creation of truly hyperbolic force-velocity curves. Limitations of velocities obtained following quick releases have also been noted.

CAREW, Thomas, E. and Caishnav, Ramesh N. and Patel, Dali J.
Compressibility of the Arterial Wall
Circulation Research, 23, 61-68, 1968

Abstract: The assumption of incompressibility has often been applied to the analysis of arterial-wall elasticity; however, the supporting evidence has been incomplete. The present study was designed to explore this problem in greater depth by accurately measuring the changes in tissue volume associated with large induced strains on 11 thoracic aorta segments excised from dogs. The radial, circumferential, and longitudinal stresses were measured as the artery was subjected to an internal pressure and longitudinal stretch greater than those in vivo. From these data it was possible to calculate the hydrostatic stress. Similar studies were also carried out on the abdominal aorta and the carotid, iliac, and pulmonary arteries. The volumetric strains observed were of the same magnitude. It is concluded that for most practical purposes arteries may be considered incompressible.

hydrostatic stress, hydrostatic strain, bulk modulus, shear modulus, volumetric strain, deviator stress, deviator strain

Burkett, Lee Nelson
Causative Factors in Hamstring Strains
Medicine and Science in Sports, Vol. 2, No. 1, pp. 39-42, 1970

ABSTRACT: The possible cause of hamstring strains was investigated in football players and track athletes. The subjects were divided into those who did (experimental) and those who did not (control) sustain hamstring strains. Five members of the San Diego Chargers Football team and 12 track athletes made up the experimental group while 50 athletes were used as controls. Three tests, cable-tension knee flexion, cable-tension knee extension, and the sit and reach were administered to each subject. Two strength relationships were found significant at the .05 level. These relationships were concerned with the strength between the hamstrings, and unequal flexion-extension strength ratio.

CAMPO., R.D. and Phillips, Steven J.
Electron Microscopic Visualization of Proteoglycans and Collagen in Bovine Costal Cartilage
Calcified Tissue Research 13:2, 83-93, 1973

CARO, C.G., Fitz-Gerald, J.M. and Schroter, R.C.
Atheroma and Arterial Wall Shear Observation, correlation and Proposal of a
Shear Dependent Mass Transfer Mechanism for Atherogenesis.
Proc. R. Soc. Lond. (Biol) 177:109-59.

Abstract:

CHEUNG, J.B.
Nonlinear viscoelastic stress analysis of blood vessels
Ph.D. Thesis, University of Minnesota, 1970

CARTON, R. W., Dainauskas, John and Clark, J. W.
Elastic Properties of Single Elastic Fibers
J. Appl. Physiol. 17(3): 547-551, 1962

Abstract: The elastic properties of elastic tissue were studied in a situation which minimized the effects of extraneous connective tissue and of the position of fibers in the elastic network. Single elastic fibers were dissected free from the ligamentum nuchae of the ox and were stretched under conditions of constant temperature and salinity. The strain was an exponential function of the applied tension. Single fibers were found somewhat less stretchable than the ligaments from which they were taken. The data given can be used to calculate the contribution of such elastic fibers to the behavior of an elastic system in which they are incorporated.

CHEUNG, J.B. and Hsiao, C.C.
Nonlinear Anisotropic Viscoelastic Stresses in Blood Vessels
J. of Biomechanics, 5:6, 607-619, 1972.

Abstract: Through the consideration of a micro-structural system with emphasis on the nonlinear deformation and molecular anisotropy, a constitutive equation for nonlinear viscoelastic materials is developed. This constitutive and other appropriate field equations are applied to the stress analysis problem of blood vessels. In order to effect a solution for such a complicated system simplifications are sought and the blood vessel is considered as a long, thick-walled viscoelastic cylinder which is transversely isotropic and incompressible. The overall radial and circumferential stresses are calculated for a given internal pressure by considering a modified deformation in a quasi-static situation.

In general the radial displacement follows the period and shape of the applied internal pressure with an obvious creep behavior. The tangential stresses are much higher at the inner wall of the blood vessel as compared to those obtained on the basis of linear viscoelastic theory. Future research in the dynamic response and temperature effects would be a step forward in understanding the behavior of the blood vessels.

Coletti, J.M., Jr., Akeson, W.H. and Woo, Savio L-Y
A Comparison of the Physical Behavior of Normal Articular Cartilage and the
Arthroplasty Surface
J.Bone Joint Surg. (Am) 54:147-60, Jan 72

Abstract: This study was undertaken in an attempt to compare the physical behavior of an experimental arthroplasty surface as characterized by load-deformation and time-deformation curves with that of a normal articular cartilage surface and to relate any changes in such behavior to observed differences in morphologic and biochemical properties of arthroplasty tissues.

A study of the rabbit metatarsophalangeal joints with arthroplasty surface and normal articular cartilage was done by using compression testing to compare the elastic and viscoelastic behaviors of these two surfaces. Consistent differences were observed.

COLLINS, R.E., Klipper, R.W., and Jenkins, Daniel E.
A Mathematical Analysis of Mechanical Factors in the Forced Expiration
Bull.Math.Biophys. 29:737-52, Dec.1967

Abstract: A one compartment, mechanical model of the human lung-thorax system is presented and mathematically analyzed. The equation relating the thoracic muscular stress to the expired air volume is developed and investigated. Assuming that the pressure drop along the airways is a linear function of air flow rate and that the effective lung-thorax compliance is constant, a form for the muscular stress as a function of time is developed. This is used to predict volume-time and flow-volume curves, which are compared to those measured on a normal individual. It appears that these theoretical results have the essential characteristics of the experimental curves. These results, coupled with the one-to-one correspondence between the parameters of the model and those of the prototype, suggest that this model should have great utility in the study of ventilatory mechanics.

Collins, R. and Hu, W.C.L.
Dynamic Deformation Experiments on Aortic Tissue:
J. Biomechanics, 5:4, 333-337, 1972

Abstract: A simple experimental scheme is described for the determination of the dynamic stress-strain relations for fresh aortic tissue within the range of strain rates up to 3.5 sec^{-1} . This is the first such work known to the authors in this dynamic range, and is considered a necessary step toward a quantitative study of traumatic rupture of the aorta. The results indicate a definite stiffening of the tissue with increasing rates of strain; the stress-strain law exhibits an exponential character.

COVELL, J.W., Taylor, R. R. and Ross, J., Jr.
Series Elasticity in the Intact Left Ventricle Determined by Quick Release
Technique.
Fed. Proc., 26:P.382 Abstract #702, 1967

Abstract Only No. Paper: In isolated muscle, the series elastic component (SEC) can be analyzed by determining the length changes following quick releases to known loads during contraction. The characteristics of the effective SEC of the intact left ventricle (LV) were determined by a quick release method in 7 dogs in which the LV contracted isovolumically against a balloon inserted via the mitral annulus. During active contraction, sequential withdrawals of 0.5 to 7.0 ml of fluid were performed rapidly (5-18 msec) by an electrically-timed, mechanical syringe. The calculated reductions of the LV midwall circumference were plotted against the corresponding changes in mean wall stress ($T=PR/2h$, $P=LV$ pressure, R =internal LV radius, h =wall thickness). The resulting load-extension curves were exponential, and the reciprocals of their slopes (dT/dl) were linearly related to T ; $dT/dl=28.8T$ (range 16.2 to 38.3T). The maximum extension of the SEC averaged 4.36% of LV circumference (range 2.63 to 5.49%) at LV pressures averaging 79/6 mm Hg (systolic/end-diastolic; range 66-107/0-15 mm Hg). The load-extension curve was unchanged by varying the time of release and by norepinephrine infusion. These data support a model for the intact LV that contains an undamped SEC, the characteristics of which resemble those of isolated cardiac

COMBS, R. G.
Analog Simulation of Thick Walled Blood Vessel Model
7th Int. Conf. on Medical and Biological Engng., Stockholm, 27-2, 1967

Abstract: When conditions are normal, blood flow to tissue is controlled by changing the diameter of small blood vessels, especially arterioles and pre-capillary sphincters. The vessels are thick walled and have such large diameters that the stress-strain relationships are nonlinear. A mathematical model has been devised to describe the relationship between transmural pressure and radius for a small segment of vessel. At this time there are no quantitative experimental data which can be used to verify or nullify the model which was run on the analog computer.

COOPER, Theodore
Physiologic and Pharmacologic Effects of Cardiac Denervation
Fed. Proc. 24:6, 1428-31, 1965

Abstract:

Cox, Robert H.

Determination of the True Phase Velocity of Arterial Pressure Waves in Vivo
Circulation Research, Vol. 29, October 1971

ABSTRACT: Results of simultaneously recorded pressure, diameter, flow and differential pressure from an arterial segment were studied by Fourier analysis. The method was applied to pressure propagation in the femoral artery of anesthetized dogs. Experimental values of phase velocity compared favorably with values predicted from a theoretical wave propagation model. The phase velocity was generally constant for frequencies over 35 rad/sec. At frequencies below 20 rad/sec, it decreased rapidly with decreasing frequency. The frequency variations of the true and apparent phase velocities were significantly different. The characteristic impedance of the femoral artery was a weak function of frequency and nearly independent of the mean arterial pressure. High frequency values of the local fluid impedance above 50 rad/sec were significantly lower than those of the characteristic impedance. It was concluded that the method can be used to obtain reliable values of phase velocity in the physiological frequency range from in vivo measurements.

Cox, R. C. and Little, K.

An Electron Microscope Study of Elastic Tissues
Proc. Royal Soc. London B. Vol. 155, pp. 232-242, 1961

ABSTRACT: Histological Elastic Tissue from the Aorta, renal artery, skin, ligamentum flavum, epiglottis, pinna and vocal cords of man at various ages has been examined in the electron microscope. The aorta of the rabbit and the ligamentum nuchae of the sheep and the goat have also been inspected. The elastica has been studied in thin sections of the whole tissue and also in the characteristic appearance in the electron microscope. The elastica was homogeneous and of low density except for the surface zone. There were neither longitudinal nor cross-striations. There was no evidence of a two-component system of elementary fibrils and amorphous cement substance within the elastic fibers.

Wide angle X-ray diffraction studies of elastic tissue isolated from human aortas of various ages, human ligamentum flavum and sheep ligamentum nuchae gave the same picture - two fairly broad haloes at 4.6 and 7.8 Å. The stretching of the sheep ligamentum nuchae by 100 and 150% did not cause crystallization to occur. The X-ray diffraction patterns of elastic tissue were quite unlike those of collagen. These findings agreed with the appearance of elastic tissue as seen with the electron microscope and with its recognized mechanical properties.

COX, Robert H.

Wave Propagation Through a Newtonian Fluid Contained Within a Thick-Walled, Viscoelastic Tube

Biophys., J. 8, 691-709, 1968

Abstract: The propagation of harmonic pressure waves through a Newtonian fluid contained within a thick-walled, viscoelastic tube is considered as a model of arterial blood flow. The fluid is assumed to be homogeneous and Newtonian, and its motion to be laminar and axisymmetric. The wall is assumed to be isotropic, incompressible, linear, and viscoelastic. It is also assumed that the motion is such that the convective acceleration is negligible. The motion of the fluid is described by the linearized form of the Navier-Stokes equations and the motion of the wall by classical elasticity theory. The frequency dependence of the wall mechanical properties are represented by a three parameter, relaxation-type model. Using boundary conditions describing the continuity of stress and velocity components in the fluid and the wall, explicit solutions for the system of equations of the model have been obtained. The longitudinal fluid impedance has been expressed in terms of frequency and the system parameters. The frequency equation has been solved and the propagation constant also expressed in terms of frequency and system parameters. The results indicate that the fluid impedance is smaller than predicted by the rigid tube model or by Womersley's constrained elastic tube model. Also, the velocity of propagation

Abstract (Cont'd):

is generally slower and the transmission per wavelength less than predicted by Womersley's elastic tube model. The propagation constant is very sensitive to changes in the degree of wall viscoelasticity.

Cox, R. C. and Little, K
An Electron Microscope Study of Elastic Tissues
Proc. Royal Soc. London B. Vol. 155, pp. 232-242, 1961

ABSTRACT (continued): The elastic tissue was arranged in the form of networks composed of branching and anastomosing fibers. The network was either loose as in connective tissue, or dense as in the expression in the fenestrated membranes and sheets of elastica. The fibers varied considerably in diameter. The network arrangement was repeated at the level of magnification of the light microscope.

Cox, Robert H.
Estimation of Pressure Gradient by Differential Pressure
Journal of Applied Physiology, Vol. 29, No. 6, pp. 904-906, 1970

ABSTRACT: The analytical aspects of the use of differential pressure as an approximation of the pressure gradient have been considered in detail. Equations expressing the relation between the differential pressure and the pressure gradient, and the propagation constant and the distance between pressure measurements were developed. Measurements of intra-arterial pressure, differential pressure, external diameter, and blood flow rate were obtained from the femoral artery of anesthetized dogs and used to compute fluid impedance and apparent phase velocity. A comparison of these two variables with the theoretical prediction of a hemodynamic model supports the conclusion of the analytical study that the differential pressure is a good approximation of the pressure gradient for the computation of fluid impedance provided the product of the propagation constant and the length of artery over which measurements are made is small. On the other hand, it is not a useful approximation for use in computing the velocity of propagation of pressure waves directly from intra-arterial pressure measurements.

Cox, Robert H.

Wave Propagation through a Newtonian Fluid Contained within a Thick-Walled Viscoelastic Tube: the Influence of Wall Compressibility
Journal of Biomechanics, Vol. 3, No. 3, pp. 317-335, 1970

Abstract: A previously developed model of wave propagation in a thick-walled incompressible tube is extended to include wall compressibility. The motion of the fluid is assumed to be described by the linearized form of the Navier-Stokes equations. The motion of the wall is described by the equations of classical elasticity theory. The frequency variation of the modulus of rigidity is described by a three parameter relaxation-type model. The Poisson ratio is assumed to be a real parameter. The solutions of the equations of motion are restricted to axisymmetric long waves. Boundary conditions are used describing the continuity of stress and velocity components in the fluid and the tube. From these boundary conditions, a set of six simultaneous equations in six unknown constants has been obtained. This set of equations has been solved numerically using a digital computer and the propagation constant and hydraulic fluid impedance determined as a function of frequency and system parameters. For constant values of the modulus of rigidity, a decrease in the Poisson ratio causes an increase in the hydraulic fluid impedance, the fluid resistance and the fluid inductance. A decrease in the Poisson ratio decreases the phase velocity of the two roots of the frequency equation. A decrease in the Poisson ratio decreases the transmission per wavelength of the first root but increases that of the second root. The effect of

Cox, Robert H.

Wave Propagation through a Newtonian Fluid Contained within a Thick-Walled Viscoelastic Tube: The influence of Wall Compressibility
Journal of Biomechanics, Vol. 3, No. 3, pp. 317-335, 1970

Abstract (continued) wall compressibility on propagation characteristics is as important as that of the wall viscoelasticity, but the influence of the former on fluid impedance is much greater than that of the latter.

Cox, Robert H.

A Model for the Dynamic Mechanical Properties of Arteries
J. Biomechanics, 5:2, 135-152., 1972

Abstract: A phenomenological model is used to represent the frequency dependence of the mechanical properties of arteries. The model was tested on mechanical properties data derived from simultaneous measurements of intra-arterial pressure and external diameter from surgically exposed femoral arteries of anesthetized dogs. The average values and standard errors of the viscoelastic data for control experiments were: Young's modulus, $18.0 \times 10^6 (+1.2)$ dyn/cm²; modulus ratio, 1.4(+0.1); and radius/wall thickness ratio, 5.2(+0.4) at a mean blood pressure of 137(+5) mm Hg. It was found that a model consisting of a spring in series with a Voigt element adequately represented data from experiments where the fundamental heart frequency was 2 Hz or more. But when the latter was 1 Hz or less, 2 Voigt elements of different time constants, in series with the spring were necessary to represent the data. The reason for this observation was that in the low heart rate experiments there are a larger number of significant harmonics present in the pressure and diameter records and as a result more extensive data were available for analysis. The values of the various viscoelastic parameters obtained from this work were found to be in reasonable agreement with data in the literature.

CRANE, H.D.

Switching Properties in Bubbles, Balloons, Capillaries and Alveoli
J. Biomechanics 6:4, 411-422, 1973

Abstract: Devices made of curved elastic membranes can exhibit switching properties similar to those of neon bulbs, tunnel diodes, and other electronic devices having N-shaped current-voltage characteristics. It is the existence of a negative-slope region in the pressure-volume characteristic--called the negative-resistance region in electronics--that produces this switching behavior. Negative-slope regions are found in the pressure-volume curves of soap bubbles, common rubber balloons, blood vessels, and the alveoli of the lungs. The basis of the negative-slope region is discussed, and some of the relevant literature dealing with on-off (or open-closed) switching control in the circulatory and respiratory systems is reviewed. It is shown that the abrupt switching that occurs in connection with an N-shaped pressure-volume curve is characteristic of normal physiological functioning.

COX, R. H.
Wave propagation through a newtonian fluid contained within a thick-walled,
viscoelastic tube: a model for arterial blood flow.
Ph.D. Thesis, Univ. of Pennsylvania, Philadelphia, Pa. 1967

Crichton, John L.
Tensile Strength of the Umbilical Cord
Am. J. obstet. Gynecol., Vol. 115, pp. 77-80, 1973

ABSTRACT: The tensile strength of the umbilical cord has been measured, and an attempt was made to relate this to placental or fetal factors. Two hundred cords were examined from term spontaneous vertex deliveries. The average load required to rupture the cords was 12.9 pounds (5.88 Kg) with a variability between 4 (1.81 Kg) and 24 pounds (10.89 Kg). The majority of cords ruptured at their placental insertion. No useful relationship was found between the cord strength and the weight of its placenta or infant, and there was no relationship between the cord length and its tensile strength. If the tension on the cord does not exceed 7 pounds (3.18 Kg) during controlled cord traction, then the cord will rupture in only 2 per cent of cases.

CROSFILL, M.L. & WIDDICOMBE, J.G.
Physical Characteristics of the Chest and Lungs and the Work of Breathing in
Different Mammalian Species
J.Physiol. 158: 1-14, 1951

Abstract: The authors have assessed the mechanical properties of the lungs in a
four individual animals of each of the following species: mouse, rat, guinea-pig,
rabbit, monkey, cat and dog,, to see if the values are consistent with the
interspecific differences in breathing pattern. Apart from applying the
results to the optimal rate hypothesis, the results are values for
commonly used experimental animals which may be worth recording.

Crowe, Alan
A Mechanical Model of the Mammalian Muscle Spindle
J. Theoret. Biol. Vol. 21, pp. 21-41, 1968

ABSTRACT: A model is set up which has properties similar to those of the
mammalian spindle. In particular, stimulation of the spindle by motor nerve
fibers produces effects accountable by way of changes in the visco-elastic
properties of the intrafusal muscle fibers.

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Crowe, Alan
A MECHANICAL MODEL OF MUSCLE AND ITS APPLICATION TO THE INTRAFUSAL FIBRES
OF THE MAMMALIAN MUSCLE SPINDLE
Journal of Biomechanics, Vol. 3, No. 6, pp. 583-592, 1970.

Abstract: A three-component model of the muscle is used in which the components change their values when the muscle is stimulated. In particular the elastic components change not only their moduli of elasticity but the unstretched lengths decrease when the muscle is in the active state. When the model is extended to the intrafusal muscle fibres of the mammalian muscle spindle it can reproduce some of the observed responses to mechanical stretch and fusimotor stimulation.

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

DANIELSON, D.A.
Human Skin as an Elastic Membrane
J. Biomechanics, 6:5, 539-546, 1973

Abstract: The equations governing the deformation of human skin are derived. First, the equations of an anisotropic, elastic membrane undergoing large deformations are recorded. Next, the kinematical condition is derived which restricts the skin to slide over the surface of a rigid foundation. Last, stress-strain relations are proposed which fit the known experimental data for skin. As a special case of this theory, the equations of a simple model for the flexure of a joint are solved. In another special case of the theory, the equations of a homogenous, isotropic, elastic membrane lying in a plane and undergoing small deformations are solved by complex variable techniques for the case of a large sheet having a circular hole and subject to biaxial tension at infinity. Finally, some problems of interest to physicians and plastic surgeons are discussed.

Danielson, D.A.
Stability of the Thin Elastic Shell Model of the Red Blood Cell
J. Biomechanics, 4:6, 611-617, 1971

Abstract: Fung and Tong have recently explained the sphering of red blood cells in hypotonic solution by showing that a thin-walled elastic membrane with the right extensional stiffness and surface tension distribution will swell into a sphere under internal pressure. In this report we investigate the stability of the spherical state of Fung and Tong's model by applying the static energy criterion, which requires a determination of the sign of the quadratic terms in the potential energy functional. It turns out that a spherical cell model with radius less than that of the equatorial radius of the original undeformed cell is indeed stable, if and only if the supposedly arbitrary elastic parameters in the model are restricted in their possible range of values.

Demiray, Hilmi
A Note on the Elasticity of Soft Biological Tissues
J. Biomechanics, 5:3, pp.309-311, 1972.

Abstract: In this short note a simple possible form of the strain energy function for soft biological tissues is studied. The similarity of the result of an example problem to experimental results is encouraging.

Diamond, George, Forrester, James S., Hargis, James, Parmley, William W., Danzig, Ronald, and Swan, H.J.C.

Diastolic Pressure-Volume Relationship in the Canine Left Ventricle
Circulation Research, Vol. 29, pp.267-275, 1971

ABSTRACT: Analysis of the passive pressure-volume filling curve of the left ventricle demonstrates that heart size and ventricular geometry exert major effects on the pressure-volume curve in the absence of changes in intrinsic muscle stiffness. Because the pressure-volume relationship is curvilinear, both quantitative and qualitative comparison of pressure-volume curves from different hearts is difficult. In the fresh isolated canine left ventricle, the pressure-volume relation was found to be almost perfectly exponential throughout a range of filling pressures from 5 to 30 mm Hg. Therefore, a precise linear and quantitative expression of the pressure-volume relation ($dP/dV = aP + b$) was developed ($r = 0.995$). The effect of isolated changes in either initial ventricular volume (mean $\Delta a = 3.1\%$) or ventricular geometry (mean $\Delta a = 27.1\%$) upon the slope, or a constant of this function was small in comparison to changes induced by rigor mortis (mean $\Delta a = 45\%$). It was concluded that the a constant was primarily affected by changes in left ventricular wall stiffness. In this manner, comparison of the pressure-volume relationship from different hearts is possible, and the contribution of changes in wall stiffness may be quantified.

Diamant, J., Keller, A. Baer, E., Litt, M., and Arridge, R. G. C.
Collagen, Ultrastructure and Its Relation to Mechanical Properties as a Function of Ageing
Proc. R. Soc. London (Biol.) Vol. 180, pp. 293-315, 1972

ABSTRACT: Tail tendons from Fischer and Sprague-Dawley albino rats of ages 2 weeks to 3 years were investigated under the polarizing microscope as regards structure and deformation behavior. Periodically extinguishing bands were observed along the otherwise featureless tendons. By analyzing the behavior of this extinction pattern under appropriate rotations of the tendon, it could be deduced that the orientation of the basic birefringent units varies periodically along the tendon and that this periodic pattern corresponds to a planar arrangement of the anisotropic entities. All the relevant parameters of this periodic structure could be determined in a representative manner from polarizing optics alone.

Subdivision of the tendons revealed regularly undulating or rather crimped subunits in good correspondence to what has been deduced from the extinction bands in the intact tendons..

The crimp angle was found to decrease while the periodicity increased - in approximate proportion to the length of the tail - with the age of the rat implying the simultaneous stretching of the fiber itself.

Stress-strain properties of tendons were measured and models for crimp

Diamant, J., Keller, A., Baer, E., Litt., M., and Arridge, R. G. C.
Collagen, Ultrastructure and Its Relation to Mechanical Properties as a Function
of Ageing

Proc. R. Soc. London (Biol.) Vol. 180, pp. 293-315, 1972

ABSTRACT (Continued): straightening were tested. It was found that a model containing inflexible hinges, corresponding to the "elastica" problem in mechanics gave reasonable fit with experiment. Analysis of stress-strain data on this basis leads to a basic load bearing unit, the diameter of which increases from 100 to 500 mm with the age of the animal.

Implications of these findings for the structure and properties of the tendons, also in relation to ageing are pointed out.

DIAMOND, George and Forrester, James S.
Effect of Coronary Artery Disease and Acute Myocardial Infarction on Left
Ventricular Compliance in Man
Circulation 45: 11-9, Jan. 1972

Abstract: The evaluation of left ventricular (LV) compliance by use of the pressure volume (P-V) relationship encounters several serious difficulties. Since the P-V relationship is curvilinear, it is difficult to quantitate. Furthermore, alterations of resting heart size and geometry also produce marked changes in the P-V curve. The first derivative of the P-V relationship, however, is a precisely linear function, expressed by the formula $dP/dV = aP + b$. The slope of this linear function, a , termed the passive elastic modulus, has been shown to be independent of initial volume and primarily and predominately determined by changes in the stiffness of the myocardium. Myocardial wall stiffness was evaluated in three groups of subjects during LV catheterization. In 13 normal subjects $a = 0.005$; in 13 with coronary artery disease $a = 0.011$; and in 12 with acute infarction $a = 0.045$. The differences in stiffness among the groups were highly significant ($P < 0.005$).

It was concluded that a measurable change in ventricular compliance occurs with the developemnt of coronary artery disease and that a further increase in wall stiffness occurs with the developemtn of acute infarction. The magnitude of increase in LV wall stiffness correlated directly with immediate prognosis: 87% of those subjects with a $\Delta P/\Delta V$ greater than 0.5 mm Hg/cc died of power failure during

Diamond, George and Forrester, James S.
Effect of Coronary Artery Disease and Acute Myocardial Infarction on Left
Ventricular Compliance in Man
Circulation 45: 11-9, Jan 1972

Ab stract: Continued
the acute stage of their illness. These alterations in compliance may invalidate
certain tradional concepts of LV function and hear failure.

Dieudonne, J.-M., Jean, C.-F., Cartier, R., and Dutertre, J.
Determination of Tissular Strain with a Tripod-Like Transducer II
Med. & Biol. Engng., Vol. 10, pp. 283-289, 1972

ABSTRACT: A tripod-like transducer has been designed to obtain basic mechanical
data in various biologic, particularly cardiovasuclar, structures. This report
describes properties of the tripod as revealed by particular calibration proce-
dures.

Relations are studied between a force applied to a spike and (a) strain
recorded from the tripod plate (e_{θ}) or (b) the displacement undergone by the tip
of the spike (d). Variables e_{θ} and d are found dependent on force magnitude and
direction. Calculated from descriptive expressions, these variables fit experi-
mental values satisfactorily. These expressions are used to derive analytically
tne angle and magnitude of force vector, the tissular strain or extension ratio
so as to render these data computable directly from recorded plate strains. The
type of obtainable information is illustrated by an aortic cyclic expansion and
compares favorably with that obtained by method I.

Diaz, Gabriela and Bruno, Gunther
Surface and Tissue Elasticity of Isolated Dog Lungs
Acta physiol. latinoam., 23; 83-93, 1973.

Abstract: The pressure-volume relationships of excised dog lungs were studied at four predetermined degrees of inflation: functional residual capacity, end-inspiratory volume, total lung capacity and mid-inspiratory or expiratory volumes. The comparisons were made with one lung distended with air whereas the contralateral lung was filled with saline solution, starting always with completely degassed lungs. It was possible to evaluate quantitatively the relative contributions of tissue elasticity and surface tension at various degrees of lung inflation, always within the physiological range of pulmonary ventilation. At the functional residual capacity level the transpulmonary pressure necessary to overcome the elastic recoil of lung tissue was almost zero, confirming von Neergaard's previous findings. In the present study it was found that approximately one fourth of the total elasticity corresponded to tissue elasticity and the rest to alveolar surface tension at the level of total lung capacity, whereas at the zone of tidal air both factors were of almost equal importance.

DOBRIN, Philip B., Doyle, James M.
Circulation Research, 27, 105-119, 1970
Vascular Smooth Muscle and the Anisotropy of Dog Carotid Artery

Abstract: Segments of dog carotid artery were held at in-situ length and studied in vitro after excitation of the muscle with norepinephrine and after poisoning of the muscle with potassium cyanide. In-situ length corresponded to a longitudinal strain of $.57 \pm .02$ relative to the unstretched length. The longitudinal elastic modulus was about 4.1×10^9 dyn/cm² at in-situ length and zero transmural pressure. This value was not altered by excitation of the vascular smooth muscle. The longitudinal stress due to traction decreased as the longitudinal stress due to transmural pressure increased, and it was suggested that this interaction underlies the relative constancy of vessel length in situ. The Poisson's ratio between the circumferential and longitudinal directions was about 0.3 and was found to decrease slightly with activation of the vascular muscle. The data for the longitudinal modulus and for Poisson's ratio were used to compute the circumferential elastic modulus. Activation of the muscle increased the circumferential elastic modulus when plotted as a function of circumferential strain. Comparison between the moduli in the two directions revealed that the arterial wall is not isotropic at physiological pressures because the circumferential elastic modulus is greater than the longitudinal modulus. Calculations indicated that assuming isotropy slightly underestimates the true circumferential modulus

Abstract (Cont'd):

at small circumferential strains, and greatly overestimates the true circumferential modulus at large circumferential strains. Active smooth muscle has little direct effect on these estimations, but does alter the error by contracting the vessel to smaller strains.

elastic modulus Poisson's ratio, changes in vessel length

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

DOBRIN, Philip B. and Rovick, Allen A.
Influence of vascular smooth muscle on contractile mechanics and elasticity of arteries.

Am. J. Physiol. 217. 1644-1651, 1969

Abstract: Segments of canine carotid artery were held at in situ length and studied in vitro after treatment with norepinephrine (NEpi) and after treatment with potassium cyanide (KCN). Activation of the vascular muscle caused contraction and greatly increased pressure-radius hysteresis. The blood vessel muscle exhibited an active stress-strain curve with a maximum stress of $.88 \pm .10 \times 10^6$ dynes/cm² for the whole wall, or 2.73×10^6 dynes/cm² for the estimated smooth muscle component of the wall. Activation of smooth muscle increased the elastic modulus when this was plotted as a function of strain. The active muscle exhibited a maximum elastic modulus of $3.99 \pm .08 \times 10^6$ dynes/cm² for the whole wall, or 12.66×10^6 dynes/cm² for the estimated smooth muscle component of the wall. Activation of smooth muscle decreased the elastic modulus when this was plotted as a function of pressure. This decrease was attributed to the reduction in radius brought about by the active muscle.

key words: smooth muscle active stress; wall volume; arterial elasticity; critical closure; length-tension curve

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Donders, Jan J.H. and Beneken, Jan E. W.
Computer model of cardiac muscle mechanics
Cardiovascular Research. Suppl. 1, 34-50, 1971

Abstract:

DOYLE, JAMES M. and DOBRIN, PHILIP B.
STRESS GRADIENTS IN THE WALLS OF LARGE ARTERIES
J. Biomechanics, 6:6, 631-639, 1973

Abstract: Elastic behavior of vascular wall, assuming the vessels to be 'thick-walled' and utilizing finite deformation theory, was investigated. It was found that canine carotid arterial wall is neither isotropic nor transversely isotropic. Previously, stress-strain relations were obtained for carotid arteries on the basis of membrane theory (Doyle and Dobrin, 1971). Since strain gradients across the wall are fairly steep, the applicability of such expressions, for pointwise evaluation of stress, required examination. The study indicated that these relationships between mean circumferential stress and mean extension ratio in the circumferential direction could be used to relate the specific circumferential stress value to the specific extension ratio at any designated point within the wall. From this analysis it was possible to evaluate circumferential and radial wall stresses. Both of these stresses are maximal at the inner surface of the intima. At this point the radial stress is equal to the transmural pressure and is compressive, while the circumferential stress is tensile and is 1.5 to 2 times the value of the mean stress, i.e. the product of transmural pressure and the ratio of internal radius-to-wall thickness. Both stresses are lowest at the outer edge of the adventitia. These stress distributions were considered with respect of the spacing of the elastic lamellae and the absence of

Abstract (Cont'd):

discernible vasa vasora in the inner third of the wall

DOYLE, J. M. and DOBRIN, P.B.
Finite Deformation Analysis of the Relaxed and Contracted Dog Carotid Artery
Microvascular Research 3, 400-415, 1971

Abstract: Elastic behavior, of dog carotid arteries, was investigated utilizing finite deformation theory. Excised segments of artery were held at in situ length and inflated. Measurements of longitudinal force, inflation pressure, and diameter were made continuously. Tests were conducted after activation of the vascular smooth muscle with norepinephrine and again after poisoning with potassium cyanide. The vessels were found to be anisotropic in their unstressed states. The partial derivatives of the strain-energy density function, with respect to the circumferential extension ratio, were computed. These functions increased exponentially. Activation of the smooth muscle caused a marked increase in stiffness in the circumferential direction; longitudinal stiffness was only slightly altered, however. It is demonstrated that the incremental modulus of elasticity in the circumferential direction is greater than the longitudinal modulus throughout most of the range of strain covered by these experiments.

DUGGAN, T.C.
Dynamic Mechanical Testing of Living Tissue
7th Int. Conf. on Medical and Biological Engng, Stockholm 27-1, 1967.

Abstract: There are no well established methods for the measurement of the mechanical properties of living human tissue. Preliminary results from a dynamic in-vivo method of mechanical testing of human tissues have to date not shown the force/displacement correlation with other parameters, eg. age, sex, etc. reported in several studies of the static response of post-mortem material.

Dutertre, J., Jean, C.-F., Cartier, R. and Dieudonne, J.-M.
Measurement of Tissular Strain with a Tripod-Like Transducer * 1
Med. & Biol. Engrg., Vol. 10, pp. 277-281, 1972

ABSTRACT: A tripod-like transducer is designed for measurement of strain patterns in biologic soft tissues. A general procedure is described to allow computation of tissular strains from recorded transducer strains, on the following principle:

Known strain patterns are created in an artificial tissue (rubber frame) for three standard orientations of the transducer. Recording of plate strains allows specification of a matrix of nine constant coefficients. These characterize the transducer and are used to compute any biologic state of strain within the accepted assumptions and tested range of strain. A deformation of a left ventricular wall during a cycle illustrates the general procedure.

Elliot, D.H.

The Biomechanical Properties of Tendon in Relation to Muscular Strength
Annals of Physical Medicine 9:1-7, 1967

ABSTRACT: 1. A study has been made of the biomechanical properties of the tendons of two groups of muscles in the rabbit. No significant difference was found between them in the stress required to cause a 5% strain or the stress required to eliminate wave-form. As the tendon of a fusiform muscle may transmit a maximum isometric tetanic tension of 2.5 kg.per sq.mm. whereas the tendon of a penniform muscle may transmit a maximum of 1.5 kg.per sq.mm., the strength of a tendon would seem to be related to its thickness and collagen content and not to the maximum tension which its muscle can exert.

2. The stress required to eliminate the appearance of wave-form on the surface of a tendon is less than 7% of the maximum tension to which it could be subjected.

3. It is probable that the normal range of transmitted tension falls within the tendon's "working capacity", its range of relative extensibility. Although the maximum contraction of a muscle may exceed this and cause some semi-plastic change, the tensile strength of a healthy tendon is more than twice the strength of its muscle.

Elliott, D.H.
Structure and Function of Mammalian Tendon
Biol.Rev. 40,pp.392-421, 1965

Abstract: Without tendons the efficient production and limitation of movement by muscles would not be possible. Their role is passive, their metabolism relatively inert and their immunity from disease almost complete. Tendons are a specialized form of connective tissue uniting muscle and bone and as such have functions essential to normal mobility. The structural unit of tendon is the fibre, consisting of fibrils of collagen, encircled by the anastomosing processes of fibroblasts. Orientation of fibrous tissue in tendon supports hypothesis of mechanical influence upon tendon growth. Tendon thickness may vary with muscle cross-section. The tendon has a tensile strength that is four times as great as the maximum tension that it has to transmit in vivo.

ELLIS, D. G.
Temperature effects on the dynamic and transient mechanical behavior of tendon
Tech.Report No.11, Univ of Michigan Medical School, Dept. Phys. Med. & Rehabilitation. 1970

ABSTRACT: Elongation responses of cat extensor digitorum communis tendon to triangular wave loading and to constant loads achieved by ramp loading were studied over a temperature range from approximately 22° to 55°C.

Attempts to develop a mathematical model for the mechanical behavior of tendon were unsuccessful but did show that the damping displayed by cyclicly loaded tendon could not be adequately described by a linear differential equation in load and elongation or by simple Coulomb friction as the major dissipative process.

ECKNER, Friedrich A.O., Brown, Barry W., Davidson, Donald L. and Glagov, Seymour
Dimensions of Normal Human Hearts, After Standard Fixation by Controlled
Pressure Coronary Pefusion
Arch Path. Vol.88, 497-507, 1969

Abstract: Controlled pressure fixation of hearts yields autopsy specimen with well preserved anatomy. Of 750 fixed hearts, 80 were considered to be "normal". These were used to establish tables of standard postmortem cardiac dimensions. Fourteen dimensions which characterize size and shape of ventricles and valvular orifices were related to age from conception, body weight, and body length according to the law of allometric growth. Chamber volumes could be calculated from volume indices used in the past. Each of the dependent variables could be predicted from one or two of the three independent variables. The tabulated data should be useful to the morphologist concerned with correlating autopsy measurements to in vivo estimates of cardiac dimensions and to clinicians concerned with finding methods for predicting and compensating for growth rate in reconstructive and prosthetic surgery.

Edman, K.A.P. and Nilsson, E.
The Mechanical Parameters of Myocardial Contraction Studied at a Constant Length of the Contractile Element
Acta physiol scand. 72.205-219, 1968.

Abstract: The time course of the active state, the force-velocity relation and the series compliance were investigated in isolated papillary muscles of the rabbit.--The force velocity curve defined at a precise length state of the contractile element and at a given time after the stimulus could be fitted by Hill's equation. The shape of the curve remained constant during the activity period, indicating that the ability to produce motion and the ability to produce tension undergo parallel changes during a myocardial contraction cycle.--The active state, at a given length of the contractile unit, had a slow onset (1/3--1/2 of the entire activity period being needed for attainment of the maximum) and did not form a distinct plateau. The time course of the active state was critically dependent on the degree of extension of the contractile unit. Evidence is presented that the duration of the active state is not definitely programmed at the start of the contraction; its final outcome is determined by the amount of shortening of the contractile element during the activity period.--The stiffness of the series elastic element, at a given union, was independent of the intensity of the active state. This fact supports the view that the active, force-producing structures in the cell do not contribute substantially to the series compliance of the cardiac muscle.

EISMAN, Martin M.
Lung Models: hollow, flexible reproductions
J. Appl. Physiol. 29(4), 531-533, 1970

Abstract: Hollow latex models of the respiratory airways are made using a metal lung cast for the pattern. Coating the pattern with latex, curing the latex and removing the pattern produce the final model. The model reproduces the airway dimensions of the rigid lung within 1.6%. Airways as small as 0.5 mm have been modeled.

rubber reproduction, pulmonary model; respiratory dynamics

Engin, Ali, E. and Wang, Han-Chou
A Mathematical Model to Determine Viscoelastic Behavior of In Vivo Primate Brain
Journal of Biomechanics, Vol. 3, No. 3, pp. 287-296, 1970

Abstract: Determination of mechanical properties of the constituents of the head is very essential for the construction of various theoretical and experimental head injury models. This paper represents a mathematical model for the evaluation of viscoelastic behavior of in vivo primate brain. From a theoretical mechanics point of view, the problem being considered is that of the steady state response characteristics of a solid sphere of linear viscoelastic material whose mating surface with the rigid container is free from shear stresses. The external load is taken to be a local radial harmonic excitation. First the response of the elastic material is determined; later the elastic response solution is converted to viscoelastic response solution through the use of the correspondence principle applicable to steady state oscillations. The paper is concluded with a discussion of a method which enables the determination of the complex dynamic shear modulus of in vivo primate brain.

EVANS, F. G. and Patrick L.M.

Impact Acceleration Stress: Proc. of a Symposium with a Comprehensive Chronologic Bibliography, p. 159, NAS-NRC Pub. 977, Wash. 1962.

IMPACT DAMAGE TO INTERNAL ORGANS

ABSTRACT: Injuries to internal organs consists of contusions, lacerations, and ruptures arising from the various types of stresses and strains produced by impact to different parts of the human body. One of the most frequent causes of injury is automobile accidents during which the occupant is injured by impact with some part of the car or by ejection from the car. This article discusses impact to thoracic, abdominal and pelvic viscera. Investigation of the different types of injuries along with the instrumentation necessary for detection of the injuries is discussed.

EVANS, F. Gaynor

BOOK

Studies on the Anatomy and Function of Bone and Joints

Springer-Verlag, Heidelberg, 1966

Evans, F. Gaynor and Vincentelli, Raul
Relation of Collagen Fiber Orientation to Some Mechanical Properties of Human
Cortical Bone
Journal of Biomechanics, Vol 2, No. 1, pp. 63-71, 1969

Abstract: The percentage of dark, light and intermediate osteons and their fragments, as seen in polarized light, was determined for 53 cross-sections of embalmed, adult human bone. Dark osteons have collagen fibers predominantly parallel with the long axis of the osteon while in light osteons, the fibers are at a sharp angle to the long axis of the osteon. Intermediate osteons are mixed.

Significant positive correlations were found between dark osteons alone, as well as when combined with their fragments, and the single shearing strength. Intermediate osteons alone, and when combined with their fragments, showed significant positive correlations with the (1) single shearing strength, (2) modulus of elasticity, and (3) percent elongation.

Significant negative correlations were found between light osteons alone, and when combined with their fragments, and the (1) single shearing strength and (2) modulus of elasticity.

No other significant correlations were found among the various types of osteons alone, or when combined with their fragments, and the mechanical properties of the specimens.

Fallenstein, G. T., Hulce, V. D., and Melvin, J. W.
Dynamic Mechanical Properties of Human Brain Tissue
Journal of Biomechanics, Vol. 2, No. 3, pp. 217-226, 1969

Abstract: Investigators have been studying the mechanical phenomena associated with impact to the head for many years. Several theories on the behavior of the brain during head impact have come from these studies but there has been a notable lack of information on the bulk mechanical properties of the brain which are necessary for the evaluation of these theories. This paper represents an initial attempt at providing such information.

The dynamic complex shear modulus of in vitro samples of human brain have been measured. Specimens from eight brains have been subjected to a sinusoidal shear stress input under resonant conditions in an electro-mechanical test device. Tests were conducted to determine the effects of time after death, refrigeration of material and shear strain dependence. A device to measure the dynamic properties of brain in vivo is described and preliminary data on in vivo tests on Rhesus monkeys is presented.

The results of the dynamic shear testing on in vitro human brain indicate that the storage modulus G' lies between $6-11 \times 10^3 \text{ dyn/cm}^2$, the loss modulus G'' lies between $3-5-6 \cdot 0 \times 10^3 \text{ dyn/cm}^2$ and the loss tangent $\tan \delta$ is in the range 0.40-0.55.

FANTUZZO, D.G. and Graziati, G.
A Mathematical Model for Articular Cartilage
7th Int. Conf. on Medical and Biological Engng, Stockholm 38-3, 1967

ABSTRACT: Various hypotheses have been presented on the structure of articular cartilage, one of which is based on a hydromechanical model. A comparison between the response of this model, on the basis of its equations, and observations of cartilaginous tissue placed under varying stress, utilizing a laboratory set, reveals many discrepancies. This method has the advantage that repeatable tests can be performed under near physiologic conditions. The selected model satisfactorily interprets the behavior of cartilage under dynamic stress, as observed experimentally and the analog computer analysis is most useful in the interpretation of the observations.

FARFAN, H. F., HUBERDEAU, R. M. AND DUBOW, H.I.
Lumbar Intervertebral Disc Degeneration - The influence of geometrical features
on the pattern of disc degeneration--A post mortem study.

J.Bone.Joint Surg. (AM) 54:492-510, April 1972

Abstract: The incidence of rupture of the anulus fibrosus is not uniform at all levels in the lumbar spine. It is customary to link the high incidence of anular rupture at the lower lumbar levels with the stress of weight-bearing, and it has been assumed that the lower joints, supporting the greatest proportion of body weight, are the first to suffer from the effects of compression loading. However, this assumption does not seem valid because the anulus has been shown to be very resistant to compression loads, much more resistant to compression than are the vertebral bodies. From a roentgenographic and anatomical study of 182 lumbar spines obtained at autopsy conclusions were reached.

FENN, Wallace O.

A Quantitative Comparison Between the Energy Liberated and the Work Performed by the Isolated Sartorius Muscle of the Frog.
J. Physiol., Lond. 80, 277-297, 1924.

ABSTRACT: (fm summary) The older work on the heat production of muscles allowed to shorten has been repeated and extended with the use of the sartorius muscle of the frog instead of the gastrocnemius. Quite different results have been obtained which are apparently due to differences in the anatomical structure of the two muscles.

The experiments provide a new explanation of the parallelism between the work of the heart and its oxygen consumption.

FICH, S. & WELKOWITZ, W.

A TAPERED REFLECTIONLESS MODEL OF THE AORTA
7th Int. Conf. on medical and Biological Engng., Stockholm, 27-2, 1967

Abstract: This paper deals with a mathematical model of the aorta which assumes a geometric and elastic taper, considers the blood a lumped mass and neglects reflection. The model was essentially verified by stopping the heart in dogs by electric pulsation, and observing the transient recovery.

FEIGL, Eric O., Simon, George A. and Fry, Donald L.
Auxotonic and Isometric Cardiac Force Transducers
J. Appl. Physiol. 23(4), 597-600, 1967

Abstract: Cardiac force gauges with improved coupling to the intact heart have been devised. The transducers are coupled to the intact heart by a set of pins thrust through the myocardium. The instruments can be used to measure tensile stress (force per unit area) in the beating myocardium under isometric or auxotonic conditions. This permits comparisons of contractile force between different experiments.

force measurement; strain gauge; myocardial force; contraction strength

Finlay, Bryan
Dynamic Mechanical Testing of Human Skin 'In Vivo'
Journal of Biomechanics, Vol. 3, No. 6, pp. 557-568, 1970

Abstract: The problems involved in measurement of the dynamic mechanical properties of human skin in vivo are examined. On the basis of these observations, the design of a rotary position servo for in vivo testing is outlined. Using this device, certain hitherto unidentified characteristics of the mechanical behavior of human skin are illustrated.

Fielding, J. William
Subtrochanteric Fractures
Clin. Orthop., 92: 86-99, May 1973

Abstract: Subtrochanteric fractures are an extremely difficult orthopedic problem. A review of the biomechanics and clinical management indicates that strong fixation devices, such as the "Zickel nail" as well as heavy one piece Jewett nails or intramedullary rods, with or without additional fixation and grafting, are generally necessary for reliable internal fixation.

Fields, R. W. And Faber, J. J.
Biophysical Analysis of the Mechanical Properties of the Sarcolemma
Can. J. Physiol. Pharmacol., Vol. 48, pp. 394-404, 1970

ABSTRACT: This paper attempts to explain the complex mechanical properties of the sarcolemma of single muscle fibers. Previously published measurements on retraction zones of frog semitendinous fibers were used as a basis for computation. A somewhat slack system of helical fibers in the sarcolemma can adequately account for the observations. It explains the shape of the tension-elongation curves of sarcolemma and its anisotropy. It permits the drastic transfiguration from normal shape to retraction zone shape in the absence of undue stresses. The angle of the helices was calculated to be 55° in the muscle fiber at rest length. This is also the angle permitting maximal volume of the muscle fiber. The Young's modulus of the fiber system was calculated to be in approximate agreement with the modulus published for collagen. With the single additional assumption that muscle fiber volume has a certain value within the range permitted by the measurements, the helical system can be shown to limit muscle fiber length between 70% and 140% of its rest length. The proposed helical fiber system is thus found to have properties that make it a likely candidate for the parallel elastic element of muscle.

FINLAY, J.B., Hunter, J.A.A. and Steven, F.S.
Preparation of human skin for high-resolution scanning electron microscopy
using phosphate buffered crude bacterial α -amylase
Jr. of Microscopy, Vol.93, Pt.1, pp.73-76, Feb.1971.

Abstract: A technique for preparing human skin for high-resolution scanning electron microscopy using phosphate-buffered crude bacterial α -amylase is described. Effects of the buffer solution alone are studied as well as the proteolytic activity of the enzyme solution used. The biochemical implications of these observations are discussed with regard to the in situ structure of the tissue.

FINLAY, J.B.
Biodynamic studies of human skin. Torsional characteristics in relation to
structure.
Ph.D. thesis, University of Strathclyde, Glasgow, 1970

FINLAY, Bryan
The Torsional Characteristics of Human Skin In Vivo
Biomed Eng. 6:567-73, Dec. 1971

Abstract: A rotary position servo has been used to assess the in-plane dynamic mechanical characteristics of the human skin on the forearm. Forty-three healthy individuals comprising 7 females and 36 males in the age range 7 to 63 years were tested. The technique has provided an objective quantitative measurement of the low-load extensibility of human skin in vivo. The broad range of results encountered in the measurement of low-load extensibility was of particular interest. Although the number of female subjects was small there was no indication of any sex dependence. However, an age dependence was noted in some of the recorded parameters.

The technique should prove to be of value in plastic surgery, studies of aging and a wide range of clinical conditions. At a research level, the full significance of the present results will not be known until they have been correlated with biochemical and microscopical investigations.

Frisen, M, Magi, M, Sonnerup, L and Viidik, A.
Rheological Analysis of Soft Collagenous Tissue. Part II: Experimental Evaluations and Verifications.
Journal of Biomechanics, Vol.2, No. 1, pp.21-28, 1969.

Abstract: As a direct continuation of Part I, where the theoretical background for the rheological model was discussed, possible operations on the model are discussed and performed on anterior cruciate ligament preparations from rabbits. Different methods of evaluating model constants are compared and other mathematical expressions than those of the model proposed are tried and discussed. Model parts are verified and numerical values are given for certain constants.

Flaherty, John T., Pierce, Joseph E., Ferrans, Victor J., Patel, Dali J.
Tucker, W.Kirk and Fry, Donald L.
Endothelial Nuclear Patterns in the Canine Arterial Tree with Particular
Reference to Hemodynamic Events
Circulation Research, Vol 30, pp 23-33, Jan.1972

Abstract: The objective of the study was (1) to measure systematically the orientation, morphology, and population density of endothelial nuclei of the canine thoracic aorta and its major branches and (2) to obtain evidence in a chronic in vivo preparation that altered flow patterns do indeed change patterns of nuclear orientation. For this purpose, a segment of the descending thoracic aorta was removed, opened longitudinally, and reclosed to form a tube with a new longitudinal axis 90° from the original vessel axis. The new segment was then sutured back in place. The animals were killed at suitable postoperative periods. Endothelial nuclear patterns were studied from en face photomicrographs of preparations stained with Evans blue dye. Results indicated: (1) In uniform vessel segments, e.g., middle and lower descending thoracic aorta, the nuclei were oriented parallel to the axis of the blood vessel, and the ratio of major to minor axes of the nucleus was large. The flow in these regions is known to be stable. (2) Nonaxial, less-ordered nuclear orientation with smaller ratios of major to minor axes were found in entrance regions of many major arteries and in the ascending aorta. (3) In chronic studies in which the flow

Abstract (Cont'd):

pattern was altered, the nuclear pattern realigned in the direction of flow within 10 days after surgery

FOLEY, John
The Stiffness of Spastic Muscle
J. Neurol. Neurosurg. Psychiat, 24: pp 125-131, 1961

Abstract: This study stemmed from an attempt to find out whether simple physical manoeuvres have any measurable effect on the spastic state as such in small children with diplegia. Muscle tone is difficult to define except in crude clinical terms, but for the purposes of the present paper it can be defined simply at that resistance which is felt by the examiner's hand on passively extending a muscle.

A simple method of measuring "tone" in the calf muscle of children with spastic diplegia is described.

Forrester, J.C., Zederfeldt, B.H. Hunt, T.K and Dunphy, J.E.
The Mechanical Behavior of Aging Skin Wounds
7th Int. Conf. on Medical and Biological Engng, Stockholm 27-3, 1967

Abstract: The structural importance of skin and other connective tissue for transmission of forces within the human body has been realized for some time. Equally important, but less well understood, is a knowledge of the mechanical properties of these tissues at different times of repair following injury. Skin damage is repaired by nonspecific connective tissue which, like skin, is a viscoelastic material. Measurement of this type of material is dependent on load, deformation and time. It is well known that stress values by themselves provide a limited amount of information. Energy absorption can vary within wide limits in specimens of the same tensile strength. The present study shows that although both ultimate stress and energy absorption values are steadily regained, the latter recovers more slowly.

Fosburg, Richard G.,
Cardiopulmonary Resuscitation
Military Medicine, 136:847-850, Nov. 1971

Abstract: The importance of prompt recognition of the urgency of cardiopulmonary resuscitation is emphasized, and a practical technique for employment of the closed method is described.

The use of drugs and electrical defibrillation is discussed together with the indications for thoracotomy and internal massage.

FRANKUS, Andrew and LEW, George C.
A Theory for Distortion Studies of Lung Parenchyma Based on Alveolar Membrane Properties
J. Biomechanics, Vol. 7, 1: pp. 101-107, 1974

Abstract: A finite element model representing the microscopic structure of the lungs is presented. Analysis of the model yields information on the mechanical properties of the lung parenchyma. The micro-properties upon which the model is based are computed by extrapolating uniaxial data calculated from experimentally obtained pressure-volume relationships of excised lungs. Macro-properties are subsequently found by assembling the micro-elements into a parenchymal structure of the lung, and analyzing its responses to non-uniformly applied forces.

Experimental information regarding the mechanical properties of lungs is lacking and this mathematical model which is based on the known pressure-volume relationships can fill a need in mechanical studies of the lungs. In particular, it provides the complete information for the element stiffness relationship in finite element analysis.

Comparison of the model properties with recently conducted macro-level distortion experiments indicates very good correlation.

Freeman, MAR, Swanson, SAV, Kempson, GE
Mechanical Abnormalities in Some Visually normal articular cartilage.
Buch Orthop 4:37-41, 1969

BIOMECHANICS: Its Foundations and Objectives
Edited by Y.C. Fung, N. Perrone and M. Anliker

Fry, Donald L.

A Preliminary Lung Model for Simulating the Aerodynamics of the Bronchial Tree
Computers and Biomedical Research 2,111-134, 1968

Abstract: A numerical method for modeling the mechanical behavior of complicated multi-phase, nonlinear, distributed, biological flow-systems is suggested with particular reference to the study of pulmonary mechanics. The major purpose of the model presented is to provide a computational tool for estimation of certain variables along the conduit system which are of physiologic and pathologic interest but cannot be measured directly. Results are presented which illustrate the distribution of pressure, conduit area, gas velocity, Reynold's number, and wall shearing stress along the bronchial tree. With proper modifications these may be extended to include distributions of other variables of interest such as temperature, "turbulent intensity," etc. Although the numerical results that are presented simulate the known mechanical behavior of the lung, any detailed interpretation must be approached cautiously at this time since many of the components and parameters of the model necessarily had to be chosen arbitrarily for lack of good experimental data.

FUNG, Y.C.

Comparison of Different Models of the Heart Muscle
J. of Biomechanics 4:4, 289-295, 1971

Abstract: The so-called Maxwell and Voigt models of muscles are shown to be equivalent, so that one is convertible into the other, if the series elasticity is not assumed to be absolutely independent of the muscle length. Different types of muscle-elasticity-modulus-versus-tension data are interpreted as yielding information about the dependence of the series elasticity on muscle length.

FUNG, Y.C.
Biomechanics, its scope, history and some problems of continuum mechanics in
physiology.
Appl. mech. Rev. 23., 1968

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FUNG, Yuang-Chen B.
BIORHEOLOGY OF SOFT TISSUES
Biorheology, Vol.10,pp 139-155, 1973

Abstract: To understand the physiological function of vital organs we must know the mechanical properties of the tissues. Experimental determination of the mechanical properties of living tissues has many difficulties, such as the small size, large deformation, active contraction, damage due to dissection, inaccessibility or non-existence of a "natural" state, and the necessity of keeping the specimens alive. In this paper, major features of the rheology of soft tissues obtained in our laboratory are summarized, and a mathematical description is offered to serve as a starting point for the analysis of the function of the organs.

Almost all published rheological data on soft tissues were obtained in one-dimensional condition-simple elongation of a slender cylindrical body, strip-biaxial or homogeneous-biaxial tension of a membrane. Recently we have collected data on two-dimensional testing of the skin, and torsion of the mesentery."

Fung, Y. C., Zweifach, Benjamin W., and Intaglietta, Marcos
Elastic Environment of the capillary Bed
Circulation Research, Vol. 19, pp. 441-461, 1966

ABSTRACT: To determine the degree to which the capillary blood vessels in vivo are supported by the elasticity of the surrounding tissue, a study was made of the elastic properties of the mesentery of the rabbit. A torsion test was made on a circular membrane of the avascular region of the mesentery, by applying a graded static torque and measuring the resulting deformation. The mesentery was found to have a modulus of rigidity in the same category as that of larger arteries and veins. It has a nonlinear stress-strain relationship with a tendency to harden at larger strains. In torsion experiments, the shear modulus G can be reduced to the following form

$$G = \mu + c_2 |\tau|$$

where c_2 is a constant and $|\tau|$ is the absolute value of the shear stress. The constant μ depends on the initial tension in the membrane. For the mesentery specimens, μ ranges from 215-1900 gm/cm², whereas the nondimensional constant c_2 has an average value of 8.23 with a standard deviation of 2.1

The hypothesis is advanced that the medium in which the capillaries of the mesentery are embedded is a gel and the capillary in effect is a tunnel in this gel. Such a hypothesis could explain the apparent rigidity of the blood capillaries.

FUNG, Y.C.B.

Elasticity of soft tissues in simple elongation

American Journal of Physiology, Vol. 213, No. 6, Dec. 1967, pp. 1532-1544

Abstract: Elasticity of living soft tissues is strongly nonlinear. Based on experimental results on rabbits mesentery, a theoretical framework is presented in which the elastic properties of soft tissues can be described. It is shown that the mathematical formulation works well also in reducing published data on the series element of the heart and striated muscles, and the skin. In simple elongation the tensile stress is nearly an exponential function of the strain in the lower stress range. Based on this fact, it is shown that although we are dealing with the finite deformation of highly nonlinear materials, the elastic property of soft tissues in tension can be expressed quite simply in most cases. It is necessary, however, to give up the usual practice of trying to characterize the elasticity of tissue by a representative Young's modulus, because this modulus varies over a very wide range, which is often zero at vanishing stress, and increases linearly as the stress increases, and therefore is meaningless unless the exact stress level is specified. New physical constants recommended are: the slope and curvature at the origin of the curve of $dT/d\lambda$ vs. T , where T stands for tension and λ stands for the extension ratio, and the tensile stress T^* (based on the original crosssectional area) at a specific value of the extension ratio λ^* .

Fung, Y.C. and Sobin, S. S.
Elasticity of the Pulmonary alveolar Sheet
Circulation Research, Vol. 30, pp. 451-469, 1972

ABSTRACT: An analysis of experimental data on the pulmonary alveolar sheet of the cat shows: (1) As far as elasticity in the plane of the sheet is concerned, the alveolar sheet may be regarded as uniform; the compliance of the posts is the same as that of the membranes. (2) Within a physiological range of positive transmural pressure, the mean thickness of the sheet varies linearly with the pressure. Also, the stress distribution in the alveolar-capillary membrane is non-uniform and nonisotropic. A theoretical sheet thickness-pressure relationship is derived in which the effect of stress resultants (sum of elastic stress and surface tension) is explicitly linked to the compliance of the sheet thickness. The sheet-flow theory then shows that average flow is very sensitive to the arteriole pressure. The flow per alveolar sheet is $(1/C)(h_a^4 - h_v^4)$. Here h_a and h_v are equal to alveolar sheet thickness at the arteriole and venule, respectively. When $p_{art} > p_{alv}$, $h_a = h_0 + \alpha(p_{art} - p_{alv})$, where p_{art} is the blood pressure in the sheet at the arteriole, p_{alv} is the gas pressure in the alveolus, α is the compliance constant for the sheet thickness, and h_0 is the thickness at $\Delta p = 0$. The constant $C = 4 fL\mu/(SA)$, where μ is the coefficient of viscosity of blood, f is a friction

Fung, Y. C. and Sobin, S. S.
Elasticity of the Pulmonary Alveolar Sheet
Circulation Research, Vol. 30, pp. 451-469, 1972

ABSTRACT (Continued): parameter (on the order of 4, depending on the post geometry) L is the average length of the streamlines in the sheet, S is the vascular space-tissue ratio (on the order of 0.9), and A is the sheet area. Comparison of this formula with the experimental results of Roos, et. al., using h_0 and α values from Glazier et. al., shows reasonable agreement.

FUNG, Y.C. and Zweifach, B.W.
Microcirculation: Mechanics of Blood Flow in Capillaries
Annual Review of Fluid Mechanics, Vol.3, pp.189-210, 1971

Abstract: (from concluding remarks) We have considered primarily the flow in tubular blood vessels. The fluid movement across the tube wall has been ignored.

Capillary blood flow has been discussed above as if it occurred in a passive system. Actually the capillary bed has a complex mechanism for control of local blood flow. The smooth muscle cells at the sphincter located at the entrance to a capillary blood vessel are believed to respond to oxygen and other myotropic agents, and to physical stretch. The mechanical property of the vascular smooth muscle is unknown, but it is clear that a more meaningful understanding of the microcirculation will require its clarification.

FUNG, Yuan-Cheng B.
Stress-Strain-History Relations of Soft Tissues in Simple Elongation
From BIOMECHANICS: ITS FOUNDATIONS AND OBJECTIVES,
Y.C.Fung, N.Perrone and M. Anliker, editors, Prentice-Hall, Inc. Englewood Cliffs,
New Jersey.

ABSTRACT: (FM Concluding remarks)

We emphasize that the intention of the present article is to glean from the field of published data some simple rules that seem to apply in the lower, physiological range of stresses. In a detailed comparison, each tissue, indeed, each specimen, is different, and one cannot expect a simple formula to account exactly for all the experimental data. In particular, although most original papers make some effort to justify the data as comparable to in situ characteristics in normal living condition, one cannot be absolutely sure. We feel, however, that these needs for further refinements should not deter us from offering a simplified general stress-strain-history law that will help biomechanics to progress beyond elementary discussion and to come to grips with significant boundary-value problems of the function of the organs.

FUNG, Y.C.

Theoretical considerations of the elasticity of red cells and small blood vessels
Fed. Proc. 25(6), 1761-1772, 1966

Abstract: Part 1. Equilibrium states of red cells.

The stress and deformation of a red blood cell are considered from the point of view of theoretical mechanics. The starting point is that the normal red cell is a biconcave disc in shape. The hypothesis that the interior of the red cell is in the state of a liquid leads to a number of predictions with regard to crenation, disc-sphere transformation, and rupture. The predictions are in qualitative agreement with known experimental results.

Part 2. Tunnel-in-Gel Concept of Capillary Blood Vessels

It is generally accepted that the tissue surrounding the blood vessels help support the vessels but is it not known to what extent this occurs. Using the avascular portion of the mesentery of rabbits, the stress-strain relationship for the mesentery was obtained and applied to the blood vessel distensibility problem. In the case of the smaller capillary blood vessel, the surrounding tissue is very much larger than the vessels, hence the elasticity of the capillary blood vessel is derived almost entirely from the surrounding tissue.

FUNG, Y.C.

A Theory of Elasticity of the Lung
ASME PAPER 73-APM-R, 1973

Abstract: The stress-strain relationship of the lung parenchymal tissue depends on the alveolar geometry, the elastic property of the alveolar walls (sheets, septa) and the surface tension characteristics. This nonlinear relationship is derived in the present paper.

Fung, Yuan-Cheng

Mathematical Representation of the Mechanical Properties of the Heart Muscle.
Journal of Biomechanics. Vol. 3, No. 4, pp. 381-404, 1970

Abstract: Heart muscle has been subjected to many experiments in many laboratories and many reports are conflicting with each other. To unify the picture, resolve the conflicts, and describe the complex phenomenon in a compact set of equations, a mathematical formulation of the mechanical properties of the heart muscle is presented on the basis of the sliding-element theory and Hill's model.

Isotonic and isometric processes, the active state and the relaxation law are analyzed. Necessary corrections to the procedures for measuring the elasticity of series element are discussed; and methods for determining the dependence of series elasticity on the length of the muscle are described.

An advantage of a concise mathematical formulation of the mechanical properties is to enable us to formulate experimental procedures to determine physiological constants. In the light of the present analysis most of the published constants require some sort of corrections. It is hoped that corrected values will become available in the future.

Galford, James E. and McElhaney, James H.

A Viscoelastic Study of Scalp, Brain, and Dura
Journal of Biomechanics, Vol. 3, No. 2, pp. 211-221, 1970

Abstract: A series of creep and relaxation experiments on scalp, brain and dura from both human and monkey is described. An analysis of a practical creep loading with a rise time is given. An empirical expression for the observed creep curves is developed and deviations from classical viscoelasticity theory noted. A four parameter Maxwell-Kelvin fluid model is proposed and fitted to the creep data.

In addition, a free vibration test using the same equipment as the creep and relaxation experiments is presented. Analysis of this experiment yields values of the complex modulus in the frequency range 10-40 Hz.

Gable, Walter D., Townsend, Frank M.
An Analysis of Cardiovascular Injuries Resulting form Accelerative Force
Aerospace Med. 929-934, 1963

ABSTRACT: Cardiovascular injuries resulting from abrupt accelerative force occurring in fixed-wing aircraft, rotarywing aircraft, and parachuting accidents are summarized. The predominant sites of heart and major vessel injury are described, and etiologic factors are discussed. Suggestions are made concerning parameters that should be given due consideration in the design of restraint systems and environmental configurations.

Ghista, D.N. and Sandler, H.
Elastic properties of the human left ventricle
Proc. Ann. Conf. Eng. Med. Biol. 10: 41.8, 1968.

NOT AVAILABLE ANYWHERE

Ghista, Dhanjoo N. and Rao, Ananta P.
Structural Mechanics of the Mitral Valve: Stresses Sustained by the Valve; Non-Traumatic Determination of The Stiffness of the In Vivo Valve.
J. Biomechanics, 5:3, 295-307, 1972.

Abstract: In order to provide the requisite structural strength for a prosthetic mitral valve, we have analysed the stresses in the in vivo mitral valve leaflets during a cardiac cycle. The valve cusps of the mitral valve are analysed as two semi-circular membranes held along the circular (fibrous valve ring) edge and supported along the straight edge (by the chordae tendinae). The critical loading condition is just prior to opening of the aortic valve, when the distended mitral valve leaflet is subject to the pressure difference between the left ventricular and left atrial chambers. For an adverse physiological loading situation, our analysis indicates that the order of magnitude of the stress that the leaflet membrane (and hence the prosthetic valve leaflet) sustains is 2.2×10^6 dyn/cm².

A vibrational analysis of the mitral valve leaflet is performed. Expressions for the stress in the leaflet and Young's Modulus of the leaflet material are obtained in terms of the dimensions of the valve leaflet and its fundamental mode vibrational frequency. The latter can be evaluated by determining the corresponding frequency of the first component of the first heart sound. Our analysis, hence, enables us to determine the stress in the leaflet and the Young's modulus (stiffness) of the in vivo leaflet at the instant of occurrence

Ghista, Dhanjoo N. and Rao, Ananta P. p.2
Structural Mechanics of the Mitral Valve: Stresses Sustained by the Valve; Non-Traumatic Determination of The Stiffness of the In Vivo Valve. Continued
J. Biomechanics, 5:3, 295-307; 1972

Abstract continued: of the first heart sound. It is noted that at this instant the valve is strained up to the transition point of its typically non-linear stress/strain characteristic. Prior to this instant, in a typical heart cycle, the valve operates in the pre-transition stress/strain range and subsequent to this instant, it operates slightly above the transition point, reaching a strain of the order of 25 per cent in adverse situations.

Ghista, Dhanjoo, N. and Sandler, Harold
An Analytic Elastic-Viscoelastic Model for the Shape and Forces in the
Left Ventricle
Journal of Biomechanics, Vol. 2, No. 1, pp. 35-47, 1969.

Abstract: An analytic model of the human left ventricle is presented, which incorporates the three dimensional shape of the left ventricle and the effects of ventricular wall thickness. The model resembles a thick-walled ellipsoid of revolution, a shape chosen because its volume most closely approximates the volume of postmortem left ventricular chambers when compared with volumes estimated by other regular three-dimensional figures of equivalent dimensions. The shape and size parameters of the model are determined from ventricular dimensions obtained from single plane cineangiography.

The model is equilibrated by a uniform internal normal stress corresponding to the measured pressure in the ventricle cavity, and zero stress on the outer surface. Elastic and quasi-static viscoelastic solutions for stresses and strains that provide for shear in the ventricular wall are obtained for uniform isotropic wall material.

Goedhard, W.J.A. and Knoop, A.A.
A Model of the Arterial Wall
J. Biomechanics, 6:3, 281-288, 1973

Abstract: On segments of thoracic aortae and common carotid arteries, static (E) and dynamic (E_C) Young's moduli were measured. Three main points were investigated. 1. The visco-elastic behavior of the arterial wall as a function of frequency, with special attention to frequencies below 2 Hz. 2. The set-up of a model of the arterial wall, matching the obtained data over the appropriate frequency range. 3. The influence of norepinephrine-induced smooth muscle contraction on Young's modulus and model outcome. The studied frequency range, except from $t=0$, ran from 0.016 Hz. It was found that this range needed an electrical model consisting of at least 4 different RC-circuits in series with a capacitance, to describe the visco-elastic behavior of the arterial wall. Smooth muscle contraction alters the obtained time constants but these remain of the same order of magnitude. The question of whether muscle contraction has an increasing or a decreasing effect on Young's modulus appears to be dependent on the experimental set-up, which is discussed.

GIKAS, Paul W.
Mechanisms of Injury in Automobile Crashes
Clin. Neurosurg. 19:175-90, 1972

ABSTRACT: (Taken fm the summary) The faulty driver may cause most of the crashes; however, the vehicle produces the injury. Efforts are needed both in crash prevention and injury prevention. Injury prevention requires a crashworthy vehicle and the use of restraint systems by the occupants. The prevention of ejection from the vehicle and the attenuation of the impact within the vehicle through the application of physical principles described above can do much to prevent injury in the event a crash occurs.

Gilbert, R., Eich, R.H. and Auchincloss, J.H. Jr.
Application of Hooke's law to the elastic properties of the lung.
Am. Rep. Tuberc. Pulmonary Diseases, 77:863-866, 1958.

Abstract: Some of the basic concepts of the resistance of materials are reviewed and their applicability to the study of the elastic properties of the lung is discussed. It is emphasized that static pressure-volume diagrams of the lung approximate only roughly the stress-strain diagrams used in engineering, and therefore should not necessarily be expected to obey Hooke's Law. It is to be emphasized further that values for compliance and elastance computed from such data do not give information concerning the material of the lung alone but are markedly influenced by size and structure.

GLAGOV, S.
Mechanical Stresses on Vessels and the Non-Uniform Distribution of Atherosclerosis
Med.Clin.North Am. 57:63-77, Jan. 1973

Abstract:

Goedhard, W.J.A
Visco-elastische eigenschappen van de arteriewand
Ph.D. thesis, Free University, Amsterdam, Netherlands 1971

GOLDIN, Marshall and Apter, Julia T.

A Relation Between Pulmonary Stress-Relaxation and Hysterésis in the Pressure-Volume Loop.

Fedn. Proc. p.551, Abstr. 1651, 1967

Abstract: Dog lungs excised while inflated with air or Ringer's solution were stretched by increments with small (2 to 6 cc) fast (10cc per second) injections of air or liquid. The intrabronchial pressure rose synchronously with each injection, then fell along an essentially exponential time course within 50 seconds for liquid- and 185 seconds for air-filled lungs to reach a final steady pressure level. Quick removal of small amounts of fluid caused a precipitous drop in pressure to zero followed by a rise, faster for liquid than for air, to a steady pressure. A static pressure-volume relation for dilation (or inspiration) and contraction (or expiration) was obtained from the steady pressure levels. It showed no hysteresis for air or liquid. However, if the pressure levels were read and subsequent forcing induced before completion of the transient, hysteresis was the rule. If readings were made 3.5 to 6.1 seconds after each forcing, the area of the hysteresis loop was the same for air and liquid. Earlier readings resulted in a greater area for liquid than for air; later readings reversed this disparity which can be explained by the greater compressibility and lower inertia of air over liquid.

GOLDMAN, Michael D. and Mead, Jere

Mechanical Interaction Between the Diaphragm and Rib Cage

J. Appl. Physiol. 35(2): 197-204, 1973

Abstract: We obtained passive volume-pressure (V-P) characteristics of the rib cage in four standing subjects during voluntary relaxation. Estimates of changes in rib cage volume (V_{rc}) based on changes in its anteroposterior and transverse diameters were related to transthoracic, transdiaphragmatic, and transabdominal pressures. Passive tensing of the diaphragm was obtained by compression of the abdomen with a pneumatic cuff. At lung volumes below FRC, abdominal compression displaced the transthoracic pressure (Prc) and transdiaphragmatic pressure (Pdi) tracings nearly equally, so that at a given V_{rc} , the change in Prc was closely similar to the change in Pdi. As a result the relationship between V_{rc} and transabdominal pressure (P_{ab}) was very nearly constant whether the diaphragm was under tension or not. We conclude that the intrinsic pressure developed by the rib cage itself, freed from the influence of diaphragmatic tension, is transabdominal pressure and that the diaphragm increases rib cage volume only to the extent that it increases transabdominal pressure. A corollary of this conclusion is that contraction of the diaphragm alone will move the chest wall along its relaxation characteristic.

GOLDMAN, E. AND GOLDMAN, Y.L.J.
Effects of Inflation on the Mechanical Properties of Collapsed Dog Lungs
Medicina (BAir) 28:107-12, May-Jun 68 (Spa.)

Abstract: The behaviour of simultaneous pressure-volume curves of isolated dog lungs of the same animal was studied. One of the lungs was previously inflated until total disappearance of collapsed areas was accomplished, while the other lung remained as a control. Three consecutive curves were performed with each lung. The results were expressed as compliance (C_L) and work of the loop (W_C) calculated from plaimetry. The present findings are in agreement with the fact that only multiple deep inspirations are sufficient to cause consistent changes in the surfact tension of the lung/

Goldman, D.E. and Hueter, T.F.
TABULAR DATA OF THE VELOCITY AND ABSORPTION OF HIGH-FREQUENCY SOUND IN MAMMALIAN TISSUES
J. Acous.Soc. Am. 28,35-57,1956

Abstract: This report is a condensed presentation of currently available data on the velocity and absorption of high-frequency sound in mammalian tissues.

Gou, Peng-Fei
Strain Energy Function for Biological Tissues
Journal of Biomechanics, Vol. 3, No. 6, pp. 547-550, 1970

Abstract: The purpose of this paper is to investigate a possible form of the elastic energy function for soft tissues, which can reproduce the characteristic feature as observed in experiments. The function is assumed to be the sum of the distortional strain energy. The relations between the axial stress and deformation in uniaxial tension are plotted.

GOW, Barry S. and Taylor, Michael G.
Measurement of Viscoelastic Properties of Arteries in the Living Dog
Circulation Research, 22, 111-121, 1968.

Abstract: Dynamic elastic moduli and viscous moduli of the arterial wall were obtained at a number of sites of systemic vascular tree of living dogs anesthetized with pentobarbital. Constants were calculated using the first harmonics of pressure and diameter obtained from a Fourier analysis of simultaneously recorded pulse waves. A Fourier analysis of pressure and diameter waves was shown to be unsatisfactory for determining the frequency dependence of viscoelastic constants because of anomalous behavior of the viscoelastic parameters. In the midthoracic aorta this behavior may have been partly attributable to artifact; however, there was strong evidence that elsewhere nonlinear pressure and diameter relationships interfered with the accurate determination of the relatively small, higher-order harmonic components.

frequency dependence of viscoelastic parameters, dynamic stiffness of arteries elastic nonlinearity.

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

GOYAL, Raj K., Biancani, Piero, Phillips, Aris and Spiro, Howard M.
Mechanical Properties of the Esophageal Wall
J.Clin.Invest, 50: 1456-65, Jul.1971

Abstract: Pressure-diameter curves of the esophagus were obtained to define its mechanical properties. The mucosal contribution to the strength of the esophagus was negligible until the outer diameter almost doubled, suggesting that small intraluminal pressures are held by the muscle layer alone. For larger deformations mucosal contribution increased and at failure the mucosa held over one-half of the failure pressure of the esophagus.

The paths followed during loading and unloading are different and exhibit hysteresis. They are influenced by the rate of pressure change, being more compliant for low rates of pressure change. They are influenced by the history of loading, being different for successive loading-unloading cycles. If enough loading-unloading cycles are repeated a stable loop is reached, which does not change thereafter.

Both the mucosa and the whole esophagus show increasing stiffness with increasing pressure. This behavior can be represented by a simple exponential relationship. However, at rapid rates of pressure increase, the esophageal muscles produce sigmoid loading curves, which gradually become exponential when repeating loading.

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Grahame, R.
Elasticity of human skin in vivo
Ann Phys.Med., 10: 130-136, 1969

Abstract: The purpose of this paper is to describe a method of measuring elasticity of skin in vivo, and to present the preliminary results of a study in which this technique was used in an attempt to elucidate the physical properties of the skin in rheumatoid arthritis and the effects of corticosteroid drugs.

Grahame, R.

A Method for Measuring Human Skin Elasticity in Vivo With Observations on the Effects of Age, Sex and Pregnancy
Clinical Science, Vol. 39, pp. 223-238, 1970

1. A method is presented for the measurement of the elasticity of human skin in vivo. A simple suction cup device is applied to the intact skin and the distortion produced in response to pre-determined negative pressures recorded. By the use of appropriate formulae stress and strain may be calculated and a stress/strain curve drawn, the gradient of which represents the elastic modulus for intact skin.

2. The test, which is simple to perform and entirely innocuous to the patient, has been shown to achieve acceptable standards of accuracy and reproducibility.

3. In the present study, the physiological variation in skin elasticity that occurs in respect of age, sex and pregnancy is investigated and the implications concerning the physiological changes that occur in skin collagen discussed.

GRANT, Michael E., Phil, D. and Prockop, Darwin J.
The Biosynthesis of Collagen (First of three parts)
N. Engl. J. Med. 286:1949-9, Jan. 1972.

Abstract:

Greenfield, Joseph C. Jr., M.D., Tindall, George T., M.D., Dillon, Marcus L., M.D., and Mahaley, M. S., M.D.

Mechanics of the Human Common Carotid Artery In Vivo
Circulation Research, Vol. XV, pp. 240-246, 1964

ABSTRACT: The purpose of this study was to evaluate the relation between lateral intravascular pressure, vessel diameter and vessel length in the common carotid artery of the human subject during life. The measurements were obtained from 13 male patients during surgical exposure of the common carotid artery for various clinical conditions.

The relationships between lateral intravascular pressure, vessel radius, and vessel length were evaluated in the common carotid artery in vivo in thirteen patients during treatment by surgery. Strain was measured in the wall of the carotid artery by means of an electrical caliper sutured to the vessel wall. Lateral intravascular pressure was measured directly with either an 18-gauge needle or a short polyethylene catheter connected to a Statham, P23Db, strain gauge. The results indicate that circumferential and longitudinal strains in the common carotid artery were both small. The mean systolic change in cross-sectional area was 2.10% (\pm SD 1.08) of the end diastolic area. In three patients a negative circumferential strain was produced by making the cross section of the vessel elliptical. During systole, longitudinal strain increased in four patients and decreased in six patients.

Greenfield, Joseph C. Jr., M.D., Tindall, George T., M.D., Dillon, Marcus L., M.D., and Mahaley, M.S., M.D.

Mechanics of the Human Common Carotid Artery In Vivo
Circulation Research, Vol. XV, pp. 240-246, 1964

ABSTRACT (cont): The average change in vessel segment length during systole was approximately 1.0% of the end diastolic length.

Greendyke, R.M.
Traumatic Rupture of Aorta
J. Am med. Ass. 195: 527-530, 1966

Abstract:

Grossman, William, Haynes, Florence, Paraskos, John A., Saltz, Stephen, Dalen, James E., and Lewis Dexter
Alterations in Preload and myocardial Mechanics in the Dog and in Man
Circulation Research, Vol. 31, pp. 83-94

ABSTRACT: Based on a myocardial mechanics approach to the analysis of left ventricular contraction, several indexes have been advanced as specific measures of myocardial contractility. Although two of these indexes, V_{max} and $[(dP/dt)/P]_{max}$ have been shown to be appropriately responsive to interventions known to alter the inotropic state, controversy has arisen as to whether they are unaffected by alterations in preload or initial cardiac muscle fiber length. This study was undertaken to determine which, if any, of the indexes obtained from myocardial mechanics analysis of left ventricular systole is independent of preload in the intact heart. Increases in left ventricular end-diastolic pressure were produced in seven dogs by infusion of dextran or whole blood and in eight patients by sudden elevation of the legs during cardiac catheterization. In dogs, elevation of left ventricular end-diastolic pressure was accompanied by a progressive decline in both V_{max} and $[(dP/dt)/P]_{max}$ measured using total pressure ($P < 0.01$). In contrast, V_{max} measured using developed pressure was unaffected over a wide range of left ventricular end-diastolic pressures. Similarly, in the eight patients, increases in left ventricular end-diastolic pressure induced by sudden elevation of the legs were consistently associated with reductions in $[(dP/dt)/P]_{max}$ measured using total pressure ($P < 0.01$) but these changes in pressure

Grossman, William, Haynes, Florence, Paraskos; John A., Saltz, Stephen, Dalen, James E., and Lewis Dexter
Alterations in Preload and Myocardial Mechanics in the Dog and Man
Circulation Research, Vol. 31, pp. 83-94, 1972

ABSTRACT (continued): had no effect on developed pressure Vmax. In the intact heart, measurements of myocardial mechanics using developed pressure appear to be independent of preload, but similar measurements using total pressure are inversely dependent on preload. This finding raises doubt as to the validity of total pressure measurements as indexes of myocardial contractility.

GUPTA, Bholā, Brinker, Wade O., and Subramanian, K.N.
Breaking Strength of Cruciate Ligaments in the Dog
J.Amer.Vet. Med. Ass., Vol.155:10, 1506-8, 15 Nov.1969

Abstract: Breaking strength of normal cruciate ligaments in dogs was determined on a tensile testing instrument. Both the anterior and posterior cruciate ligaments were tested simultaneously and, in some cases, separately. This information could be applied to other prostheses used in clinical cases of ruptured cruciate ligaments in dogs. It was suggested that a constant factor related to body weight be used to evaluate the approximate strength of the anterior cruciate ligament.

Grimm, Arthur F., Katele, Kazimieras V., Kubota, Ryo, and Whitehorn, William V.
Relation of Sarcomere Length and Muscle Length in Resting Myocardium
Am. J. Physiol. 218(5):1412-1416, 1970.

Abstract: Muscle length-tension curves were determined for isolated rat left ventricular papillary muscle. The ascending limb of the developed tension curve extended from 70 to 100% of optimum length. However, in this region the resting tension curve extended only from 85 to 100% of optimum length; below 85% of optimum length there was essentially no resting tension. It is concluded that myocardium has a "slack" length below the 85% length. Following formalin fixation and standard paraffin embedding technics, sarcomere length were determined using the optical microscope. Sarcomere lengths were found to be directly related to muscle lengths at lengths greater than 85% of optimum. Below this point no relationship existed; sarcomere lengths remained relatively constant. Since the myocardium and presumably the sarcomeres can actively shorten below this point, a diastolic sarcomere lengthening force must exist to restore sarcomeres to the 85% length. It is pointed out that the 85% length is probably less than the minimum sarcomere of muscle length within the ventricle in diastole.

Haut, Roger C. and Little, Robert W.
A Constitutive Equation for Collagen Fibers
J. Biomechanics, Vol. 5:5, 423-430, 1972

Abstract: A constitutive equation for collagen fibers is developed in the form of the 'quasi-linear' viscoelasticity law suggested by Y.C. Fung. This mathematical model is used to predict the experimental responses of tests of collagen fiber bundles extracted from the tails of mature rats. All experimental tests were conducted with the specimens immersed in a constant temperature saline bath. From relaxation tests, two material constants were obtained and used to predict the results of constant strain rate tests, hysteresis loops, and sinusoidal tests.

Hakuno, Tohru
Pulmonary Surface Tension and Phospholipid Metabolism in Diplococcal and
Mycoplasmal Pneumonia
Acta Med. Nagasaki 15: 82-100, 1972

ABSTRACT: In attempt to evaluate the mechanism, by which the tendency of atelec-
tasis was produced in diplococcal and mycoplasmal pneumonia, this study was done.

Hamsters were used as materials. The result showed the low surface activity
in diplococcal and mycoplasmal pneumonia. Furthermore, the cause of the low sur-
face activity was investigated especially from the point of the quantitative and
qualitative alteration of phospholipids which was a major component of pulmonary
surfactants. The results suggested that the decrease of saturated fatty acids
and the increase of unsaturated fatty acids of the lung extracts was a factor,
by which the low surface activity was induced in both pneumonic groups.

On the other hand, the lung extracts contained erythrocytes in the pneumonic
group. Hence, in the pneumonic group. Hence, in the pneumonic group the low
surface activity may result from the contamination due to the exudation of intra-
vascular component such as serum. Fatty acid composition of lecithin of the lung
extracts in pneumonic group was not similar to that of serum lecithin.

In consequence, it was suggested that the qualitative alteration of lecithin
of the lung extracts might be a factor of the low pulmonary surface activity.

Hall, R.H.
Variations with pH of the tensile properties of collagen fibers
J. of the Soc. Leather Trades Chems. 35, 195-210, 1951

Unable to obtain article. Journal is not in any of U of M libraries.

Hanson, P.G.

Cardiac displacement and thoracic vascular trauma resulting from abrupt deceleration of dogs.

Aerospace Medicine 38:1259-1263, 1967.

Abstract: Abrupt deceleration (impact) in the long axis of the body (G_z) may produce traumatic rupture of the thoracic aorta and great vessel branches originating from the aortic arch. The mechanism of vascular trauma may involve tearing action from sudden displacement of the heart and thoracic viscera. These experiments were designed to study the dynamics of cardiac displacement during and after $-G_z$ (head first) impact of anesthetized dogs. The animals were restrained in form-fitted capsules and exposed to $-G_z$ deceleration over a range of 20 to 40 G. High-speed radiographs of the thoracic cavity were taken at various times during deceleration. Radiograms showed that the heart underwent severe inertial displacement and oscillatory rebound. At impact levels above 35 G, vascular damage occurred in branches of the brachiocephalic and subclavian arteries. These data suggest that violent displacement of the cardiac mass is a major cause of vascular trauma from G_z impact.

Hardung, V.

Die Bedeutung der Anisotropie und Inhomogenität bei der Bestimmung der Elastizität der Blutgefäße. I. Mitteilung
Angiologica 1: 141-155, 1964.

Hardung, V. and Laszt, L.
Die Beziehung zwischen Last und Verkürzungs-geschwindigkeit beim Gefäßmuskel
Angiologica 3: 100-113, 1966

Abstract: The force-velocity relation of vascular muscles has been studied from purely mechanical measurements in order to gain some information on a possible influence of arterial contractions on blood transport. It has been found that also these muscles exhibit much the same behavior as has been found by Hill for skeletal muscles, that is to say the speed of shortening V is related to the load K according to the equation.

$$(K + a)(V + b) = (K_i + a)b$$

where a and b are constants and K_i is the load supported by isometric stretch. The constant a , which is a measure for the heat of shortening, determined from a phasic contraction (after electric stimulation) is significantly different from the value obtained with a tonic contraction (stimulated by K -ions). The latter values scatter indeed around zero. This seems to be the appropriate condition for the arteries to contract with the smallest expense of energy after any systolic extension.

Hardung, V.
Dynamische Elastizität und innere Reibung muskulärer Blutgefäße bei verschiedener
durch Dehnung und tonische Kontraktion hervorgerufener Wandspannung
Arch. F. Kreislauff, 61: 83-100, 1970

Abstract: The present paper deals firstly with the description of a new instrument for the measurement of a complex modulus of elasticity $E = E' \cos \phi + i E' \sin \phi$ of arteries and other elastomers. Ringshaped arterial segments were subjected to a sinusoidal strain. The resulting stress usually leads the strain by a phase angle. $E' \cos \phi$ is called the dynamic modulus of elasticity and $E' \sin \phi$ the loss constant, which can also be represented by the product of angular frequency ω and a viscosity constant η . Both quantities depend mainly on the initial stress in the arterial wall and of the frequency of the forced vibration.

Hardung, V.

Einfluss der Muskelkontraktion auf die Ausbreitungsgeschwindigkeit und Dämpfung der Pulswellen (the influence of Muscular Activity on the Speed of Propagation and Damping of Pulse Waves)

Angiologica 8: 347-354 (1971)

Abstract: If we suppose that the smooth muscle of the vessel wall develops an additional stress when the vessel wall is stretched, a mathematical analysis shows that in the absence of a natural positive damping of the pulse wave a negative damping constant might result, whereas the propagating speed of the pulse wave will be but slightly altered. This effect occurs only when the additional stress lags behind the elastic deformation. In reality, the positive damping due to viscoelasticity will generally be greater than the negative one due to muscle activity, in such a way that the positive damping will only be reduced by the latter. But some experiments on dogs let us surmise, that the negative damping exceeded the positive one.

Hardung, V.

Über eine Methode zur Messung der dynamischen Elastizität und Viskosität kautschukähnlicher Körper, insbesondere von Blutgefäßen und anderen elastischen Gewebeteilen.

Helv. Physiol. Acta 10: 482-498, 1952

Abstract: The aim of this work was the development of a suitable apparatus for the measurement of dynamic elasticity of rubberlike materials which might be used for blood vessels and eventually some other elastic tissues. Forced vibrations of different low frequencies from about 1 to 15 cycles per sec. are used for this purpose. The elastic modulus is calculated from the sinusoidal stress and strain curves obtained by photographic recording. The small phase shift between the stress and the strain can be used for a rough estimation of the viscosity of the materials tested.

Hardung, V. and L. Laszt
Untersuchungen über die Hamodynamik des Karotiskreislaufes mit Hilfe von
Impedanzmessungen
Angiologica 8: 17-30 (1971)

Abstract: The main purpose of the present work was to study the influence of muscular activity on the dynamic behavior of the carotid artery. To this purpose we determined the input impedance of the vessel as a function of frequency. On the other hand, we calculated such impedances theoretically for an elastic tube model closed at the peripheral end, using different parameters such as speed of propagation, damping constant and length. Even a mere qualitative comparison of the experimentally obtained with the calculated impedance-curves yields the following interesting results: if we cancel the muscular activity by injection of papaverine, the carotid clamped at the peripheral end shows a picture which closely resembles the theoretical one. Also a natural clamped carotid, not influenced by any drug, still shows some general features of the theoretical picture. On the other hand, a striking difference can be observed under the influence of the pressure reducing polypeptide firstly obtained by Laszt. In this case, phase shifts between pressure and flow are largely enhanced beyond the theoretically calculated limits from -90° to $+90^\circ$. These large phase-shifts can only be account

Hardung, V. and L. Laszt
Angiologica 8: 17-30 (1971)

Abstract; continued:
only be accounted for by a negative damping constant β . This, in turn, means that we must introduce in the theory some kind of an amplifying element due to muscular activity.

A further interesting result can be obtained if we record pressure and flow shortly after the removal of the clamp. In this case, the impedance-curves show the behavior of a tube with an open end not encountered normally in the arterial circulation. This might be attributed to reactive hyperemia of the peripheral vessels.

Hardung, V. and L. Laszt

Versuche in vitro über den Einfluss der Muskelkontraktion auf die Dynamik der Gefasswand

Angiologica 9: 81-88 (1972)

Abstract: The present paper deals, firstly, with an in vitro determination of impedance of large sections of carotide arteries. These experiments were thought of as a complement to our earlier experiments on the living animal. Their results can also be explained by a diminished damping factor, when the vascular muscles are brought into a contracted state.

In some further experiments, pressure alone was recorded; the vessel was connected to a pump with sinusoidal movement of its piston, as in the first series of experiments. If the pump is set in such a position that, at the beginning of its movement, the piston is near the entrance for the artery attached to it, and when the vessel is inactive, the pump will produce pressure waves whose maxima will coincide with the static pressure before the onset of pumping.

On the other hand, if the vessel is brought to an excited state by application of histamine, the pressure maxima exceed the pressure at rest. We conclude, therefore, that an excited vessel will produce additional forces or tension when it is quickly stretched and will follow the stretch, even when the frequency of these stretches is as high as 1 to 4 cps.

Harkness, R.D.

Mechanical Properties of collagenous tissue

TREATISE ON COLLAGEN, Vol. 2, part A. B.S. Gould, ed. 1968 p.247-310

Six parts, I. Introduction; II. Properties of Individual Tissues; III. Effects of Mechanical Stress on Living Tissues; IV. The Mechanical Properties of Tissues in Unusual and Pathological conditions; V. Measurement of Mechanical Properties to Determine the Nature of Mechanical Linkages in Tissues; VI. Conclusions.

PART VI CONCLUSIONS:

In this article an effort has been made to concentrate on what appear to be the more functional aspects of the mechanical properties of connective tissues. This may have caused the purely mechanical aspects to have been considered more briefly than they deserve. But the properties of even these structures, which might be considered as no more than anti-gravity devices, do appear to be too complex to be understood easily. Therefore, it seems important to be selective in investigation. Even though the article has concentrated on functional aspects some have been passed over, either because their significance in terms of mechanical properties is unclear—for example, the molecular sieving effect of connective tissue components or because too little information was available, for example on the movement of cells through connective tissues. The reason for this lack of information is probably that the nature of the basic materials from which connective tissues are made has

HARKNESS, R.D.
Mechanical Properties of Collagenous Tissue
TREATISE ON COLLAGEN, Vol.2, Part A. 247-310, 1968

Conclusions continues:
has only recently begun to be clearly established. It is to be hoped that it
will now be possible to pay more attention to the manner in which they work
mechanically, since this is the biological basis for their existing at all.

HAYES, W.C.
Mechanisms of Human articular cartilage
PhD dissertation. Evanston, Ill.: Northwestern University 1970

Haut, Roger C. and Little, Robert W.
Rheological Properties of Canine Anterior Cruciate Ligaments
Journal of Biomechanics, Vol. 2, No. 3, pp. 289-298, 1969

Abstract: The mechanical properties of canine anterior cruciate ligaments are studied at different strain rates and in different environments. A tibia-anterior cruciate ligament-femur preparation is tested preventing rupture at points of attachment. The data is compared with other investigations of ligaments and tendons and is plotted by use of the constitutive equation proposed by Y. C. Fung. Good agreement is obtained using Fung's exponential relationship and two numerical parameters are suggested for evaluation of future test data.

Hawthorne, Edward W.
Symposium on Measurements of Left Ventricular Volume. Part III Dynamic Geometry of the Left Ventricle
The Am. Jr. of Cardiology, Vol.18, 566-573,1966

Abstract: Some instantaneous geometric changes of the left ventricle during the cardiac cycle have been discussed. It is suggested that changes of size, shape and wall thickness provide special mechanical advantages to the ventricle during the various phases of the cardiac cycle.

It is proposed that the equivalent geometric model of the left ventricle is a thick-walled, non-prolate ellipsoid. Changes in wall thickness alter the stresses distributed across the ventricular wall and adjust the wall stress during the cardiac cycle within certain limits as yet undefined and for reasons which are as yet not understood.

For any given heart rate, myocardial inotropic state and ventricular pressure the stresses and tension within the ventricular wall are major functions of not only pressure but ventricular size, shape and wall thickness.

HAYES, W.C. and Mockros, L.F.
Viscoelastic Properties of Human Articular Cartilage
J. Appl. Physiol. 31(4), 562-568, 1971

Abstract: Shear and bulk creep compliances of human articular cartilage are evaluated from independent creep tests in torsion and uniaxial strain. Linearity of the compliance coefficients in the loading range tested indicates that the results are applicable to viscoelastic analyses of synovial joint mechanics. The measured compliances for normal and degenerative tissue are compared and found to differ significantly. Preliminary investigations also suggest that flow processes are not important in the initial stages of the deformation of normal tissue.

elasticity; viscoelasticity; synovial joint mechanics; shear modulus; bulk modulus; creep tests; degenerative cartilage

Henderson, A.H., Brutsaert, D.L., Parmley, W.W. and Sonnenblick, E.H.
Myocardial Mechanics in Papillary Muscles of the Rat and Cat
Am. J. Physiol. 217(5): 1273-1279, 1969.

Abstract: Species differences in myocardial mechanics were studied in rat and cat papillary muscles. The intrinsic velocity of contractile element shortening (V_{max}) was 3 times higher in the rat at comparable low frequencies. Resting and developed tension at the top of the length-tension curves was similar, but time to peak tension was 3 times shorter in the rat while peak rate of tension development (dt/dt) was correspondingly higher. Increased rates of contraction in the rat were associated with decreases in V_{max} and dt/dt contractility was not further augmented by paired stimulation, whereas at higher frequencies this increased contractility but, in contrast with the cat, did not shorten time to peak tension in both species and increased contractility but only slightly at low frequencies in the rat. These species differences imply basic differences in the control of intracellular calcium movement or in rates of the contractile process.

Hefner, Lloyd L., and Bowen, Earle T., Jr.
Elastic Components of Cat Papillary Muscle
Am. J. Physiol., Vol. 212, No. 5, pp. 1221 to 1227, 1967

ABSTRACT: The isotonic quick-release method was used to study the elastic components of cat papillary muscle. The data were analyzed in terms of two different conceptual models. The results suggest that parallel elastic component is parallel to both the contractile element and the series elastic component (model I) rather than parallel only to the contractile element (model II). Equations for calculating the force and the velocity of shortening of the contractile element for either model are presented.

cardiac muscle physiology; elasticity of cardiac muscle; biological models.

Heinl, Peter

[Mechanical Activation and Deactivation of the Isolated Contractile Structure of Frogs Sartorius by Rectangular and Sinusoidal Length Changes] (German)
Pflugers Arch. Vol. 333, pp. 213-226, 1972

ABSTRACT: Fibers of frogs sartorius were extracted with glycerol and stored for up to 2 months at -16°C without losing their contractility, while the calcium sensitivity was partly lost during longer storage. Freshly glycerinated (fully calcium sensitive) fibers were suspended in ATP-salt-solution with 10^{-7} - 10^{-6}M Ca^{++} and fibers with partially lost calcium-sensitivity (older than 2 months) were suspended in calcium-free ATP-salt-solution (10^{-8}M Ca^{++}).

Quick stretch by 0.1 - 1% of the fiber length caused an immediate tension rise followed by a small tension fall and a secondary delayed tension rise. The maximum of delayed tension was obtained by stretching 0.5-0.8% L_0 . The delayed tension, but not its kinetics decreased with decreasing actin-myosin-overlap (range 2.2-3 μm). After quick release the immediate tension fall was often followed by a small tension recovery passing into a delayed tension fall. Calcium was not essential for the delayed tension production if the fibers were aged or suspended at pH 8.

During sinusoidal length changes (0.1-1% L_0 ; 4-45 c/s) the sinusoidal tension changes lagged behind, so that the fibers produced positive work, which was maximum at the frequency of 20 c/s.

Henderson, J. Michael, and Wyllie, James M.
Seat Belts - Limits of Protection: A Study of Fatal Injuries Among Belt Wearers
17th Stapp Car Crash Conference, SAE Paper No. 730964, pp. 35-66

ABSTRACT: Because the use of seat belts when available is mandatory in Australia and now at a high level, a high proportion of those who crash are wearing seat belts. The further protection of these occupants is high priority.

This paper reports a study of a series of fat-ally injured occupants of recent-model passenger cars, performed in order to investigate the potential for extension of the limits of seat belt performance in crashes that are currently fatal.

Improvements in seat belt design and installation should reduce a proportion of current losses from death and injury, but further reductions in these losses will demand attention not only to the crashworthiness of the car but also to the characteristics of the other vehicles and roadside structures that are commonly impacted.

Hildebrandt, J.
Extension of Small-Strain Theory to Finite Deformation of Cylindrical Vessels by Internal Over-Pressure
Angiologica 7: 257-272, 1970.

Abstract: Calculations of the pressure distention of closed cylindrical vessels using classical infinitesimal-strain theory predict that, for isotropic materials the length remains fixed while the diameter increases linearly with pressure. These predictions can be verified experimentally only if the radial deformation is less than 2-3%. This paper develops formulae applicable to deformations up to approximately 10 times the above, based on a modification of infinitesimal theory. The results predict significant lengthening of isotropic vessels, and ballooning or 'blow-out' above a certain pressure. It is shown that the classical stresses contain a common hydrostatic component which must be subtracted before the stresses can be integrated across the wall thickness to yield wall tensions. When the hydrostatic component is taken into account, Laplace's law is found to hold for thick-walled vessels as well as for thin-walled vessels.

key words: pressure distention; Elastic cylinders; infinitesimal theory; lengthening isotropic vessels

HILDEBRANDT, J.
Models of Pressure-Volume Hysteresis
Bull Physio-path.resp., 8, 337-350, 1972

Abstract: Current models of lung hysteresis may be classified as - equivalent - models, in that they seek to describe data by arbitrary mathematical formulations or with idealized mechanical components without particular regard to underlying molecular processes or mechanisms. One such model consisting of plastoelastic and linear viscoelastic elements is reviewed. It is applicable in the linear portion of the PV curve for tidal volumes (V_t) up to 10-15% of TLC. For larger amplitudes other models have to be developed. Efforts have been made to clarify hysteretic mechanisms employing two preparations: (a) whole lung, either air or liquid filled and (b) tissue strips dissected from lung. A comparison of air and saline PV curves reveals that, at least for slow cycles, 75-80 % of hysteresis is attributable to the lung lining. However, several similarities between tissue and lining hysteresis do exist suggesting perhaps that some fundamental mechanisms are shared. Deductions from stress adaptation of lung lining point to the existence of many solid-like characteristics at the air-tissue interface, rather than liquid-like in which only a single equilibrium tension might exist. The lining may be regarded as a lossy elastic material, exhibiting static hysteresis and viscoelasticity. It may undergo a phase transition to a fluid-like state

HILDEBRANDT, J.
Models of Pressure-Volume Hysteresis
Bull Physio-path.resp., 8, 337-350, 1972

Abstract: Cont. near TLC. At lower volumes the viscous energy losses could more closely resemble those seen in long-chain cross-linked polymers and elastomers.

Lung hysteresis; viscoelasticity; plastoelasticity; lung surface tension

Hildebrandt, J.

Comparison of Mathematical Models for Cat Lung and Viscoelastic Balloon Derived by Laplace Transform Methods from Pressure-Volume Data
Bulletin of Mathematical Biophysics, Vol.31, 651-667,1969

Abstract: The mechanical properties of some hollow organs are most conveniently described by a pressure-volume relationship. If the material exhibits hysteresis, the p-v relation must include provision for time-dependent or path-dependent properties. Provided the amplitude of deformation is fairly small and the hysteresis is primarily of the viscoelastic type, a linear description is possible. That this may take the form of a simple transfer function in which material properties are implicit is illustrated for the case of a rubber balloon. The transfer function was derived from the pressure transients which follow step changes in volume produced in a fluid-filled plethysmograph. The applicability of the transfer function in predicting responses to other forcing functions was tested by varying the balloon volume sinusoidally over a frequency range of 1000, at 4 different amplitudes. The good agreement between the linear model and all types of data justifies the use of Laplace transform methods and the assumption that superposition holds. When isolated cat lung is tested in the same manner, the transfer function quantitatively predicts the magnitude ratio of sinusoidal responses but only about two-thirds of the phase angle. The additional energy

Abstract (Cont'd):

loss per cycle is interpreted as arising from static hysteresis. The analysis thus provides a simple means of estimating the relative contributions of viscoelastic (dynamic) and static hysteretic processes to the total damping in a material.

HILDEBRANDT, J., Fukaya, H. and Martin, C.J.
Stress-strain relations of tissue sheets undergoing uniform two-dimensional stretch
Jr. of Applied Physiology, 27:5, 758-762, 1969.

Abstract: Data from simple elongation experiments do not provide sufficient information to predict the stresses occurring with large two-dimensional distention of tissue sheets. Almost uniform biaxial extension of nearly isotropic sheets was therefore produced experimentally to obtain the requisite stress-strain relationships. The sheet was mounted flat in a holder with a circular orifice and then inflated by positive pressure to form a bubble shape. By observation of both horizontal and vertical relative separation of small markers near the center of the sample the radius of curvature and the strain in this region were determined. Tension was obtained by Laplace's law and from tension and stress. Complete stress-strain curves of condom rubber, dog pericardium and cat mesentery were compared. Equations which fit the latex data are not directly applicable to the description of tissue properties, but can be adapted for this purpose by introducing simple multiplicative functions of hyperbolic character. One, two, or three material constants are required to achieve an approximate description of both uniaxial and biaxial deformation in rubber, pericardium, and mesentery, respectively. The prediction from classical elasticity theory that biaxial stress is twice uniaxial stress holds only in the

Abstract (Cont'd):

first portion of the stress strain curve. At greater extensions, the ratio may be considerably more or less than two.

tissue elasticity; two-dimensional stress-strain; biaxial deformation; nonlinear continuum mechanics

Hildebrandt, J, Fukaya H and Martin, C. J.
Completing the Length-Tension Curve of Tissue
Journal of Biomechanics, Vol. 2, No. 4, pp. 462-467, 1969

Abstract: General equations describing the relationship between tension and length of tissue have to date been based on data obtained primarily by simple elongation, i.e. positive strains. The portion of the curve representing negative strains should be described by the same equations. In practice this portion can be found either by one-dimensional compression, or more conveniently, by uniform two-dimensional extension of tissue sheets. The entire curve cannot be predicted by extrapolation from the results of either elongation or compression alone, and must be completed experimentally. Data from four types of tissue are presented, and a suitable mathematical form describing the complete length-tension curve is given. The limitations of data from one-dimensional and uniform two-dimensional extension experiments with respect to the full description of the mechanical properties of tissue are also discussed.

HILDEBRANDT, J.
Pressure-volume Data of Cat Lung Interpreted by a Plastoelastic, Linear
Viscoelastic Model.
J. Appl. Physiol. 28(3), 365-372, 1970

Abstract: Lung volume of isolated cat lungs was forced in a plethysmograph both sinusoidally and stepwise at a series of amplitudes and frequencies. From the pressure(stress) relaxation following the step, a linear viscoelastic model in the form of a transfer function was derived. Predictive sinusoidal P-V loops were computed from this transfer function and compared with experimental data. The frequency-dependent compliance of lung loops was quantitatively in agreement with that of the model, but only about two-thirds of the lung's hysteresis could be explained by linear viscoelastic mechanisms. It is postulated that the remaining hysteresis arises from rate-independent plastic strain. A model for plastic strain consisting of series Prandtl bodies with a distribution of yield points is shown to have several essential characteristics needed to describe the dependence of both loop area and compliance on amplitude of deformation, i.e., tidal volume.

lung mechanics; hysteresis; plasticity

HILDEBRANDT, J., Fukaya, H. and Martin, C.J.
Simple Uniaxial and Uniform Biaxial Deformation of Nearly Isotropic
Incompressible Tissues
Biophys. J. 9, 781-791, 1969

Abstract: A method is developed for analyzing in a unified manner both uniaxial and uniform biaxial strain data obtained from nearly isotropic tissues. The formulation is a direct application of nonlinear elasticity theory pertaining to large deformations.

HOFFMAN, Brian F., Bassett, Arthur L. and Bartelstone, Herbert J.
Some Mechanical Properties of Isolated Mammalian Cardiac Muscle
Circulation Research, 23, 291-312, 1968

Abstract: Isolated preparations of mammalian cardiac muscle have been employed to study possible mechanisms responsible for changes in diastolic compliance. Muscles have been studied at rest and during isometric and afterloading contractions, at fixed initial length and during programmed, cyclic changes in length and under the influence of paired stimulation, catecholamines, and elevated extracellular calcium concentrations. The results obtained indicate that, although there is a series viscous element in cardiac muscle, which accounts for stress-relaxation, some changes in compliance apparently result from alterations in the extensibility of the contractile element. This conclusion is based primarily on experiments showing shifts in the apex of the length-tension curve produced by action of inotropic agents which alter diastolic compliance and on experiments showing that the rate and extent of relaxation of afterloaded contractions depend on the extent of shortening during contraction.

cat, dog, cardiac muscles contractility,

Hill, A. V.

The Effect of Load on the Heat of Shortening of Muscle
Proc. R. Soc. London (Biol) Vol 159, pp. 297-312, 1964

ABSTRACT: During the process of shortening against a load a muscle liberates extra energy as work and heat. The methods used in measuring the extra heat due to shortening have been critically examined and are described in some detail.

The constant α of the heat of shortening depends on P , the load lifted, according to an average linear relation for frog sartorii at 0°C.

$$\alpha/P_0 = 0.16(\pm 0.015) + 0.18(\pm 0.027)P/P_0$$

P_0 is the maximum force developed at constant length.

The constant α of the heat of shortening can no longer be regarded as the same quantity as the constant a of the characteristic equation $(P+a)v = b(P-P)$ relating velocity (v) of shortening to load; but α/P_0 and a/P_0 , being always of the same order of size, are almost certainly connected in some way. The original (Hill 1938) conclusion that α and a were the same was probably due to a persistent error in the measurement of α , making it about 30% too great.

In the original (Hill 1938) hypothesis the rate of extra energy liberation $(P+\alpha)v$ during shortening was taken to be proportional to $(P-P)$, i.e., to the gap between the maximum force a muscle could exert and the actual load it had

Hill, A. V.

The Effect of Load on the Heat of Shortening of Muscle
Proc. R. Soc. London (Biol) Vol. 159, pp. 297-312, 1964

ABSTRACT(Continued): to lift. In its simple form this idea must be abandoned; but a modification is suggested which still provides the characteristic equation and supplies a connexion between α and a .

The assumptions made in calculating the heat of shortening are examined; to regard it simply as a change, produced by shortening, in the maintenance heat would make little difference. Further advances in the chemistry of contraction may allow the facts to be expressed in more concrete terms.

Hill, A. V.

The Efficiency of Mechanical Power Development During Muscular Shortening and Its Relation to Load

Proc. R. Soc. Lond. (Biol) Vol. 159, pp. 319-324, 1964

ABSTRACT: When shortening occurs during a maintained isotonic contraction, as Aubert (1956) found during shortening at constant speed, the "efficiency" remains very constant throughout, even over a considerable range of length. The efficiency varies largely with the load P , being zero at $P = 0$ and $P = P_0$ (isometric). Near its maximum around $P/P_0 = 0.5$ the efficiency (in from sartorii at 0°C) is consistently about 0.45⁰.

The form of the relation between efficiency and load is discussed, particularly in view of recent findings on the heat of shortening of muscle.

The mechanical power developed during shortening is greatest when $P/P_0 = v/v_0 =$ about 0.3; but the efficiency here is only 3 to 5% less than its maximum.

Hill, D. W. and Condon, P. I.

Measurement of the Tensile Strength of Corneal Tissues

Exp. Eye Research, Vol. 11, pp. 143-144, 1971

ABSTRACT: The technical features of a tensiometer to measure the strength of small excised corneal strips were reported, and a film shown illustrating its use and the techniques of experimental surgery were employed in the study of the rabbit cornea. A preliminary investigation of the healing of corneal wounds sutured with, 6-0 plain and chromic collagen, 8-0 twisted virgin silk, and 8-0 monofilament nylon was reported. Virgin silk and nylon gave the most satisfactory wound strengths throughout the healing period, but virgin silk excited more tissue reaction and was accomplished by epithelial downgrowth.

Hill, R.B., Marantz, Elizabeth, Beattie, B.A. and Lockhart, J.M.
Mechanical Properties of the Radula Protractor of *Busycon Canaliculatum*
Experientia 24:91-2, 15 Jan 1968

HIRSCH, Arthur E. and Ommaya, Ayub K.
Protection from Brain Injury: The Relative Significance of Translational
and Rotational Motions of the Head after Impact
14th Stapp Car Crash Conf, 1970, pp 144-151, paper SAE 700899

ABSTRACT: The rotational and translational rigid body motions of the head after impact were evaluated by high-speed cinematography in Rhesus monkeys with and without a cervical collar. When a collar was worn, animals displayed increased tolerance to occipital impact for the onset of cerebral concussion. Although head rotations were reduced in this nonconcussed protected group, translational motion of the head exceeded that attained by concussed monkeys not wearing collars but struck at equivalent impulse levels. These data emphasize the inadequacy of current head impact tolerance criteria which relate the occurrence of brain injury to translational head motions.

Hirsch, Carl and White, Augustus A.
Characteristics in the Thoracic Spine Motion. Studies on Autopsy Specimens
Clinical Orthopaedics & Related Research 75:156-63, Mar-Apr.1971.

Abstract: (fm Summary) To describe motion characteristics of thoracic spine, 27 autopsy specimens were studied by 2 experimental technics. In the first, the motion between segments of 2 vertebrae was observed under controlled conditions. In the second, the motion between larger segments of the spine, including three-dimensional movements, were analyzed.

Hirsch, C.
Experimental Designs in Investigations of Mechanical Properties in Biological
Tissues
Arch Orthop Unfall-Chir 71:142-147, 1971

Abstract: A combination of materials testing machine with electronic steering and recording system that satisfies requirements from a rheological and biological point of view is presented. The aim of improving equipment in this field is to control testing conditions, both with regard to testing milieu and the behavior of time-dependent materials, and also to facilitate mathematical and statistical interpretation.

The system to be described satisfies the following requirements:

1. Permits testing in a milieu with suitable temperature and humidity.
2. Gives well-defined constant speed of deformation with a wide range for selection.
3. Performs the electronic recording of corresponding load and deformation values without time delay and with sufficient frequency response.

Hirsch, Carl
The Reaction of Intervertebral Discs to Compression Forces
The Jr. of Bone and Joint Surgery, Vol.37-A, No.6 pp.1188-1196, Dec.1955

Histand, Michael B. and Anliker, Max
Influence of Flow and Pressure on Wave Propagation in the Canine Aorta
Circulation Research, Vol. 32, pp. 524-529

ABSTRACT: Data on wave speed acquired from 20 anesthetized dogs showed that the thoracic aorta was essentially nondispersive for small artificially generated pressure waves traveling in the downstream or the upstream direction and having frequencies between 40 and 120 Hz. The amplitude of these waves decayed exponentially with the distance traveled. The attenuation was independent of frequency and pressure if the distance was measured in wavelengths. The logarithmic decrement of the downstream waves ranged between 0.7 and 1.0, whereas that of the retrograde waves was between 1.3 and 1.5. The discrepancy in the attenuation for the two directions appeared to be due to the taper of the thoracic aorta. Simultaneous measurements of the transmission times of waves traveling downstream and upstream indicated that small pressure perturbations were convected with a speed that was approximately equal to the mean flow velocity. The speed of such perturbations depended strongly on the aortic pressure level at which they were generated. For normal pressure pulses generated by the heart, the speed of small perturbations at systole might be 30% higher than that at diastole. Theoretical studies have shown that such changes in wave speed due to variations in pressure and flow produce marked nonlinear effects in hemodynamics.

Ho, K. J., Lin, C. Y., Galysh, F. T., Patel, A. S. Liu, L. B. and Taylor, C. B.
Aortic Compliance: Studies on its Relationship to Aortic Constituents in Man
Arch. Pathol. 94: 537-46, Dec., 1972

ABSTRACT: Aortic compliance and its relationship to the aortic constituents were studied in seven female and six male aortas. The pressure-volume curve, initial volume and circumference, and various constituents of aortic wall, i.e., elastic, collagen and reticulum fibers, smooth muscles, fat, acid mucopolysaccharides, and calcium were determined quantitatively. The pressure-volume curves were transformed into tension-circumference diagrams. The initial and final slopes of the diagrams of proximal aortas of both sexes were always greater than those of the distal aortas. Differences in the initial circumferences may account for these differences. The steepness of the initial slope was positively correlated mainly with the elastic content of the aorta. The final slope, on the other hand, was related intimately to the severity of atherosclerosis.

HODGSON, V.R., GURDJIAN, E.S. and THOMAS, L.M.
Experimental Skull Deformation and Brain Displacement Demonstrated by Flash
X-Ray Technique
J. Neurosurg. 25, 549-552, 1966.

Abstract: This paper discusses visual study of the mechanisms of concussion or motion of the brain during impact. 'Stop Motion' x-ray equipment is now available which permits penetration of such dense media as the skull of an animal in extremely short exposure times. We have applied this flash x-ray technique to the study of skull deformation and relative motion or displacement of the brain during the moment of impact of a blunt blow to the head. Using intravascular contrast media or lead tags embedded in the brain and brain stem, distortions occurring at various instants during impact can be recorded with x-ray exposures in the order of nano seconds. This technique appears to provide a means for extending our existing knowledge of the mechanisms of concussion.

Hoeve, C.A.J. and Flory, P.J.
The Elastic Properties of Elastin
J. Am. Chem. Soc. 80: 6523-526, 1958.

Abstract: Force-temperature measurements have been carried out on elastin (ox ligament ligamentum nuchae) held at fixed elongation and immersed in glyco-water (3:7) mixture. The equilibrium degree of swelling of elastin in this mixture is independent of temperature, and the retractive force is directly proportional to the absolute temperature. It follows that $(\partial E/\partial L)_{TV} = 0$ for elastin and hence that the internal energy of the elastin chain is independent of its conformation. Contrary to previous studies on elastin, in which the influence of changes of swelling with temperature were overlooked, the thermoelastic behavior offers no indication whatever for crystallization on stretching at any elongation. The shape of the stress-strain curve is explained in terms of the morphology of native elastin; the abrupt rise in stress at high elongations is attributed to straightening out of the initially curled fibers of collagen which are associated with the native elastin.

HOLMAN, Mollie E., Kasby, C.B., Suthers, M.B. and Wilson, Jane A.F.
Some Properties of the Smooth Muscle of Rabbit Portal Vein
J. Physiol. 196: 111-132, 1968

Abstract: (Summary) 1. The morphology of the smooth muscle of the rabbit portal vein and its innervation were studied with fluorescence and electron microscopy. Two layers of smooth muscle were observed in the tunica media: an inner layer of circularly arranged muscle cells and an outer layer consisting of bundles of smooth muscle cells arranged in a near longitudinal direction. The membranes of neighbouring smooth muscle cells were occasionally fused to form 'tight junctions'. 2. Bundles of non-myelinated nerve fibres were observed in the adventitia, and between bundles and layers of smooth muscle cells in the media. Studies on longitudinal sections with fluorescence microscopy revealed a network of varicose noradrenergic axons. 3. Electrical and mechanical activity was recorded from longitudinal strips of smooth muscle from the media of the vein with a sucrose-gap apparatus. 4. The preparation was spontaneously active under minimal resting tension (less than 150 mg) and at temperatures above 28°C. Slow depolarizations led to a burst of spikes (multi-spike complexes), which correspond to rhythmic contractions. In 10% of preparations, the interval between multi-spike complexes showed a slower depolarization, suggesting the record was from a pace-maker region.

Holman, Mollie, E., Kasby, C.B., Suthers, M.B. and Wilson, Jane A.F.
Some Properties of the Smooth Muscle of Rabbit Portal Vein
J. Physiol. 196:111-132, 1968

Abstract cont.

5. The frequency of spontaneous activity (3-27 beats/min) was very sensitive to changes in temperature and tension.
6. Noradrenaline in low doses caused an increase in frequency of the multi-spike complexes. Higher doses caused maintained depolarization.
7. Responses to repetitive electrical stimulation of the vein were qualitatively similar to those in response to exogenous noradrenaline. The relation between the mechanical response and the various parameters of stimulation was consistent with the stimulation of sympathetic nerve fibres in the wall of the vein.
8. The actions of isoprenaline, phentolamine and propranolol indicated the presence of α 'excitatory' and β 'inhibitory' adrenergic receptors on the smooth muscle.

HODGSON, V. R., Thomas, L.M., Gurdjian, E.S., Fernando, O.U., GREENBERG, S.W.
AND Chason, M.D.
Advances in Understanding of Experimental Concussion Mechanisms
13th Stapp Car Crash Conf. 1969, SAE Paper 690796.

Abstract: This paper is an in-depth study of the mechanism of concussion. Prior to 1967, concussion experiments were conducted exclusively on dogs, but after results of trials on dogs, cats, and stump-tail monkeys, the authors concentrated on the latter.

Varying numbers of blows, from different angles were delivered to 12 monkeys. Results, both organic and behavioral, are discussed.

HOOD, William B., Jr., Murray, Raymond H., Urschel, Charles W., Bowers, John A., Clark, James G.
Cardiopulmonary Effects of Whole Body Vibration in Man
J. Appl. Physiol. 21(6), 1725-1731, 1966

Abstract: Supine whole-body x-axis sinusoidal vibration in four human volunteers was found to produce increases in mean arterial blood pressure, heart rate, cardiac output, oxygen consumption, and minute volume of ventilation. These physiologic effects were more marked at 1.2 g peak acceleration than at 0.6 g and at 8 and 10 cycles/sec than at frequencies to either side of this range. The changes observed were shown to be similar to those produced either by passive movement of the relaxed extremities or by mild muscular exertion. It is postulated that whole-body vibration elicits these changes by reflex stimulation of muscular contraction, and that such a mechanism may play a role in producing the physiologic effects of active muscular exercise.

vibration physiology; acceleration physiology, biomechanics; vibration and exercise, passive limb movement

HOOD, William P. Jr., Thomson, Walter J., Rackley, Charles E., and Rolett, Ellis L.
Comparison of Calculations of Left Ventricular Wall Stress in Man from Thin-Walled and Thick Walled Ellipsoidal Models
Circulation Research, Vol. XXIV, pp. 575-582, 1969

ABSTRACT: Using angiocardigraphic data from 50 human subjects, a comparison was made of calculations of circumferential wall stress in the left ventricle based on the thin-walled ellipsoidal model of Sandler and Dodge and the thick-walled ellipsoidal model of Wong and Rautaharju. The Sandler and Dodge formula consistently overestimated mean stress as determined from the Wong and Rautaharju model. The degree of overestimation in terms of percent error usually varied between 5% and 15% and overall averaged about 10% at end-systole as well as at end-diastole. Analysis of the various factors influencing the discrepancy between calculations indicated that the expected increase in error associated with an increase in wall thickness during systole tended to be mitigated by a concomitant change in chamber geometry, specifically, an increase in the ratio of major to minor semiaxis. This study, then, offers an estimate of the error introduced by employing the Sandler and Dodge or similar thin-walled ellipsoidal models for computation of mean circumferential stress.

Hoppmann, W. H., Wan, Lee
Large Deformation of Elastic Tubes
Journal of Biomechanics, Vol. 3, No. 6, pp. 593-600, 1970

Abstract: In this paper a study is made of the large deformation of elastic tubes. Analysis is confined to the case of static deformation. The energy of deformation is considered to be a function of the three strain invariants only. In order to determine its form for actual materials, it is expanded in its Taylor's series. From the theoretical analysis of the inflation and extension of tubes, linear algebraic equations in the elastic constants are developed. Using these and appropriate measurements of diametral change and longitudinal stretch, obtained from experiments, elastic constants for the non-linear theory of elasticity are explicitly determined with the aid of a computer program. The highly non-linear forms of deformation of tubes computed on the basis of the theory are compared with our experimental findings for a latex rubber tubing and for some bio-physical data taken from the literature.

HORIE, T. and Hildebrandt, J.
Volume History, Static Equilibrium, and Dynamic Compliance of Excised Cat Lung
J. Appl. Physiol. 33(1), 105-112, 1972

Abstract: Stress adaptation and dynamic compliance (C_{dyn}) were compared in excised cat lung at three selected volume levels following three volume histories. At the same volume level but with different histories, transpulmonary pressures (P_{tp}) remained discrete during air filling, but were very similar with saline. During a 20-min period of stress adaptation P_{tp} changed about 0.5 cm H₂O with air and about 0.1 cm H₂O with saline. Since at the same gas volume the three P_{tp} levels did not converge to a common pressure, it was unlikely that surface tensions (σ) converged toward the same equilibrium γ. Dynamic studies with air also demonstrated discrete tidal loops for different histories with the same end-expiratory volume level (V_e). Compliance also varied for each history, and only partially converged with time. Comparable PV loops in saline-filled lung were almost indistinguishable from each other; changes in compliance were only about 1/10 as large. Stable end-expiratory γ obtained from a Δγ vs. initial γ diagram at Δγ = 0 was almost independent of size of tidal volume (V_t), but stable end-inspiratory γ increased approximately linearly with V_t.

stress adaptation,; in situ surface tension; air- and liquid-filled lung

HORT, W.
Quantitative Morphology and Structural Dynamics of the Myocardium
Methods Achievm exp. Path. Vol.5, pp 3-21, 1971

ABSTRACT: (SUMMARY) In this paper, some methods of quantitative morphology of the heart are described. The most significant findings concern the quantitative morphology of normal and pathological growth of the heart, the structural dynamics of the myocardium during systole and diastole, and the structural alterations in the myocardium in acute dilation and chronic cardiac insufficiency. The influence of the pericardium on the heart is also discussed.

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2

HOUK, J.C.
A mathematical model of the stretch reflex in human muscle systems.
M.S. thesis, Massachusetts Institute of Technology, Cambridge, 1966
Cited by Milhorn, H.T. (1966) The Application of Control Theory to
Physiological Systems. Saunders, Philadelphia

Hugholtz, Paul G., Ellison, R. Curtis, Urschel, Charles W., Mirsky, Israel
and Sonnenblick, Edmund H.
Myocardial Force-Velocity Relationships in Clinical Heart Disease
Circulation, 41:191-202, 1970

Abstract: Myocardial force-velocity relationships were studied in 33 children and young people with varying heart lesions. From analysis of left ventricular pressures and consideration of left ventricular geometry, measured from biplane angiocardiograms, maximal contractile element velocity (V_{max}) was determined by extrapolation of a stress-velocity plot to zero stress. The value of V_{max} in each patient was compared with the assessment of cardiac function by usual hemodynamic criteria (left ventricular end-diastolic pressure [LVEDP], volume [LVEDV], and ejection fraction [EF]).

In general, patients with normal LVEDP, LVEDV, and EF had values for V_{max} above 3 circumferences/sec. Patients with elevated LVEDP or LVEDV or with EF below 0.5 had lower values for V_{max} . Three patients whose usual catheterization data suggested normal ventricular function were found to have low V_{max} . In all three, other evidence for myocardial abnormality was found. Several patients with excessive afterloads had impaired function by conventional criteria, yet had normal V_{max} .

Evaluation of myocardial mechanics in many with measurement of V_{max} appears

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Hugholtz, Paul G., Ellison, R. Curtis, Urschel, Charles W., Mirsky, Israel
and Sonnenblick, Edmund H.
Myocardial Force-Velocity Relationships in Clinical Heart Disease
Circulation, 41: 191-202, 1970

Abstract: continued
to aid significantly in evaluating patients with heart disease by giving an index to the state of the myocardium not available from routine catheterization data.

Hugo, N.E., Epstein, L., Cone, A. and Bennett, J.E.
The Effect of Primary Wounding on the Tensile Strength of Secondary Wounds
Surg. Gynec Obstet. 131: 516-8, Sept.1970

ABSTRACT: (Summary) Secondary wounds were created in the middorsal area of white male New Zealand rabbits five, nine, and 12 days after primary wounds were made in the midventral area. The tensile strength of these wounds was measured at five, nine, and 12 days and compared to control wounds. Those secondary wounds created nine and 12 days after primary wounding and tested at 12 days exhibited a statistically significant increase in their tensile strength. These data suggest a secondary wound phenomenon which is effective when the secondary wounds are created during the collagen phase of the primary wound and are then tested during the peak of the collagen phase. Previous reports in which no secondary wound phenomenon was elicited may be explained by too early creation of or testing of, the secondary wound.

Huntsman, L.L., Nichols, G.L., Verdugo, P. and Pollack, G.H.
New Instrument for Mechanical Testing of Tissues.
Proc. 24th Annu. Conf. Eng. in Med. Biol. 13:50, 1971

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HUXLEY, A.F. and Simmon, R.M.
Mechanical Properties of the Cross-bridges of frog striated muscle
J. Physiol (Lond) 218: 59-60, Oct.71.

Abstract: This article is a study of the mechanical properties of the cross-bridges of frog striated muscle.

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HUXLEY, H. E.
The Mechanism of Muscular Contraction
Science, 164:1356-1366, 1969

Abstract: Recent structural studies suggest a revealing model for cross-bridge action at variable filament spacing.

Haas, G. M.
Elastic Tissue
Arch Pathol. 27:334-365, 1939

Jacobs, H. Kurt, McConnel, David P., Rowley, Blair A. and South, Frank E.
A Force Transducer for Cardiac Muscle Strips
Journal of Applied Physiology, Vol. 35, No. 3, pp. 436-438, 1973

ABSTRACT: A transducer system employing a pressure-sensitive transistor is described for application to isometric contractions of ventricular muscle strips. A variable amplification interface is shown. Sensitivity of the system was adequate not only for high (ca. 1g) tension production but also for low (ca. 25 mg) tension development. The output was linear and drift problems were overcome by circuit modifications and mounting methods.

heart muscle; ventricular strips; tension production

Jacquemin, C. and Varene, P.
Elastic Properties of the Thoraco-Pulmonary System Pulmonary Compliance.
Poumon Coeur. 24:889-938, 1968

JAMES, D. W. and TAYLOR, J.F.
The Stress Developed by Sheets of Chick Fibroblasts in Vitro
Exper. Cell. Res. 54: 107-10, Jan. 1969

SUMMARY: 1. When confronted explants of chick frontal bone are cultured on glass, fibroblasts grow out from all sides of each explant, and form a confluent cell sheet in the region between them. If the cells on the non-confronted aspects of one explant are detached, then the explants are drawn towards each other by the fibroblast sheet connecting them.

2. Tension thus developed has been measured directly using a calibrated micro-spring balance, and found to be about 3.4×10^4 dynes/cm² of cross-sectional area of the cell sheet between the cultures.

3. Heating the cultures above 40°C caused a decrease in tension within the cell sheets (to 1.7×10^4 dynes/cm²) which may indicate that contraction of an extended fibroblast depends upon more than a single mechanism.

JEWELL, B.R. and Wilkie, D.R.

An Analysis of the Mechanical Components in Frog's Striated Muscle
J. Physiol. 143, 515-540, 1958

ABSTRACT: (fm summary) An attempt has been made to test the theory that the form of the isometric myogram is governed by the isotonic force-velocity curve and the stress-strain curve of the series elastic elements. In order to do this, all three curves have been accurately measured on the same muscle at the same time, at 2°C.

The anatomical sites of the series and parallel elastic components are discussed. Direct microscopic observation of the contracting muscle shows that about half the series compliance is in the pelvic tendon. The remainder is probably distributed along the muscle fibres.

Jewell, B.R. and Blinks, J.R.
Drugs and the Mechanical Properties of Heart Muscle.
Ann. Rev. Pharmacol. 8: 113, 1968

Abstract:

JEWELL, B.R. and WILKIE, D.R.
The Mechanical Properties of Relaxing Muscle
J. Physiol. 152, pp. 30-47, 1960

Abstract: (summary) A simple indirect method has been used to record simultaneous changes in length and tension in a frog's sartorius muscle during various types of muscle twitch.

In all cases the fall in tension eventually becomes exponential and the decay constant was found to be independent of the sequence of changes in length and tension that the muscle had undergone.

An isotonic quick-release technique has been used to follow the decline in activity in the muscle.

The use of various measurements for assessing activity is discussed. According to some criteria, activity persists at 0°C for as long as 0-9 sec after a shock.

The question of the heat production at late times is discussed.

Jones, Don F.
Back Injury Research: A Common Thread
Am. Ind. Hyg. Assoc.J. 33:596-602, Sept. 1972

Abstract: Attempts to reduce back injuries associated with manual lifting and handling have resulted in the development of several lifting techniques which might be described as mechanical, hip-flex, kinetic, dynamic and natural. Examination of the literature indicates that each has merits and no single method is suitable for all persons in all situations. This paper takes an objective look at the principles involved in an attempt to expose some common threads, thereby permitting a more realistic evaluation of the applicability of each method.

JONES, E. Chang, I-Dee and Anliker, M.
Effects of Viscosity and external constraints on wave transmission in blood vessels.
SUDAAR Rep. No.344. Dept. of Aeronautics and Astronautics, Stanford Univ.,
Stanford, Calif., 1968

This reprint is not available from authors or Stanford University. Univ. of Mich. Libraris do not have copies of the SUDAAR Rept.

Kelly, John J. and Hoffman, Brian F.,
Mechanical Activity of Rat Papillary Muscle
Am. J. Physiol., Vol. 199, No. 1, pp. 157-162, 1960

ABSTRACT: Isometric contractions of isolated rat papillary muscles driven at a constant rate have been recorded from paired muscles from hearts of rats 2-6 months of age. At 37° C and a rate of 30/min. tension reaches maximum in 30-60 minutes and then declines slowly during the succeeding 4-12 hours. The maximum tension and the rate of decline with time are related to the diameter of the muscle; however, it has not been possible to demonstrate a definite limit to diameter below which the contraction of the muscle is independent of variations in size. Most factors which increase the force of contraction do not prevent the slow decrease in tension with time. Two exceptions are low temperature (27°C) and high rate (180/min); under either of these conditions a steady level of tension is maintained for several hours or more. The response of the isolated rat papillary muscle to various physiological alterations is consistent and reproducible if variations in size are considered.

Kelman, G. Richard

A New Lung Model: An Investigation With the Aid of a Digital Computer
Computers and Biomedical Research, Vol. 3, 241-248, 1970

ABSTRACT: The properties of a new lung model, based on the assumption that ventilation and perfusion in the pulmonary alveoli are log-normally distributed, have been investigated with the aid of an ICL 4/50 digital computer. The behaviour of this model agrees well with established ideas in respiratory physiology, and predicted values of the oxygen, carbon dioxide and nitrogen alveolar-to-arterial tension differences accord with experimentally determined values in the literature. It is suggested that this model may prove valuable in clinical and physiological research; it permits the quantification of abnormalities of pulmonary function in terms of the parameters of the patient's hypothetical log-normal alveolar frequency distribution, rather as they are at present quantified in terms of such hypothetical parameters as "physiological dead space" and "percentage pulmonary venous admixture."

KELSALL, Margaret A. and Visci, Marguerite
Aortic Cartilage in the Heart of Syrian Hamsters
Anat. Rec., 166: pp. 627-634

ABSTRACT: A C-shaped bar of hyalin cartilage was present in the fibrous tissue around the aortic orifice in the heart of all 70 male and 10 female Syrian hamsters, 103 to 843 days old. This cartilage has the same cellular and intercellular characteristics as the tracheal cartilages. Fibers from four of the six lunulae of the semilunar aortic valves, the aortic sinuses and vestibule, and cardiac muscle adjacent to the posterior semilunar valve insert onto the fibrous capsule and the protuberances of the aortic cartilage. A few fibers from the ventricular and interatrial septa and the aortic cusp of the mitral valves are also attached to the fibrous capsule. Cartilage did not occur around the pulmonary orifice or in other regions of the heart with the exception of a chondroma in the aortic valve. The C-shaped aortic cartilage in this hibernating species is discussed in relation to its possible significance in preventing collapse of the aortic orifice and the possibility of increasing coronary blood flow.

Kempson, G.E.
Mechanical properties of human articular cartilage.
Thesis, University of London, 1969

Kempson, G. E., Muir, Helen, Swanson, S. A. V. and Freeman, M. A. R.
Correlations Between Stiffness and the Chemical Constituents of Cartilage on the
Human Femoral Head
Biochim Biophys Acta, Vol. 215:70-77, 1970

ABSTRACT: A method is described, in outline, for measuring the compressive stiffness of articular cartilage on the human femoral head, in vitro. Indentations were measured normal to the articular surface, and from these measurements creep moduli were calculated at 2 sec after application of the load. Correlations between the stiffness and the following quantities were determined: (1) Total glycosaminoglycan content, (2) chondroitin sulphate content, (3) 'keratin sulphate' content, and (4) collagen content. These quantities were determined from chemical analyses of the indented areas of cartilage and expressed as a percentage of the dry weight.

The following observations were made: there was a statistically significant correlation between the stiffness, expressed as the creep modulus, and the total glycosaminoglycan content. Approximately equal correlation coefficients were recorded between the stiffness and chondroitin sulphate and 'keratan sulphate' content respectively; however, at a given concentration, the influence of 'keratin sulphate' on the stiffness, was greater than that of chondroitin sulphate. In contrast, the correlation between stiffness and collagen content was considerably less significant.

KEMPSON, G.E., SWANSON, S.A.V., & Freeman, M.A.R.
Stiffness Variations in Femoral Head Articular Cartilage
7th Int. Conf. on medical and Biological Engng, Stockholm, 38-5, 1967

Abstract: Osteoarthritis is known to disturb the structure of articular cartilage and disease commonly involves the hip joint. The present study is concerned with the mechanical properties of the cartilage covering the normal femoral head. This covering has been shown to vary systematically in stiffness. The present results show no systematic variation of stiffness with age. An understanding of the properties of the covering on the femoral head is essential to understanding osteoarthritis.

KEMPSON, G. E.
Mechanical Properties of Articular Cartilage
J. Physiol (Lond) 223: 23P, May 1972.

Abstract: (The article) Articular cartilage experiences both compressive stresses normal to the articular surface and tensile stresses parallel to the surface. The mechanical properties of the tissue both in compression and tension are therefore important factors in determining the load carriage characteristics of cartilage. Two series of tests which were performed to investigate the above properties were described.

First, an indentation study of the variation in compressive stiffness of cartilage on the human femoral head was performed. It was found that the stiffness varied in a systematic manner and the observed stiffness pattern suggested that it was related to the load distribution on the femoral head. Chemical analyses were performed on the specimens after mechanical testing the compressive stiffness was related to the chemical constituents of cartilage. The preliminary results of a current investigation into the interrelationship between the compressive stiffness of cartilage and the fixed charge density were presented.

The second investigation which was presented is that to determine the tensile characteristics of cartilage in planes parallel to the articular surface. Specimens were tested from four areas on the femoral condyles of human knee joints and at increasing depth below the articular surface. Each specimen was oriented

Kempson, G.E.
Mechanical Properties of Articular Cartilage
J. Physiol(Lond) 223: 23P, May 1972

Abstract-continue of article

either parallel to or perpendicular to the predominant collagen fibre direction in the superficial zone of cartilage. It was shown that the tensile properties vary with depth below the surface and that the superficial zone is a highly anisotropic layer which possesses superior tensile properties to the remaining cartilage. It was shown that the tensile properties of visibly normal areas of cartilage which were situated near to pathological lesions were inferior to those of corresponding areas on normal joint surfaces. The results of the tension tests were also related to the chemical constituents of cartilage.

KENEDI, R.M., Gibson, T., Daly, C.H. and Abrahams, M.
Biomechanical Characteristics of Human Skin and Costal Cartilage
Fedr.Proc. 25:3,1084-1095,1966

Kenedi, R.M., Daly, C.H. and Gibson, T.

The Determination, Significance and Application of the Biomechanical Characteristics of Human Skin.

Digest of the 6th International Conf. on Medical Electronics & Biological Engineering, 1965, Tokyo, pp.531-534.

ABSTRACT: The paper presents certain aspects of the investigations relating to the load-deformation characteristics, their correlation with changes in the skin micro-architecture due to load, culminating in a model concept which, it is believed, will give, on further refinement, a rational basis for quantitative prediction.

KLEIN, M., Nejad, N.S., Lown, B., Hagemeyer, F. and Barr, I.
Correlation of the Electrical and Mechanical Changes in the Dog Heart during
Progressive Digitalization
Circulation Research, 29, 635- 645 ,1971

Abstract: Changes in the mechanical and electrical properties of the intact dog heart were studied during progressive digitalization with acetyl strophanthidin, ouabain, and digoxin. Heart rate was held constant at 180 beats/min to eliminate shifts along the interval-strength curve. Inotropic effects produced by the digitalis drugs were assessed from increments in peak left ventricular isovolumic (dP/dt)/P. Alterations in impulse formation and conduction were measured by the presence of repetitive ventricular extrasystolic responses elicited with low energy diastolic endocardial stimuli. The repetitive ventricular responses could be detected both before ventricular tachycardia supervened and again after it subsided. The inotropic response to acetyl strophanthidin, ouabain, and digoxin was similar, though it developed over different time intervals. Peak (dP/dt)/P increased linearly until ventricular tachycardia occurred. Time ratio of onset of repetitive ventricular responses to the onset of ventricular tachycardia was comparable for all three drugs: 62±5 (SE)% for acetyl strophanthidin, 68±5% for ouabain, and 68±2% for digoxin. This corresponded to 60-70% of the total increment in peak (dP/dt)/P. Repetitive ventricular responses may reflect increased cardiac automaticity, possibly associated with loss of intracellular potassium.

Abstract (Cont'd):

acetyl strophanthidin ouabain digoxin, ventricular tachycardia; repetitive ventricular response; contractility; peak isovolumic (dP/dt)/P

KNIVITY, Y. AND COLLINS, R.
Nonlinear Wave Propagation in Viscoelastic Tubes: Application to Aortic Rupture
J. Biomechanics, 7:1, pp.67-76, 1974

Abstract: Recent statistical surveys into the causes of automobile fatalities have shown that traumatic rupture of the aorta followed by immediate exsanguination is responsible for a significant percentage of traffic deaths in the United States. The object of this investigation is to understand a possible mechanism for this failure. A mathematical analysis is presented of the motion of blood in a distensible viscoelastic segment of aorta subjected to a decelerative force field. Calculations of axial wall strain and strain-rate indicate that wave propagation resulting in abrupt shock-like transitions along the aortic wall may well account for the transverse ruptures observed, when compared with the limited amount of rupture data presently available. The analytic method and numerical solution by a two-step Lax-Wendroff differencing scheme are sufficiently general to describe a wide variety of initial and boundary conditions related to blunt impact to the thorax.

Kobayashi, A. S. and Staberg, L. G.
Mechanics of Mackay-Marg Tonometer
The American Society of Mechanical Engineers, 73-WA/Bio-21, 1973

ABSTRACT: A finite element model of the human corneal-scleral shell was used to analyze the response of a Mackay-Marg tonometer. The results of this analysis correlated well with experimental results obtained by others. The analysis also indicated that a smaller plunger of approximately 1 mm in diameter is necessary to measure with better accuracy the intraocular pressure independent of variations in the structure of each ocular shell. Thus, this study demonstrated the utility of a finite element model in seeking an optimum design of a tonometer.

KOBAYASHI, A.S., Staberg, L.G. and Schlegel, W.A.
Viscoelastic Properties of Human Cornea
Experimental Mechanics, pp. 497-503, Dec.1973

Abstract:Viscoelastic response of intact human cornea subjected to physiological intraocular pressure was determined from local deformations measured by a flying spot micrometer. One eye of a paired specimen was prepressurized at 15 mmHg for at least 8 hr while the other eye was left unpressurized before testing. Test results of five paired eyes showed that in prepressurized enucleated eyes, the viscoelastic response was insignificant while significant viscoelastic response existed in the nonpressurized eyes. The latter viscoelastic properties were characterized by a five-element linear viscoelastic model and a nonlinear hereditary integral by Fung.

KOENEMAN, J.B., Lindan,O., Reswick,J.B. and Scanlan, R.H.
Viscoelastic Properties of Brain Tissue
7th Int. Conf. on Medical and Biological Engng, Stockholm 38-8, 1967

Abstract: Quantitative data on the mechanical properties of brain tissue are required to study brain damage caused by external forces and pathological conditions. Brain tissue can be characterized as consisting of closely-packed elastic cells held together primarily by colloidal or secondary forces. Very little of the structural properties of the tissue is due to mechanical inter-twining of the glial cell feet with blood vessels or other entanglements. Permanent deformation is caused by the relative motion of whole cells. Thus permanent set is very small if the cells are strong enough to prevent whole cell motion.

KONDO, Atsuo and Susset, Jacques G.
Physical Properties of the Urinary Detrusor Muscle, A Mechanical Model Based
Upon the Analysis of Stress Relaxation Curve
J. Biomechanics 6:2, 141-152, 1973

Abstract: The viscoelastic properties of dog urinary bladder have been quantitatively studied in vivo and in vitro. The thickness of the bladder wall was taken into consideration when the stress in the detrusor muscle was calculated. Thirty ml of saline were rapidly injected three times successively with an interval of three minutes. The force-deformation diagram was found to be a non-linear relationship. The relaxation curve could be analyzed into three exponential components. Subsequently, a mechanical model was formed, and its mathematical formulae were composed based upon the correlation between the length change of the Hooke elements and the volume increment. Four elastic constants, three time constants, and three viscous coefficients were measured respectively. The urinary bladder does not obey Hooke's law because of the specific configuration of collagen fibers. The quantitative evaluation of the physical properties of detrusor muscle can be utilized as a clinical diagnostic tool to supplement conventional cystometry.

KONDO, A.
Viscoelastic Properties of Urinary Bladder
Ph.D. thesis University of Sherbrooke. Quebec, Canada

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KRAFKA, Joseph, Jr.
Comparative Study of the Histo-Physics of the Aorta
Am. J. Physiol. 125, 1-14, 1939

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KRAFKA, J.
The mechanical factors in arteriosclerosis
Arch. Pathol. 23: 1-19, 1937

Abstract:

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KRESCH, Edward and Noordergraaf, Abraham
Cross-sectional Shape of Collapsible Tubes
Biophysical Journal, Vol.12, 274-94, Mar.1972

Abstract: In order to quantify the collapse phenomenon in veins, this paper presents a mathematical analysis of the cross-sectional shape of a flexible tube as its internal pressure varies. Quantitative results are presented in terms of the physical parameters of the tube, such as wall thickness and Young's modulus. It is assumed that the tube is thin walled, that no stretching occurs, that the cross-sectional shape is elliptical when the transmural pressure is zero, and that the longitudinal prestress is zero. The equations were solved on a digital computer which displayed the cross-sectional shapes on an oscilloscope, which were then photographed. A selection of these photographs is presented. Curves are shown which give the cross-sectional area and compliance as functions of transmural pressure. Other curves are shown which are useful for interpolation, and for use in the experimental determination of the physical parameters which may otherwise be difficult or impossible to measure accurately.

Kroeker, Edwin J. and Wood, Earl H.
Comparison of Simultaneously Recorded Central and Peripheral Arterial Pressure Pulses During Rest, Exercise and Tilted Position in Man
Circulation Research, Vol. 3, pp. 623-632, 1955

ABSTRACT: Central aortic or subclavian, brachial, radial and femoral pressure pulses were recorded simultaneously in 12 healthy subjects during conditions of rest, exercise and 70 degree head-up tilt. Peripheral systolic pressure at rest uniformly exceeded the central systolic pressure generated by the same heartbeat. The average radial pulse pressure was 146, 146 and 165 percent of central pulse pressure during rest, exercise and tilt while radial mean pressures were 94, 93 and 98 percent of central mean pressures respectively. Summation of the incident pulse wave with reflected waves from the periphery and resonance effects in the peripheral arterial systems may produce these changes in pressure and contour.

Kuchar, N. R. and Ostrach, S.

A Thick-Walled Viscoelastic Model for the Mechanics of Arteries
Journal of Biomechanics, Vol 2, No. 4, pp. 443-454, 1969

Abstract: A knowledge of the mechanics of arteries is of importance in the determination of vessel rheological properties and in the studies of blood flow and certain arterial diseases. Most existing arterial models treat only wave motions; however, other types of motion, in particular those associated with flow development and other end effects, occur in the vascular system. Thus, a model is needed which can be applied to a variety of possible types of motion.

An arterial model is described which includes the effects of thick walls, linear viscoelasticity and wall tethering. The forms of the displacements and stresses are found independently of the exact form of the applied fluid stresses: thus, the results are applicable to a range of possible dynamical conditions. Displacements and stress states can then be found from experimental or theoretical knowledge of the blood pressure and flow. The results are applied to flow development and wave propagation regions in the arteries.

KUCHAR, N. R. and Ostrach, S.

Flows in the Entrance Regions of Circular Elastic Tubes
In Biomedical Fluid Mechanics Symposium, pp.45-69, ASME, New York 1966

Abstract: This paper deals with entrance effects associated with the laminar flows of viscous fluids in circular elastic tubes. In general, entrance effects occur in both the dynamics of the fluid (flow development) and in the motion of the tube walls. The mathematical model chosen for this study corresponds closely to the physical situation found in many of the important vessels of the mammalian circulatory system.

Differential equations describing the motions of the fluid and the tube walls are set up and discussed for the case of unsteady (but pulsating) flow. Then, for the subcase of steady flow, the equations are solved analytically to determine the pressure distribution, the fluid velocity distributions, and the displacement of the tube wall. Based on these solutions, the hydrodynamic entrance length and the entrance length associated with the elasticity of the tube are determined. The physical and mathematical significance of the entrance effects is discussed.

It is found that the entrance effects associated with the elastic tube have a "boundary layer" behavior and can lead to a narrow region of high bending stresses in the tube.

Kukhareva, L. V., Frenkel, S. Ya., Ginzburg, B. M., and Vorob'ev, V. L.
Influence of Load on Order-Disorder Transition in Native Collagen Fibres
Biorheology, Vol. 7, pp. 37-53, 1970

ABSTRACT: The influence of external stress on the hydrothermal and chemical (induced by water solutions of KCNS and HCl) contraction of native collagen fibers has been investigated. The experiments were made in the isometric and isotonic measurements modes. The coincidence of isometric and isotonic data permits the consideration of a certain portion of the isometric curve as a phase equilibrium curve similar to the pressure-temperature curves of phase equilibrium for the low molecular weight substances. The existence of a certain critical tension and of a corresponding critical temperature in the case of hydrothermal contraction and of a critical composition of environment in the case of chemical contraction was suggested, and their values were calculated for the systems under consideration. Thermodynamic calculation gives us an estimate of the enthalpy of melting $\Delta H_U = 2.12 \pm 0.3$ kcal/mole of peptide units in the case of hydrothermal contraction and correspondingly of a certain "enrichment of salt" $\Delta c = 4.6 \cdot 10^{-2}$ moles KCNS/mole of aminoacid units in the case of KCNS-contraction. The cooperativity parameters for both processes were estimated, and their order was found to be 10^{-4} . The nature of the transition occurring is discussed in terms of the general theory of order-disorder transitions in unidimensional ordered systems. The conclusions drawn are confirmed by x-ray evidence.

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KUCHAR, Norman R. and Ostrach, Simon
Unsteady Entrance Flows in Elastic Tubes with Application to the Vascular System
AIAA Jr. Vol.9No.8, 1520-26, Aug.1971

Abstract: Flow development effects in the large arteries are investigated analytically using a mathematical model of pulsatile, viscous flow in a semi-infinite, thick-walled elastic tube. A coupled set of differential equations and boundary conditions for the fluid and tube motions, containing approximations valid for the large arteries, is solved using Fourier series and Laplace transform techniques. Results include fluid velocity and pressure distributions and tube wall displacements and stresses. It is found that flow development depends primarily on the Reynolds number and the unsteadiness parameter with wall elasticity of secondary importance. The development length is comparable to the lengths of many arteries, and within the development region wall shear stresses are high. Thus, flow development effects can be important in the large arteries.

Lab, Max J. and Morris, G.A.

A calliper for sampline relative movement of tissue surfaces

J. Physiol. (1on) 224: 55-56, 1972

Abstract: During investigations on the ventricles of intact frog hearts it was necessary to record qualitatively the relative movement of two points on either side of an electrode on the endocardium. This was done using a calliper.

LaBan, Myron M.

Collagen Tissue: Implications of Its Response to Stress in Vitro

Arch.Phys. Med. Rehabil. 43: 461-466,1962

Abstract:

LAIRD, J. D. and MADRAS, P.N.

A Comparison of Aortic Distensibility in vivo and in vitro in the same animal.

Proc. 8th ICMBE, Chicago, Ill. 1969

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Lambossy, P.
L'anisotropie des arteres
Angiologica (Basel) 4: 129-146, 1967

ABSTRACT: Some experiments on the relation of internal pressure with diameter and length on samples of arteries showed a very marked increase in length, which can not be explained by theory if the arterial tube is supposed to behave as an isotropic material. Indeed the theory gives no change of length, when the internal pressure is raised. We are therefore lead to assume anisotropic behavior to be the cause of it.

In a theoretical part some formulas are established for the case that only the behavior in the direction of the vessel axis is distinguished from the other ones with a particular Young's and a particular Poisson's modulus. The other principal directions, the radial and the tangential ones are considered to be equivalent with a common pair of Young's and Poissons moduli.

Based on a series of measurements which have been made by Schonemberger at the department of Physiology at Fribourg one a sample of cow's aorta we undertook a determination of these four moduli. But having only two equations at our disposal, we had to make the additional hypothesis of constant volume for the wall material in order to obtain a third one. In reality the problem remains undetermined, but nevertheless we were able to draw with a high probability the following useful

Lambosy, P.
L'anisotropie des arteres
Angiologica (Basel) 4: 129-146, 1967

Abstract: continued conclusions:

1. The transversal modulus of elasticity is about three times greater than the longitudinal one.
2. Both moduli increase simultaneously with increasing internal pressure.
3. Poisson's modulus related to longitudinal stretch is fairly constant and its value is approximately 1/3.

As a final conclusion we have to point out that the experiments based on internal pressure rise only are not sufficient for a complete determination of four constants. They have indeed to be completed by other experiments based on a different principle.

Landowne, Milton
Characteristics of Impact and Pulse Wave Propagation in Brachial and Radial Arteries
J. Appl. Physiol., Vol. 12, No. 1., pp. 91-97, 1958

ABSTRACT: Externally induced impact waves may be propagated along the living artery. Such transients are often followed by a "free vibration," which, with adequate recording, exhibits a natural frequency of the order of 30-45 cycles per second and often appears underdamped. These transients are modified in transmission over the brachioradial arterial segment. The velocity of impact waves, like the velocity of cardiac pulse waves, is pressure dependent. This relation has been analyzed in detail for a group of males. In general, the change in velocity with pressure is large in comparison to differences between individuals at the same pressure. An averaged relation between pressure (p) mm Hg, and velocity (v) m/sec., for 94 subjects is given as $v^2 = -(27 \pm 19) + (4.9 \pm .4)p - (.0083 \pm .0018)p^2$. From this description, together with stated assumptions about the interpretation of wave velocity, the pressure-volume relation of this artery is developed. From this, and stated dimensional assumptions, a stress-strain curve is presented. The equivalent modulus of elasticity is calculated to be $0.1 - 3.4 \times 10^7$ dynes/cm², for the type of stress used in these studies. The velocity of impact waves at diastolic pressure is shown to be greater than the velocity of cardiac pulse waves.

LANDOWNE, Milton
A Method Using Induced Waves to Study Pressure Propagation In Human Arteries
Circulation Research 5, 594-601, 1957

Abstract: This report describes a method for utilizing externally induced impacts as a means of studying the propagation of pressure waves in intact human arteries. Because it is a new method its description is prefaced by a brief presentation of several factors relevant to wave propagation in living vessels; the description is followed by a critical evaluation.

LAING, Patrick G.
Compatibility of Biomaterials
Orthop.Clin.North Am. 4:249-73, Apr. 1973.

Abstract:

Lanir, Y. and Fung, Y.C.
Two-Dimensional Mechanical Properties of Rabbit Skin--I. Experimental System.
J.Biomechanics, Vol.7,pp.29-34, 1974

Abstract: An experimental system for two-dimensional tests of soft tissue was developed. It can perform in vitro two-dimensional tests at different rates (up to 6.0 mm/sec) as well as two-dimensional relaxation and creep tests. Effect of the temperature on two-dimensional stresses and strains can also be measured. Data reduction is greatly improved with the help of on-line PDP 8/e computer.

LAWTON, R.W.
The thermoelastic behavior of isolated aortic strips of the dog.
Circ. Res. 2: 344-53, 1954

ABSTRACT: A detailed thermodynamic study of isolated strips of dog aorta is basic to the interpretation of the nonlinear and apparently rubber-like elastic behavior of such specimens. Experimental data indicate that the retractile force in isolated aortic strips of the dog is entropic. Volume changes with elongation in such strips are negligible. However, a large negative internal energy contribution to the total force is present at small elongations. Studies of aortic strips extracted with alkali suggest that the latter force arises from the elastic tissue itself.

Lawton, Richard W., M.D.
Variability of the Viscoelastic Constants Along the Aortic Axis of the Dog
Circulation Research, Volume VIII, pp. 381-389, 1960

ABSTRACT: This report presents a study of 47 aortic strips from 34 mongrel dogs, using a polymeric model. A statistical analysis of the variations in dynamic elasticity and damping which occur with location along the arterial axis and during stretch and retraction of aortic strips is presented.

The application of elastomeric theory to the study of the viscoelastic properties of the dog's aorta shows that the same value of the elastomeric parameter β may be used to describe the elastic behavior of aorta strips under both static and dynamic conditions. The variations in the parameter β and the damping fraction γ with the strip's location may be distinguished only for the extremes of the central arterial axis because of the wide variability of mechanical properties among dogs. The viscoelastic properties apparently do not correlate with the measured geometric properties of the unstressed aortic strip.

LEE, G. and Hoppin, F.G., Jr.
Lung Elasticity
In: Biomechanics: Its Foundations and Objectives, Fung, Perrone, Anliker, eds.
Prentice-Hall, Englewood Cliffs, N.J., Chapter 14, pp. 317-335, 1972

Abstract: (summary) There is need for development of techniques and theory, for measurement and description in every aspect mentioned above, and for correlation of solid and structural mechanics with other biomechanical, physiological, and pathological aspects of the lung. We hope that the material contained in this chapter may serve to clarify and to emphasize such a need.

Lee, J. S.
Slow Viscous Flow in a Lung Alveoli Model
Journal of Biomechanics, Vol. 2, No. 2, pp. 187-198

Abstract: A theoretical analysis of the flow pattern and the law of resistance of blood moving in a model of lung alveoli is presented. The model consists of two parallel flat membranes interconnected by regularly spaced circular posts. It is structurally an idealization of the internal geometry of the pulmonary alveolar septa. An approximate solution which gives a reasonable representation for flow around a circular post confined between two plates, is extended to construct a periodic solution for the present problem. The solution is found to be adequate when the sheet-thickness-to-post-diameter ratio is not much larger than one. The resistance of the flow as a function of the geometric parameters is computed. It is shown that the posts are very effective in increasing the flow resistance. Numerical results are shown to agree substantially with experimental measurements of the resistance.

Lee, Jen-Shih, Frasher, Wallace G., and Fung, Yuan-Cheng B.
Two-Dimensional Finite Deformation Experiments on Dog's Arteries and Veins
AFSOR Scientific Report 67-1980 29 p., 1967

ABSTRACT: Most published data on the blood vessel elasticity were obtained either in simple elongation or in simple inflation, but not simultaneously. For finite deformations, such data are insufficient to formulate a three-dimensional stress-strain law even if the material is isotropic and incompressible. They are also subject to the basic criticism that the Young's modulus was presented without reference to the stress levels at which the modulus was measured. Since the blood vessels are highly nonlinear, the Young's modulus for a specimen varies continuously from almost zero at the undeformed state to a large final value, and a statement of the modulus without the corresponding stress level is meaningless. The purpose of the experiments reported in the present paper is to illustrate a scheme remedying these difficulties. The tests consist of (1) a longitudinal stretching while the diameter of the vessel was maintained, (2) a lateral distension with the length of the vessel fixed, (3) stress relaxation at fixed strain, and (4) cyclic deformation. Two Lagrangian stresses (stresses based on the vessel's undeformed state) and two extension ratios are used to describe the deformed state of the vessel under a symmetric loading. The non-linearity in the elasticity, and the dependence of the stress on the strain-history is demonstrated.

LEE, J.S., Frasher, W.G. and Fung, Y. C.
Comparison of Elasticity of an Artery in vivo and in Excision
J. Appl. Physiol. 25(6), 799-801, 1968

Abstract: A simple method of measuring the elasticity of an artery is presented. A segment of an artery was anchored at two ends and plucked at the middle in the manner of a slingshot. The force of plucking and the deflection of the midpoint were measured. The results show that the effect of cutting an artery on its elasticity is small.

effect of cutting; slingshot; plucking

LEE, Kwang Soo
Present Status of Cardiac Relaxing Factor
Fedr.Proc. 24:6, 1432-37, 1965

Abstract:

Lehmann, Justus F., Warren, C. Gerald, Pemberton, Donald R., Simons, Bernard C. and DeLateur, Barbara J.

Load-Bearing Function of Patellar Tendon Bearing Braces of Various Designs
Arch. Phys. Med. Rehabil. 52:366-70, Aug. 1971.

ABSTRACT: The measurements discussed in this paper have shown that the shell design which relieves skeletal weight bearing incorporates a rigid closure. The long shell even though it does not contribute to the weight-bearing function of the brace, may provide maintenance of alignment of the skeletal structures. The greatest increase in the weight-bearing function of the brace was obtained by raising the shell so that the heel cleared the shoe by 1 inch. A fixed ankle design combined with a steel sole plate extending to the metatarsal heads provided greater weight bearing than free ankle designs, including the cable ankle joint. Maximal weight bearing was obtained with a fixed ankle design, 1-inch heel clearance and additional training to use the weight-bearing areas of the brace optimally and avoid the active pushoff. Even though rocker-bottom designs combined with a fixed ankle provided the best weight-bearing function of the brace throughout the stance phase, these designs had the severe drawback of being basically unstable and produced an abnormal gait pattern.

Even though this paper has provided quantitative information on the weight-bearing function of various designs and adjustments of PTB braces, no information was obtained regarding the amount of weight bearing that may be optimal in clinical use.

Abstract (Cont'd):

It is conceivable that in some of these cases the brace which maximally relieves the skeletal weight bearing may not lead to optimal clinical results.

LEVINE, H.J.
Compliance of the Left Ventricle
Circulation 46: 423-6, Sept. 1972

LEVIN, A. and Wyman, J.
The Viscous Elastic Properties of Muscle
Proc. R. Soc. B101, 218-243, 1927

Abstract:

LEW, Hyok Sang
Electro-Tension and Torque in Biological Membranes Modeled as a Dipole Sheet in
Fluid Conductors.
J. Biomechanics, 5:4, 399-408, 1972

Abstract: The active transport process produces an unequal ion concentration across the biological membranes and thus creates a difference in the electrostatic potential across the membrane. The electric field in the membrane resulting from the membrane potential should create electric charge polarizations in molecules constituting the membrane. The electrostatic force on these polarization charges buried in the membrane structure can result in a tension and torque in a curved membrane. In this study, a thin membrane bearing a series of parallel line dipoles, which separates two fluid conductors of different electrostatic potential, is analyzed as a two-dimensional model of biological membranes. The results of the analysis show that such a membrane possesses a tension and torque resulting from the coulombic interaction between electric charges in the membrane as well as with charges outside the membrane. This indicates that biological membranes can have a tangential strength which can support a compressive tangential force, and a bending stiffness which can support an externally imposed bending moment. The expression of the electro-bending stiffness obtained in this study is applied to the biconcave geometry of red blood cells and their sphering process.

Lewartowski, Bohdan, Sedek, Grzegorz and Okolska, Anna
Direct measurement of tension within left ventricular wall of the dog hear
Cardiovascular Research 6: 28-35, 1972

Abstract: The method of direct measurement of tension within the left ventricular wall of the open-chest dog is described. Stress is calculated from the records obtained and the wall thickness; the results are compared with those obtained by using the formulas published in the literature.

LEYTON, R. A. and Sonnenblick, E. H.
The Sarcomere as the Basis of Starling's Law of the Heart in the Left and Right Ventricles.
Methods Achiev. Exp. Pathol. 5:22-59, 1971

Abstract: (fm Introduction) Recently, important advances in evaluating cardiac function have been derived from the realization that the performance of the heart as a pump depends upon the contractile activity of the heart as a muscle. Since contraction of the entire organ reflects the summated and integrated function of its individual contractile elements, investigations of cardiac muscle ultrastructure in conjunction with quantitative studies of cardiac muscle physiology have been conducted. This article will review certain aspects of this work: (a) including the ultrastructural basis of the Frank-Starling mechanism, where increased fiber length engenders an increased force of contraction; (b) the ultrastructural basis of such aspects of ventricular function as the relative constant relation between stroke volume and end diastolic volume in a wide range of species; and (c) the ultrastructural correlates of ventricular dilatation and cardiac failure.

Lieberman, David A., Faulkner, John A., Craig, Albert B. Jr., and Maxwell, Leo C.
Performance and histochemical composition of guinea pig and human diaphragm
J. Appl. Physiol., Vol. 34, No. 2, pp. 233-237, 1973

ABSTRACT: Our purpose was to relate the fiber composition of the diaphragm to the decline in maximum tension and in maximum voluntary ventilation (MVV) over time. In isolated guinea pig diaphragm, three fiber types were classified and three types of fatigue observed. An initial rapid decline in tension corresponds to the area of the diaphragm composed of low oxidative fast-twitch (LFT) fibers and a subsequent slower rate with the percentage of high oxidative fast-twitch (HFT) fibers. The percentage of maximum tension maintained after 20-30 min of stimulation correlates with the percentage of high oxidative slow-twitch (HST) fibers. Seven men performed MVV tests of from 15 sec to 5 min duration. In tests conducted for 1 min, MVV is 82% of the MVV after 15 sec. No further decrease occurs in tests administered for 5 minutes. In human diaphragm, 76% of the fibers are HFT and HST. Our data are consistent with the hypothesis that a relationship exists between muscle performance and histochemical characteristics in guinea pig and human diaphragm.

muscle fatigue, maximum voluntary ventilation, skeletal muscle fibers, succinic acid dehydrogenase activity, myofibrillar ATPase activity

Life, Jeffry S. and Pince, Bruce W.
Response of the Canine Heart to Thoracic Impact During Ventricular Diastole and Systole
Jr. of Biomechanics, Vol.1 No.3, 169-174, 1968.

Abstract: This experiment was performed to determine if cardiac injury, as a consequence of thoracic impact, is related to the contractile state of the myocardium at the time of impact.

Twenty-six male dogs (20-25 kg) were anesthetized and impacted at various times in their cardiac cycles using a vertical impact generator. The results indicate that ventricular injury is dependent (in part) on the contractile state of the ventricular myocardium at impact. In all cases of ventricular rupture, the myocardium was in the high pressure phase of the cardiac cycle (i.e. systole). Neither right nor left ventricle showed gross pathology if impact occurred during the low pressure phase of the cardiac cycle (i.e. diastole).

Linden, R. J.
The Contractile Properties of Cardiac Muscle'
Advance 24:450-5, Jun.1968

Lipschitz, Robert, DeMaHerbe, Michael and Pettifor, Andrew
S. Afr. J. Surg. 7:93-108, 1969
Some Medical and Engineering Considerations of the Design of an Intra-Thoracic
Artificial Heart.

Abstract:

Little, Robert C.

Dynamics of Stress Relaxation in Skeletal Muscle

Am. Jr. of Physiology, Vol.217, No.6, 1665-1671, Dec. 1969

Abstract: The frog gastrocnemius was subjected to a quick sustained stretch to various lengths. Muscle tension was followed for 5 min. In some experiments, periodic isometric contractions were produced during the period of stress relaxation. Analysis of the data permitted construction of an average stress-strain curve that represented the elastic elements of the muscle before and after stress relaxation. This plot also suggested that shortening of the elastic element of the muscle occurred because of movement of two different viscous units. The contraction response followed a characteristic course at all levels of stretch. It increased during early stress relaxation, reached a peak, and then fell during the terminal poststretch period. The gastrocnemius muscle showed a postcontraction "slip" in tension during the early poststretch period. This was related to amount of stretch and time after stretch. This data permitted deduction of changes in sarcomere length during stress relaxation. A muscle model was suggested that contained two viscous elements with different time constants. One of these elements may be associated with the tendon.

LIU, Y.K., Laborde, J.M. and Van Buskirk, W.C.

Inertial Properties of a Segmented Cadaver Trunk: Their Implications in Acceleration Injuries

Aerospace Med. 42(6): 650-657, 1971

Abstract: In order to implement a new generation of mathematical models and manikins being developed to study the response of the human body to acceleration or impact, the inertial properties of the body need to be known to the degree of detail required by these models. As of now, the inertial properties of the body are known only in meager detail, and then only for the limbs and the torso as a whole. Since each of these recent models requires a knowledge of the distribution of these properties, a program to acquire this data was initiated.

An unembalmed male cadaver of medium height and build was obtained and quick-frozen. The intervertebral discs were located by means of X-ray and transverse cuts were made through the cadaver at each disc. The mass, center of mass, and mass moments of inertia about the three principal axes were then determined for each segment.

These inertial properties were then used as the input for a previously developed mathematical model of spinal response to impact. The specific situation studied is that of seat ejection in high speed aircraft. The results provide an explanation for the high incidence of fracture sustained by the lower-thoracic vertebrae during this maneuver.

Lowenhiel, Peter

On the Mechanism of Cortical Bridging Vein Rupture

Proc. International Conf. on the Biokinetics of Impacts, Amsterdam, Jun 26-27, 1973

Abstract: A common head injury in car crash victims is rupture of the parasagittal bridging veins. These ruptures are not only seen at the surface of the brain, but also in the depth of the convolutions in the gray and the white matter. The cause of these deeper ruptures has been obscure and has been described as gliding contusions. In order to explain this type of injury the dynamic properties of the bridging veins were investigated. The results indicate that the elongation capacity of the vessels is strongly dependent on the elongation rate. Thus, at static loading, the elongation may be more than 100% while at elongation rates at about 500 sec^{-1} the elongation capacity is reduced to 20%. The deformation of the brain close to the brain surface is considerable, when the head is subjected to angular acceleration and will elongate the bridging veins more than 20%, thus causing rupture.

Lundin, G.

Mechanical Properties of Cardiac Muscle

Acta Physiol. Scand. 7, Supp.20, 1-84, 1944.

Lyszczarz, Jerzy

Mechanical Properties of the Lungs

Acta Physiologica Polonica, Vol. XXII, No. 3, Suppl. 2, 469-480, 1971 (POL)

Abstract: This paper contains a discussion of the mechanics of respiration and a review of the literature on the subject. The mechanical properties of the lungs in man and mammals are assessed on the basis of knowledge of the $V/P_{0.1}$ ratio which expresses the actual compliance of the lungs. This ratio may undergo various changes in relation to the factors causing these changes. When the respiratory movements increase considerably their amplitude the curve of $V/P_{0.1}$ forms a loop called--the loop of static hysteresis which reflects the influence of surface forces on the mechanical properties of the lungs. The action of these forces plays also an important role in changes of compliance produced by certain other factors, such as pulmonary edema and anesthesia. Similarly, the mechanical obstacles in a part of the bronchial tree have a considerable influence on the compliance which decreases then parallelly with increasing respiratory rate returning to normal level after several seconds of breath-holding in inspiration.

Of all structural elements of the lungs the fibrillary elements have the greatest role in the compliance--especially the elastic fibers--while the collagen fibers and mucopolysaccharides increase probably the compactness of the stroma counteracting mechanical injuries. Other structural elements are, probably, without greater importance.

Lyszczarz, Jerzy

Physical Properties of the Lungs and Their Contribution to the Regulation of the Respiratory Cycle

Acta Physiol 19:441-46, Jul-Aug. 1968 (Pol).

Abstract: This paper is a discussion of the principles governing the mechanism regulating the respiratory function using the knowledge of respiration mechanics. The data obtained on the role of economic factors in the regulation of the respiratory cycle seem to indicate that, like many other regulatory processes occurring in living organisms, the ventilation process is also subjected to economic requirements. Nevertheless many facts still remain unclear and do not allow to view this problem in a wider aspect the lack of knowledge of the energy expenditure for the respiratory activity is a serious gap in this respect. Data are also lacking as regards regulation in various pathological conditions, neither are the pathways known by which this regulation is effected.

MacCanon, D.M., Bruce, D.W., Balfus, J. and Argano, B.J.
An Intrapericardial Ventricular Mural Tension Gauge
J. Appl. Physiol. 25(3), 322-323, 1968

Abstract: A thin flat flexible myocardial wall tension gauge has been devised by sealing a foil gauge in a plastic envelope. The device responds linearly to longitudinal stress and permits closure of the pericardium over the gauge.

Cardiodynamics; wall tension

MacWilliam, J.A.
On the Properties of the Arterial and Venous Walls
Proc. Roy. Soc. (London) Ser.B. 70: 109, 1902

This volume is not available anywhere in the United States or Canada. Apr.1974

Malindzak, George S. and Meredith, Jesse H.
Comparative Study of Arterial Transmission Velocity
Journal of Biomechanics, Vol. 3, No. 3, pp. 337-350, 1970

Abstract: For the purpose of determining the arterial transmission velocity experiments were performed on anesthetized mongrel dogs by recording arterial pressure measured simultaneously at two positions along the axis of the abdominal aorta. Four independent methods; pulse wave velocity (PWV), apparent phase velocity (APV), "true" phase velocity (TPV) and correlation propagation velocity (CPV) were used for comparison and for the future purpose of providing a reliable index with which to relate and to compare changes of elastic constants of the arterial wall with arterial disease. Of these four velocity determinations, the PWV proved to be the least reliable. The relationship between the APV and TPV suggests the experimental differences may be related to arterial reflections. On the other hand, the CPV, as measured by the cross correlation technique, was less subject to beat-to-beat variations than was the PWV, in actual determination, although the CPV is a much easier method and a more consistent measure of the arterial pressure pulse transmission velocity. In these studies, the apparent terminal vascular impedance of the arterial transmission line appears to match the apparent characteristic impedance of the large arteries.

MALLOS, Alexander, J.
An Electrical Caliper for Continuous Measurement of Relative Displacement
J. Appl. Physiol. 17(1), 131-134, 1962.

Abstract: An electrical recording caliper for the continuous measurement of relative displacement has been developed. The details of design, operation, and performance are described. The frequency response was uniform (+5%) through 25 cycle/sec. An approximately 0.5% error related to the mechanical impedance of the device was estimated to occur. The system is linear and free of hysteresis. Base line and gain stability are acceptable.

MARCEY, J.

Recherches sur la tension arterielle.

In Physiologie Experimentale, Travaux du Laboratoire de M. Marey, edited by G. Masson. Paris, Librairie de l'Academie de Medecine, 1878, Vol.4 P. 179.

MARKOLF, Keith L.

Deformation of the Thoracolumbar Intervertebral Joints in Response to External Loads, A biomechanical study using autopsy material
J. Bone Joint Surg.(Am) 54:511-33, Apr 72

Abstract: The role of mechanical forces in the production of spinal injury and disc degeneration has been a topic of widespread interest. Knowledge of the deformations of the intervertebral joints in response to external loads is important if the forces and moments developed in the spine are to be linked in a quantitative fashion to possible modes of injury or abnormal motions of the intervertebral joint. The objective of the present study was to measure experimentally the mechanical response of the thoracic and lumbar intervertebral joints to external forces and moments and to quantify these load-deformation characteristics by examining stiffness values for tension, compression, bending in two planes, shear in two planes, and torsion.

Static loading tests on fresh human spinal segments obtained at autopsy were performed to measure the deformation of thoracic and lumbar intervertebral joints in response to lateral bending moment, flexion moment, extension moment, torsional moment, anteroposterior and mediolateral shear force, axial tension force, and axial compression force. The findings in these tests are as follows:

Marshall, R. and Widdicombe, J.G.
Stress relaxation of the Human Lung
Clin.Sci. 20: 19-31, 1961

Marshall, Robert and Dubois, Arthur B.
The Viscous Resistance of Lung Tissue in Patients with Pulmonary Disease
Clin.Sci. 15: 473-483, 1956

Martin, J. David and Marlyn E. Clark
A Viscoelastic Correction to the Complex Propagation Via Pressure-Displacement
Experiments
Proc. 19th Annual Conf. Blood Flow Dynamic section, Engineering in Medicine and
Biology, 1966

MASHIMA, Hidenobu and Matsumura, Moto
The Effect of Temperature on the Mechanical Properties and Action Potential of
Isolated Frog Ventricle
The Japanese Jr. of Physiology, 14, pp 422-438, 1964

Abstract: This study was done with the purpose of determining the active state
curve and the factors for the frog muscle to perform work, and to examine the
effect of cooling on the mechanical properties in relation to the action
potential and in comparison with those of skeletal muscle.
1. The effect of temperature on the mechanical properties and the action potential
of isolated frog ventricle were studied. 2. On cooling the maximum tension and
contraction times increased while the maximal rate of rise of tension decreased.
3. The force-velocity curve was both hyperbolic and linear at different tempera-
tures. 4. The duration and intensity of the active state increased on cooling.
5. Work performed depended on the initial length of the muscle, the load and
temp. 6. The relation between active state and calcium movement and energy
mobilizing mechanism in cardiac muscle was discussed.

Mason, P.
The Viscoelasticity and Structure of Keratin and Collagen
Kolloid-Z. 202: 139-147, 1965

Abstract: Viscoelastic properties of keratin and collagen fibres immersed in aqueous media have been measured at frequencies between 1 kc/s and 20 kc/s and at temperatures between 0° and 100°C. Elastic and viscous moduli were derived from wave-propagation measurements which enabled fibres to be tested while they were held at different extensions. Wave velocities, generally of the order of 1,000 m/s, were readily obtained with an accuracy of about + 2%; the attenuation, and thus the viscous modulus component, could be determined only approximately.

Matsumura, Moto and Nagai, Torao
Dynamic Visco-elastic Properties of Glycerol-extracted Muscle Fibers
Jap.J. Physiol. 13, 246-259, 1963

Abstract: The purpose of the work in this article is to obtain detailed information on the viscoelastic properties of glycerol-extracted muscle fibers during contraction and relaxation, and thereby to find out some clue to the mode of contractile system.

1. The dynamic stiffness increased during contraction and decreases during relaxation.
2. When sinusoidal changes in length are less than 1.5% of muscle length, the fiber obeys Hooke's law.
3. Complex modulus varies at different frequencies.
4. Elastic modulus and viscosity are calculated based on the rheological analysis.
5. When muscle is stretched, the stiffness is always increased.
6. Visco-elastic properties and their changes in contraction process of glycerol-extracted muscle are similar to those of living muscle.

Matthews, Frank L. and West, John B.
Deformation of the lung by its Own Weight
J. Physiol.(London) 215: 53P, May 1971

ABSTRACT: This article analyses the distribution of gravity-induced stress, strain and surface pressure in a theoretical model of the lung using the finite element technique.

Matthews, F.L. and West, J.B.
Finite Element Displacement Analysis of a Lung
J. Biomechanics, 5:6, 591-600, 1972

Abstract: There is considerable physiological evidence that the regional variation in pleural pressure and expansion of the lung is largely determined by gravity. In this paper a method is given based on the technique of finite elements which determines theoretically the mechanical behaviour of a lung-shaped body loaded by its own weight. The results of this theoretical analysis have been compared with actual measurements of alveolar size and pleural pressures in animal lungs.

MAXWELL, James A. and Anliker, Max

The Dissipation and Dispersion of Small Waves in Arteries and Veins with Visco-elastic Wall Properties
J. Biophys. 8:920-950, 1968

Abstract: Theoretical and experimental evidence suggests that the dissipation of high frequency pressure waves in blood vessels is caused primarily by the viscoelastic behavior of the vessel wall. In this theoretical analysis the vessels are considered as fluid-filled circular cylindrical shells whose walls have isotropic and homogeneous viscoelastic properties and are subjected to an initial axial stretch and a transmural pressure. If the wall material is incompressible and behaves as a Voigt solid in shear, the results predict a decrease in wave amplitude per wavelength which is essentially independent of frequency over a wide range. This finding is in qualitative agreement with recent experiments on anesthetized dogs. A parametric study also shows a great sensitivity of the dissipation to changes in transmural pressure and axial stretch. Axisymmetric waves are only mildly dispersive, while all nonaxisymmetric waves are highly dispersive and exhibit much stronger damping per wavelength at low frequencies than do axisymmetric waves.

MEAD, Jere
Mechanical Properties of Lungs
Physiol. Rev. 41: 281-330, 1961

Abstract: This article reviews just one aspect of respiratory mechanics and even within the limits implied by the title does not attempt to be comprehensive. Instead, specific topics are taken up in detail. Rohrer's method of analysis is the basis for most measurements of respiratory mechanics. A large share of the remainder deals with the elastic behavior of lungs and the contribution of surface phenomena to it. Major advances have been made in this area over the past 10 years and it seems particularly important to discuss them in detail.

MEAD, Jere, Takishima, Tamotsu, and Leith, David
Stress Distribution in Lungs: a Model of Pulmonary Elasticity
J. Appl. Physiol. 28(5):596-608,1970

Abstract: Although lungs are exposed to transpulmonary pressure, the air spaces within are distended solely by forces applied from surrounding tissues. By relating these forces to the areas on which they operate, we derive the effective pressure distending air spaces. In uniformly expanded lungs this pressure probably approximates transpulmonary pressure. In nonuniformly expanded lungs the effective distending pressure differs from transpulmonary pressure, and in the appropriate sign to reduce the nonuniformity. This interdependence of air-space distention bears on a number of aspects of pulmonary function, including the size of air spaces which may be expanded from the gas-free state, the static and dynamic stability of air spaces, the dryness of air spaces, the forces distending airways and blood vessels within lungs, and the distribution of pulmonary edema. The principal function of the mechanical interdependence would appear to be to support uniform expansion of air spaces. The principal functional risk that it entails is increase in capillary transmural pressure in regions which become subjected to abnormally high outward-acting stress.

MEHMEL, H.C., KRAYENBUEHL, H.P. and Wirz, P.
Isovolumic Contraction Dynamics in Man According to two Different Muscle Models
J. Appl. Physiol. 33(4), 409-414, 1972

Abstract: In eight patients without major left ventricular (LV) dysfunction end-diastolic pressure (EDP) was raised by methozamine from 13 to 20 mm Hg following propranolol and atropine. The velocity of contractile elements (Vce) and the extent of CE shortening (TS) during isovolumic contraction were calculated according to a two-component model (I) using total pressure (TP) and a three-component model (II = Maxwell model) using developed pressure (DPO). Vce equals $(dP/dt)/28 \cdot TP$ or $(dp/dt)/28 \cdot DP$. Linear extrapolation of Vce vs. TP yielded $V_{max}(I)$. $V_{max}(II)$ was determined considering the curve Vce vs. DP as a hyperbola. In contrast to model II, peak measured Vce(I) was a finite value and occurred 37 msec after onset of contraction. After propranolol and atropine TS (I) was 6.7% and TS(II) 13.5% of circumference; $V_{max}(I)$ was 1.59 circ/sec, $V_{max}(II)$ 5.16 circ/sec. Up to an increase of EDP of 16 mm Hg $V_{max}(I)$ did not vary more than 9% in either direction, whereas $V_{max}(II)$ showed rather large but inconsistent changes. Thus, the time course of Vce and the absolute values of TS favor the use of model I.

velocity of contractile elements; myocardial contractility; time to peak measured velocity; total isovolumic shortening of the contractile elements, preload dependency of V_{max}

MEISS, R.A.
Ultrastructural and Mechanical studies on cat intestinal smooth muscle.
Ph.D. Thesis, University of Illinois, Urbana, Illinois, 1969

MeIlroy, M.B. and Eldridge, F.L.
The Measurement of the Mechanical Properties of the Lungs by Simplified Methods
Clin.Sci. 15: 329, 1956

Melvin, J. W., Stalnaker, R. L., Roberts, V. L. and Trollope, M. L.
Impact Injury Mechanisms in Abdominal Organs
17th Stapp Car Crash Conference, SAE Paper No. 730968, pp. 115-126

ABSTRACT: Blunt abdominal trauma is a major cause of death in the United States. However, little experimental work has been done to clarify the mechanism of blunt abdominal injury and to quantify tolerance parameters for the abdominal organs.

This paper describes a joint study by the Highway Safety Research Institute and the Section of General Surgery of The University of Michigan in which direct impacts were applied to livers and kidneys. The tests were performed in a high-speed testing machine at a controlled ram velocity and stroke limit. The organ was surgically mobilized in anesthetized Rhesus monkeys and then placed on a load cell while still being perfused in the living animal. Tests were performed at ram speeds of 120, 6000, and 12000 in/min (5, 250, and 500 cm/s). The resulting load-deflection data were normalized and average stress-strain curves plotted for each test. In addition, the resulting injury severity was estimated immediately after impact using an injury scale of 1 to 5.

A discussion of the injury mechanisms observed in the tests is given, and correlation between injury severity and the mechanical parameters of stress, strain, and strain energy produced in the tissue of the organ is presented.

Melvin, J. W., Snyder, R. G., Travis, L. W., and Olson, N. R.
Response of Human Larynx to Blunt Loading
17th Stapp Car Crash Conference, SAE Paper No. 730967, pp. 101-114

ABSTRACT: Direct impact to the larynx is usually prevented in accidents by the protective nature of the chin. In some situations, the occupant motions leave the larynx unprotected and susceptible to impact by the steering wheel rim or instrument panel. As one of the unpaired vital organs of the body, there is no easy way to provide an alternative for its functions when the larynx is lost or damaged. Information available on the tolerance of the unembalmed human larynx to force is quite limited.

This paper describes a multidisciplinary study to determine the response of unembalmed human larynges to blunt mechanical loading and to interpret the response with respect to clinical data. Fresh intact larynges were obtained at autopsy and tested at either static or dynamic loading conditions utilizing special test fixtures in materials-testing machines. Load and deformation data were obtained up to levels sufficient to produce significant fractures in both the thyroid and cricoid cartilages. Additional information was obtained in the form of permanent dimensional changes through direct measurements and location of fracture sites by use of xeroradiography. Final evaluation of the damage was performed following dissection of the laryngeal structure. The results of the tests are analyzed and interpreted in relation to establishing tolerance criteria for laryngeal loading.

MERCKER, K., El-Zayat, A.F., Youssef, H. Hosny, Abdel-Rahman, H., Sabry, M.,
Bibars, M. and Khashaba, S.
Volumetric Measurements of the Heart in Egyptian Athletes
J. Egypt Med. Assoc. 54:213-29, 1971

Abstract: The heart size is dependent on body weight, age and total volume of blood. The radiological size and shape of the heart depends on the position of diaphragm, shape of bony thoracic cage, phase of respiration or contraction of the ventricles and pathological heart conditions. It is now well accepted that athletes develop alteration in both size and shape of the heart. Heart volume determination in groups of Egyptian athletes in various sporting games according to the method of Rohrer and Kahlsdorf modified by Mushoff and Reindell revealed no statistically significant differences between football, volleyball and basketball players as well as cyclists and boxers. Heart volume of wrestlers was much lower than in athletes of other sports. The results were compared with those reported in foreign literature. The mean value of the longest horizontal diameter of the heart for Egyptian athletes was found to be higher than in adult untrained males. The heart volume/body surface area ratios were discussed.

MERTZ, Harold J. and Gadd, Charles W.
Thoracic Tolerance to Whole-Body Deceleration
Proc. 15th Stapp Car Crash Conf., SAE Paper 710852, pp.135-157, 1971

Abstract: A professional high diver, instrumented with accelerometers performed sixteen dives from heights between 27-57 ft. For each dive, he executed a 3/4 turn and landed supine on a 3-ft deep mattress which consisted of pieces of low-density urethane foam encased in a nylon cover. Using FM telemetry, sagittal plane decelerations were recorded for a point either on the sternum or the forehead. Impact velocities and corresponding stopping distances for the thorax and the head were calculated from high-speed movies of the dives.

For a 57-ft dive, the impact velocity of the thorax was 41 mph with a corresponding stopping distance of 34.6 in. The peak resultant deceleration of the thorax was 49.2 g with a pulse duration of 100 ms. The maximum rate of change of the deceleration of the thorax was 5900 g/s. No discomfort was experienced as a result of this impact.

The maximum forehead deceleration occurred during a 47.0 ft drop and exceeded 56 g with a Gadd Severity Index greater than 465. This peak acceleration was the result of a localized impact to the skull produced by a hard spot in the helmet worn by Ross Collins and resulted in a brief, sharp head pain.

The results obtained from these experiments are compared with whole-body tolerance data obtained by other investigators and a long duration acceleration

Abstract (Cont'd):

tolerance level of 60 g with a pulse duration of 100 ms is recommended for the thorax in the A-P and P-A directions.

METZ, H.D.

A preliminary investigation of some in vivo mechanical properties of monkey brain.

Masters Thesis, University of West Virginia, Morgantown, W.Va., 1968

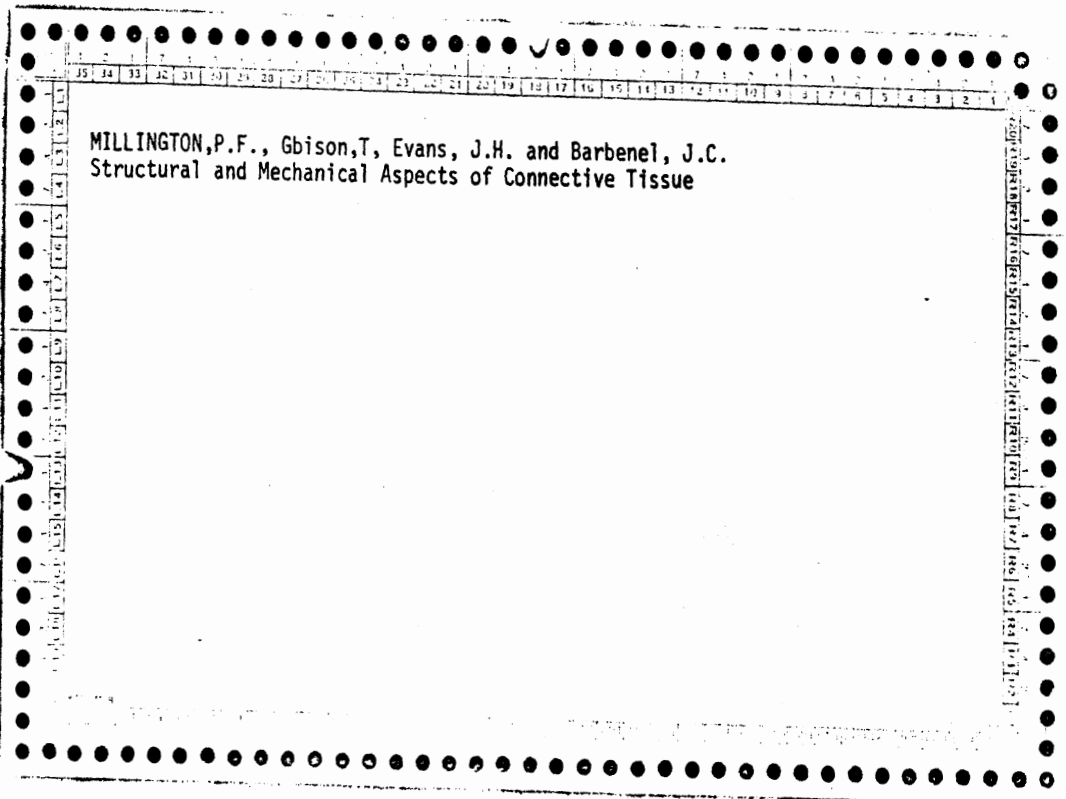
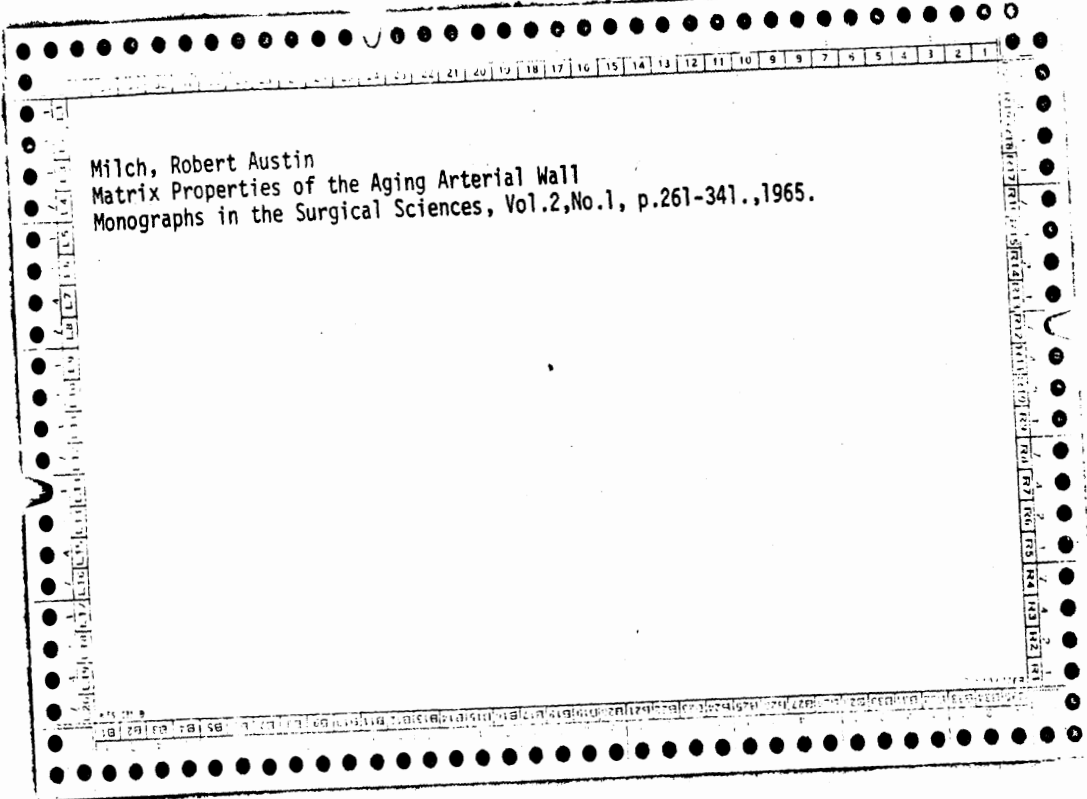
Metz, Howard, McElhane, James and Ommaya, Ayub, K.
A Comparison of the Elasticity of Live, Dead and Fixed Brain Tissue
Journal of Biomechanics, 3:4, 453-458, 1970

Abstract: The opposition to the intracranial expansion of a thin elastic cylinder in live, dead and fixed brain tissue has been measured and compared. An analysis of the data, assuming an elastic material, indicates that the elastic modulus increases concavely upward with strain and varies between 1.0×10^5 and 3.5×10^5 dyn/cm² for the range of the strain tested. Death and fixation of brain tissue increases the modulus but does not appear to change the manner in which it varies with strain.

Meyer, K. H. and C. Ferri
Die elastischen Eigenschaften der elastischen und der kollagenen Fasern und ihre
molekulare Deutung.
Arch. Ges. Physiol. 238: pg. 78, 1936

Meyer, Kurt, H. and Picken, L.E.R.
The Thermoelastic Properties of Muscle and Their Molecular Interpretation
Proc. Roy. Soc. London, S.B., 124: 29-55, 1934

Abstract:



MINNS, R.J., SODEN, P.D. and JACKSON, D.S.

The Role of the Fibrous Components and Ground Substance in the Mechanical Properties of Biological Tissues: A Preliminary Investigation
J. Biomechanics, 6:2, 153-166, 1973

Abstract: Stress-strain and relaxation tests were conducted on human tendon, aorta and bovine ligamentum nuchae which have different arrangements and proportions of elastin, collagen and ground substance. The removal of the ground substance with an enzyme or a chelating agent induced a decrease in stress level, stiffness, relaxation, hysteresis and other time-dependent effects in all three tissues. These changes could be largely explained by a reduction in the effective viscosity of the interfibre matrix although some other factor seemed to be present in the case of tendon, possibly a change in the relationship between the collagen fibres and the glycoproteins in the matrix.

Treating aorta and nuchal ligament with formic acid to remove collagen and other material produced a marked decrease in stress level and time-dependence and also a decrease in the stress and strain at rupture which may be due to the removal of collagen that normally prevents premature rupture at weak points in the elastic network.

MIRSKY, Israel and Parmley, William W.

Assessment of Passive Elastic Stiffness for Isolated Heart Muscle and the Intact Heart
Circulation Research, 33, 233-243, 1973

Abstract: A sensitive method was developed for detecting stiffness changes in the left ventricle. Stress-strain relationships (σ - ϵ) were obtained in the form $d\sigma/d\epsilon = k\sigma + c$ from published studies on eight normal canine hearts, five infarcted canine hearts, and seven isolated cat papillary muscles. Utilizing pressure-volume relationships, the elastic stiffness ($d\sigma/d\epsilon$) and the stiffness constant (k) were also evaluated in patients with normal ventricles, inappropriate hypertrophy, and congestive cardiomyopathy. The k values were 35.0 ± 1.7 (isolated muscle, 30°C), 37.3 ± 1.9 (normal canine, 23°C), and 23.9 (infarcted). For the patient groups, k and the passive elastic stiffness were 15.8 ± 0.3 and 249 ± 22.4 g/cm² for 13 normal patients, 26.4 ± 1.7 and 286 ± 32.0 g/cm² for 7 patients with inappropriate hypertrophy, and 20.1 ± 1.2 and 1360 ± 209 g/cm² for 6 patients with congestive cardiomyopathy. The results indicate that (1) k is sensitive to stiffness changes due to infarction, (2) hypertrophy causes an increase in the value of k although elastic stiffness remains within normal limits, and (3) k for the intact human heart is lower than it is for isolated muscle.

elastic modulus; intact heart; stress strain; pressure-volume relationships; compliance; wall stiffness

Mommaerts, W. E. H. M.
Energetics of Muscular Contraction
Physiol Rev. 49: 427-508, 1969

Abstract:

MOMMAERTS, W. F.
The Variable Contractile Strength of the Heart
UCLA Forum Med. Sci. 10:135-8, 1970

Morgan, F.R.
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Soc. Leather Trades Chem. 44, 170-181,1960

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Morgan, G.W. and Kiely, J. P.
Wave Propagation in a Viscous Liquid Contained in a Flexible Tube
The Jr. of the Acoustical Soc. of Am. 26:3,p.323-328,May 1954

Abstract: A theoretical analysis of the propagation of pressure waves through liquid filled flexible tubes is presented. Expressions are derived which show the dependence of phase velocity and damping factor on the viscosity of the liquid, and on internal damping in the tube wall. The analysis is restricted to tubes with thin walls and to waves whose amplitude is infinitesimal and whose wavelength is large compared to the radius of the tube.

Moritz, Alan R. and Atkins, Joseph P.
Cardiac Contusion, an experimental and pathologic study
Archives of Pathology, 25: 445-462, 1938

Abstract: The objective pathologic criteria for distinguishing between a cardiac contusion and a cardiac infarct vary in usefulness according to the age of the lesion. In the case of a recent myocardial lesion, the only evidence that should almost invariably serve to identify an otherwise indeterminate injury as an infarct is the finding of recent coronary occlusion. Pathologic changes more likely to be found in early contusion than in early infarction include massive interstitial hemorrhage, laceration and tissue disorganization. Since all of these changes may be seen following spontaneous rupture of an early infarct, they are not conclusive. In the case of an older myocardial lesion there is no means of distinguishing objectively between contusion and infarction. Deposits of hemosiderin in myocardial scars are more likely to be seen in healed contusions than in healed infarcts, but since hemosiderin is seen occasionally in healed infarcts its presence is not conclusive. Three months after injury hemosiderin is found infrequently in traumatic scars, so that its absence in no way excludes the possibility of a lesion having been of traumatic origin. The presence or absence of remote coronary occlusion does not serve to identify a myocardial scar as having resulted from infarction or contusion inasmuch as a heart the seat of occlusive coronary disease may have a superimposed traumatic lesion and a heart

Moritz, Alan R. and Atkins, Joseph P.
Cardiac Contusion, an experimental and pathologic study
Archives of Pathology, 25:445-462, 1938

Abstract: continued
with a large healed infarct may have no demonstrable coronary occlusion. The pathologic characteristics of the scars of myocardial contusion and infarction are frequently identical, and the presumptive nature of their origin must be determined by historical data rather than by postmortem examination.

Moritz, A. R.

Pathology of Trauma, 2nd Edn, Lea and Febiger, Philadelphia, Pennsylvania 1954

Chapter 4 - Mechanical Injuries of the Cardiovascular System. P.133

Chapter - 5 - Mechanical Injuries of the Respiratory System P.181

Chapter 6 - Mechanical Injuries of the Alimentary Canal-Injuries of the Esophagus p223-225.

McCarter, R. J. M., Nabarro, F. R. N., and Wyndham, C. H.

Reversibility of the Passive Length-Tension Relation in Mammalian Skeletal Muscle
Archives Internationales de Physiologie et de Biochimie, Vol. 79, pp. 469-479
1971

ABSTRACT: When an isolated skeletal muscle is stretched and then allowed to relax, it does not return to its original length. In a series of several successive stretch-relax cycles there is a gradual elongation of the muscle and each hysteresis loop is displaced in the direction of increasing length, relative to the previous loop.

The passive length-tension diagrams of circulated soleus muscles or fats was investigated. In a series of successive stretch-relax cycles, the curves obtained are similar to those reported for isolated muscles and single fibres. The large difference in area between the first hysteresis loop and that of any succeeding loop is attributed to irreversible damage occurring in the first cycle. After a series of stretches, creep recovery of the length of the muscle did not produce an accompanying recovery of strength. Ability to bear stress was only restored by active shortening of the muscles under no load, followed by a rest interval. Creep recovery of length, followed by isometric contraction at the shortened length, did not restore strength. A possible explanation of this is given in terms of the different structural reorganization which is brought about by the two types of contraction.

McCutchen, C.W.
The frictional properties of animal joints
Wear 5: 1-17, 1962

ABSTRACTS: The porosity and stiffness of cartilage were measured. These properties are discussed in relation to the hypothesized "weeping bearing" properties of animal joints. A series of friction experiments were performed which provide confirmation that animal joints are weeping bearings. These experiments also confirm that synovial fluid is an excellent lubricant for cartilage.

McELHANEY, James H., Stalnaker, Richard L., Roberts, Verne L. and Snyder, Richard G.
Door Crashworthiness Criteria
Proc. 15th Stapp Car Crash Conf. pp.489-517, SAE Paper #710864, 1971

Abstract: A Study of the biomechanical factors concerned with the design of side structures and doors, for crashworthiness has been made. Questions regarding optimum stiffness, location of reinforcing members, effect of armrests and padding have been answered within the framework of injury criteria models. Results of animal studies, cadaver studies and anthropometric dummies have been combined to produce injury criteria for lateral impacts to the head, thorax and abdomen. Impacts were applied utilizing a specially designed "air gun" in a laboratory environment emphasizing reproducibility and control. Full scale crash simulations were performed on an impact sled to verify the results of the more specialized tests and analyses. Scaled models of current production doors were used in the animal series. Scaling relationships for various species of animals have been developed and extrapolated to man. Significant differences in right and left side tolerances to impact were noted and detailed. Additional verification of the Maximum Strain Criteria Model (MSC) is reported. Critical impact velocities for various body sites have been developed for several categories of impact and are presented in ways thought to be most meaningful to designers.

McELHANEY, James H., Stalnaker, Richard L. and Estes, Michael S.
Dynamic Mechanical Properties of Scalp and Brain
Proc. Rocky Mountain Bioengng Symp. pp.67-73, 1969.

ABSTRACT: The research described in this paper is the specification of the mechanical properties of the scalp and brain in sufficient detail to allow the construction of appropriate physical and mathematical models. The results of experiments indicate that the brain is relatively incompressible with a bulk modulus of 300,000 psi. Its response in the capillary rheometer indicates it is more solid than fluid, while compression tests have yielded a model which characterizes its compressive response over a wide range of strain rates.

McMahon, S.M., Permutt, S. and Proctor, D.F.
A Model to Evaluate Pleural Surface Pressure Measuring Devices
J. Appl. Physiol. 27(6), 886-891, 1969

Abstract: Devices which have been used for measuring pressure in the pleural space were tested in a model system where the surface pressure which existed before the insertion of these sensors was known precisely. Systematic differences were found between the pressure which existed before the insertion of the sensor and the pressure seen by the sensor. The pleural cannula, fluid-filled catheter, and air-filled needle were generally found to underestimate the surface pressure; whereas the air-filled balloon overestimated the surface pressure. Certain underlying principles which influence the ability of a sensor to measure surface pressure accurately were defined. They suggested that an appropriate sensor to measure pleural pressure should be thin and flat. A flat Starling resistor most accurately measured surface pressure in the model system.

intrapleural pressure,; Starling resistor

McMahon, S.M., Proctor, D.F. and Permutt, S.
Pleural Surface Pressure in Dogs
J. Appl. Physiol. 27(6), 881-885, 1969

Abstract: End-expiratory pressures were measured in the left pleural space of dogs with pairs of Starling resistors. Pressures were analyzed in terms of body tilt position and posture upon a tilt table. In supine animals in the horizontal position, the pressures acting on the cranial and caudal sensors were alike. In animals placed in the right-side-down posture, the sensors were most nearly alike in the 45° head-up position, but not in the horizontal position. This difference may represent the influence of the heart and mediastinal structures on pleural surface pressure. The intrapleural pressure gradient in the right-side-down posture was 0.16 cm H₂O/cm for the 90° head-up position and 0.21 cm H₂O/cm for the 90° head-down position. In the supine posture, the average gradients were 0.20 cm H₂O/cm for the 90° head-up and 0.31 cm H₂O/cm for the 90° head-down positions.

Starling resistor; pleural pressure gradient; posture; gravity

McMaster, J.H. and Weinert, C.R., Jr.
Effects of Mechanical Forces on Growing Cartilage
Clin. Orthop. 72:308-314, Sep-Oct, 1970.

Abstract: (Summary) This study further defines the postulates of Hueter and Volkmann concerning the response of actively growing cartilage to physical forces and leads to the following conclusions:

1. The mitotic rate of embryonic cartilage can be stimulated by minute compressive and distractive forces.
2. This response is decreased by a force of 2.0 mg/cm² applied for more than 48 hrs.
3. The newly-formed cartilage is quite malleable, possessing properties similar to those of a highly viscous fluid. Malleability may play a role in the development of congruous joint surfaces whose configuration permits optimal weight distribution. Malleability may also be an important factor in the genesis of deformities when the skeleton is subjected to abnormal forces. Calcification and ossification of cartilage may reduce malleability and transfer a record of the effects of mechanical forces on cartilage to bone.

McNeal, John E.
Scleroderma and the Structural Basis of Skin Compliance
Arch Dermatol/107:699-705, 1973

Abstract: The architecture and fiber structure of the dermis in scleroderma were compared to normal skin using techniques of polarization microscopy, horizontal sectioning, and manipulation of fresh tissue under the microscope. Scleroderma-tous skin was not significantly different from normal in any of the structural features studied, yet skin compliance, which is an intrinsic property of normal dermal architecture, was markedly reduced. Manipulation of thin fresh tissue sections under the microscope indicated that loss of compliance was probably related to abnormally strong adhesive forces bonding together otherwise normal fibers. By contrast, in compliant, normal skin, independent fiber mobility was consistently demonstrated. With routine microscopy, the appearance that the structure of the dermis in scleroderma is altered is probably produced by the close compacting of fibers that are abnormally adherent but show no structural alteration.

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Nachemson, Alf L. and Evans, John H.
Some Mechanical Properties of the Third Human Lumbar Interlaminar Ligament
(Ligamentum Flavum)
Jr. of Biomechanics, Vol.1 No.4, 211-220, 1968.

Abstract: The interlaminar ligament between the neural arches of L3 and L4 vertebrae of 10 post mortem subjects, aged 13-79 yr, was subjected to tension tests in Ringer solution. The ligament was almost perfectly elastic in behavior. This property could be due to high contents of elastic fibers in the ligament as the proportion of elastic to collagen fibers, as obtained by biochemical assay in four ligaments was 2:1. The ligament prestresses the disc by a force ranging 1500 g in the young to 400g in the aged. It accounts for the intra-discal pressure of about 0.70 kg/cm² as found by pressure measurements in autopsy spines. The elasticity of the ligament prevents it from protruding into the spinal canal in backward bending. In forward bending it exerts a momentum of up to about 30 kg cm, which is small load compared to the load on the disc in the living man. The ligament exhibits non-linear viscoelastic properties, but the time dependent behavior is less significant than in skin, tendon or costal cartilage. Values for stress and strain at rupture ranged from 100 kg/cm² at 70 per cent in the young to 20 kg/cm² at 30 per cent in the elderly, respectively with significant age correlation for stress. The Modulus of Elasticity at rupture decreased significantly with age from 1.000 kg/cm² in the young to 200 kg/cm² in the aged.

Nachemson, Alf and Elfstrom, Gosta
Intravital Dynamic Pressure measurements in Lumbar Discs
Scand.J. Rehabil.Med. Supp.#1 Vol.2, 1-40, 1970

Abstract:

NAGANO, H.

Function and Structure of the Lung. A new concept of the lung function observed from the structure.

IRYO (Tokyo) 24: 748-57, Oct. 70 (JAP)

In Japanese and is not at the Univ of Mich.

Nahum, A.M. AND Schneider, Dennis, C.

Soft Tissue Injuries and Injury Tolerance Levels

Proc. International Conf. on the Biokinetics of Impacts, Amsterdam, Jun 26-27, 1973

NAHUM, Alan M., Gadd, Charles W., Schneider, Dennis C. & Madeira, Richard G.
Tolerances of Superficial Soft Tissues to Injury
The Journal of Trauma, 12:1044-52, Dec. 1972.

Abstract: (Summary) Effects of selected impacts to localized areas of the superficial tissues are presented. Test conditions, including time of exposure to the loading, have been chosen in such a way that it is believed the results may be of practical value in indicating approximate tolerances of the superficial tissues to common types of accidental loading.

The geometrical shapes of the impacting tips, the intensities of impact, and the magnitude of the resulting tissue damage are given in sufficient detail to enable the tests to be duplicated on artificial simulations of the biological materials, and thus to determine their suitability for the construction of anthropometric dummies.

Nakashima, Teruyuki, and Tanikawa, Junji
A study of human aortic distensibility with relation to atherosclerosis and aging
Angiology 22:477-90, Sept. 1971

Noble, Mark I. M., Bowen, T. Earle, and Hefner, Lloyd L.
Force-Velocity Relationship of Cat Cardiac Muscle, Studied by Isotonic and Quick
Release Techniques
Circulation Research, Vol. XXIV, pp.821-833, 1969

ABSTRACT: Contractions of isolated cat papillary muscle were studied using a lever system with an electromagnetic load which allowed an on-line computer to control the experiment and to process all the data. Isotonic force-velocity curves were determined in 17 cat papillary muscles; the curves were not hyperbolic. Force-velocity curves at constant time in the contraction and constant contractile element length were obtained with a systolic quick-release technique in 9 muscles. The velocity of shortening after release to low force was almost always less than the maximum recorded following release to slightly higher force. When quick-release force-velocity curves determined at different times in the contraction were compared, the maximum velocity occurred at approximately 60% of the time to peak isometric force. The fall in velocity at lower forces was more marked later in the contraction. The shape of the quick-release force-velocity curves was found to depend on muscle length. At a constant time of release, and ignoring the low force end of the curves, the quick-release force-velocity relationships were not hyperbolic at muscle lengths appreciably below optimum, but near the optimal length the curves were hyperbolic.

Noble, Mark I. M., Bowen, T. Earle, and Hefner, Lloyd L.
Force-Velocity Relationship of Cat Cardiac Muscle, Studied by Isotonic and
Quick Release Techniques
Circulation Research, Vol. XXIV, pp. 821-833, 1969

ABSTRACT: (continued) When these quick-release force-velocity curves were corrected for the presence of an elastic element in parallel with the contractile element force-velocity curves were hyperbolic.

KEY WORDS: myocardium force-velocity relation length-force curve
systolic quick release muscle models active state of cardiac muscle
A.V. Hill's equation

Noble, Mark I. M. and Else, Wendy
Reexamination of the Applicability of the Hill Model of Muscle to Cat Myocardium
Circulation Research, Vol. XXXI, pp. 580-589, 1972

ABSTRACT: In cat papillary muscles, which were perfused with oxygenated physiologic saline at 26° C and contracting isometrically at 15 beats/min, shortening steps were imposed 330 msec after stimulation--near the peak of isometric twitch force-- and 170 msec or 250 msec after stimulation--during force development. The force immediately following the shortening step was measured. From the results at 330 msec, we predicted the results at the earlier times assuming that the sudden drop in force was due to recoil of a series elastic component (SEC) alone; however, the actual results differed from the predicted results. The shortening step required to drop the force to zero at the earlier times was greater than predicted; in other words, the force immediately following a shortening step predicted to drop the force to zero was finite. The results are not compatible with the hypothesis that the sudden drop in force accompanying the shortening step (the quick-release phenomenon) is due to the sudden recoil of the SEC, which is stretched to different lengths at the two times. They are compatible with the hypotheses that (1) the quick-release phenomenon is a property of the contractile component or (2) the SEC compliance is a function of the degree of activation. Therefore, we concluded that nonseries elasticity contributes to the quick-release

Noble, Mark I. M. and Else, Wendy
Reexamination of the Applicability of the Hill Model of Muscle to Cat Myocardium
Circulation Research, Vol. XXXI, pp. 580-589, 1972

ABSTRACT (continued) phenomenon and should be considered when the Hill model is applied to heart muscle. In particular, isometric contraction cannot be modeled by a contractile component stretching an SEC of constant physical characteristics.

KEY WORDS Contractile component series elastic component quick-release
phenomenon myocardial contraction active state isometric twitch

Noordergraaf, A., Verdouw, P.D., van Brummelen, A.G.W., & Wiegel, F.W.
Analog of the Arterial Bed
In Pulsatile Blood Flow, edited by E.O. Attinger, New York; McGraw, p.373-387, 1963

Abstract: In this chapter results obtained from an analog computer that simulates the action of the left ventricle and of the systemic arterial tree will be presented after a brief description of the setup of this computer. Some of the results will be compared with results secured from others' experiments on dogs.

Normand, I.C.S.
The Effects of Surface Forces on the Lungs
Brit.J.Dis.Chest 62: 169-87, 1968

Abstract:

Ommaya, A.K., Yarnell, P., Hirsch, A.E. and Harris, E.H.
Scaling of Experimental Data on Cerebral Concussion in Sub-Human Primates to
Concussion Threshold for Man
Proc. 11th Stapp Car Crash Conf., pp.47-52, SAE Paper #670906, 1967.

Abstract: A method of extending the results of experiments on concussion-producing head rotations on lower primate subjects to predict the rotations required to produce concussions in man is presented. A rational scheme of development of the overall investigation is outlined. Theoretical scaling factors are derived and discussed and the results of concussion-producing tests on the Rhesus monkey are presented in chart form. A chart of angular acceleration required to produce concussion in the Rhesus monkey indicates that an acceleration of 40,000 radians per second² will have a >99% probability of producing concussion. The scaling factors presented herein tentatively indicate that an acceleration of 7,500 radians per second² will have the same probability of producing concussion in man.

Ostreicher, H.L.
Field and Impedance of an Oscillating Sphere in Viscous-Elastic Medium with an
Application to Biophysics.
J. Acoust. Soc. Am. 23:6 707-714, 1951

ABSTRACT: With an application to human tissue in view, a theoretical analysis of the behavior of mechanical vibrations in a medium with elastic, viscous, and relaxation properties is made. For this purpose, the equations of wave motion in a viscoelastic medium are discussed in general and solved for two problems, which are significant for the propagation and the transfer of vibration energy: (1) energy propagation and absorption in plane waves, (2) field and impedance of an oscillating sphere.

The results show that the energy is propagated in two kinds of waves, the relative intensities of which change strongly with frequency: transverse waves, owing to the shear elasticity and viscosity, and compression (acoustical) waves, owing to the volume compressibility of the medium. A more detailed treatment is then accomplished for human muscle tissue by inserting the approximate values of its elastic constants into the general formulas, thus explaining the behavior in a frequency range from 0 up to several hundred kc.

Oberman, Albert, Myers, Allen R., Karunas, Thomas M., and Epstein, Frederick H.
Heart Size of Adults in a Natural Population -- Tecumseh, Michigan
Circulation, Vol. 35, pp. 724-733, 1967

ABSTRACT: Roentgenological determinations of the transverse diameter and cardiothoracic ratio in 3,985 subjects aged 20 years or more, from Tecumseh, Michigan, represent the first report on the measurement of heart size in a total community. The influence of cardiovascular abnormality, height, and weight on heart diameter and cardiothoracic ratio is determined across all age and sex divisions for the entire adult population. A consistent hierarchy of heart diameter, independent of age, height, and weight, has been demonstrated so that the diameter of the hearts of abnormal males > normal males > abnormal females > normal females. Heart diameter, especially in the males, distinguishes the abnormal segment of the population more effectively than the cardiothoracic ratio, but an age and sex-specific cardiothoracic ratio may be the most valuable in the clinical situation. Both measurements relate directly to age, sex, and weight, but the relation to height is dependent on weight. Study of heart size in a general population reveals that measurements as simple as heart diameter and cardiothoracic ratio may be effectively applied to clinical and epidemiological cardiovascular evaluations.

Heart size epidemiology Transverse heart diameter Cardiac enlargement Cardiothoracic ratio Cardiovascular

Parke, W. W., and Schiff, D. C. M.
The Applied Anatomy of the Intervertebral Disc
Ortnop. Clin. North Am., Vol. 2, No. 2, pp. 309-324

ABSTRACT: The intervertebral disc is the fibrocartilaginous complex that forms the articulation between the bodies of the vertebrae. Although it provides a very strong union ensuring the degree of intervertebral fixation that is necessary for effective muscular action and the protective alignment of the neural canal, the summation of the limited movements allowed by each disc imparts to the spinal column as a whole its characteristic universal motion. The discs of various spinal regions may differ considerably in size and in some detail, but they are basically identical in their structural organization. Each consists of two components - the internal semifluid mass, the nucleus pulposus, and its laminar fibrous container, the anulus fibrosus.

Parmley, William W., M.D., Brutsaert, Dirk L., M.D., and Sonnenblick, Edmund H.
Effects of Altered Loading on Contractile Events in Isolated Cat Papillary Muscle
Circulation Research, Vol. XXIV, pp. 521-532, 1969

ABSTRACT: When the mode of contraction of the cat papillary muscle is changed abruptly from isotonic to isometric, the tension of the first isometric contraction is as much as 22% greater and lasts substantially longer than the subsequent stable isometric contractions attained after a few beats. This previously undescribed phenomenon is largely independent of preload or inotropic influences, but is greatly diminished at lower temperatures. Force-velocity curves equivalent to the first isometric contraction revealed a maximum velocity of shortening $9.5 \pm 2.0\%$ greater than that of the stable isometric contraction. Thus apparent changes in muscle contractility can occur whenever there are sudden substantial changes in tension development. This effect may be due to transitory changes in free intracellular calcium or, alternatively, to the presence of a viscous element in close association with the contractile element.

KEY WORDS: viscous element contractility isotonic isometric homeometric
autoregulation V_{max} paired stimulation

Parmley, Loren F., Mattingly, Thomas W., Manion, William C. and Jahnke, Edward J. Jr.
Nonpenetrating Traumatic Injury of the Aorta
Circulation, Volume 17, 1086-1101, Jun. 1958

Abstract: Rupture or laceration of the aorta is a more common result of non-penetrating traumatic injury than is generally appreciated. Approximately 15 per cent of individuals with traumatic rupture survive temporarily. If the lesion is promptly diagnosed appropriate surgical treatment may be life-saving. Diagnosis may be difficult and at times the rupture may remain clinically silent for variable periods. The natural course from aortic rupture to false aneurysm formation with secondary rupture of the aneurysm may be brief or extend over many years. Surgical treatment of a false aneurysm that has remained stable for a prolonged period has been successful, but in some instances conservative management may be the treatment of choice.

PARODI, Eduardo N., Kaiser, Gerard A., Wolff, Marianne, Kovalik, A.T.W. & Malm, J.R.
Comparative Study of the Tensile Strength of Autogenous Systemic Veins & Preserved
Venous Homografts

J. of Surg. Res. 12:99-104, 1972

Abstract: (Summary) There is a minimum decrease of tensile strength in saphenous vein
veins after irradiation (5%), when compared to fresh controls.

2. This difference is larger in cephalic and brachial veins (45-55%), when compared
to the fresh saphenous vein controls.

3. There is no demonstrable morphological alteration in the saphenous vein walls
after irradiation and freezing.

4. We suggest the use of saphenous vein homografts, sterilized by irradiation
and preserved by freezing, in those cases in which it is not feasible to use
saphenous vein autografts.

Partington, F. R. and Wood, G. C.

The role of non-collagen components in the mechanical behaviour of tendon fibers
Biochim. Biophys. Acta. 69. 485-495, 1963

SUMMARY: Determination of load-extension curves of rat-tail tendon fibres showed
that when extension was restricted to 2% the slope of the linear portion of the
curves was unchanged in successive tests. The change of slope resulting from
enzymic treatment was used to assess the damage effect of hyaluronidase and trypsin.
Pure hyaluronidase had no significant effect indicating that chondroitin sulphate
A and C and hyaluronic acid are not important in stabilising the fibres according
to this criterion. Other preparations of hyaluronidase did damage the fibres and
this is attributed to the presence of enzymic impurities which attack interfi-
brillar matrix rather than the collagen of the fibres. Evidence is presented
that it is the non-collagenous protein of the matrix that is attacked and which
is important in stabilising the native fibres.

Patel, Dali J., Mallos, Alexander J, and Fry, Donald L.
Aortic mechanics in the living dog
J. Appl. Physiol. Vol. 16, No. 2, 293-299, 1961

ABSTRACT: The relationship between longitudinal strain, circumferential strain, lateral intravascular pressure, blood velocity, and longitudinal motion was examined in the aortas of 25 living thoracotomized dogs. Electrical calipers with adequate recording characteristics were used for instantaneous measurement of diameter and length. The results indicate: a) with inspiration, the thoracic aorta increased in length and the abdominal aorta shortened. b) During cardiac systole the length in the thoracic aorta increased with a rise in pressure, mean value for longitudinal extensibility $\times 10^3$ was 15% (± 4.8 S.D., ± 1.1 S.E.M.) per centimeter H_2O pulse pressure. The mean value for the ratio of circumferential extensibility to longitudinal extensibility was 10. c) The abdominal aorta shortened with cardiac systole. This shortening is thought to be produced by elongating strain of the thoracic aorta. d) The absolute magnitude of aortic wall velocities, both radial and longitudinal, was very small as compared to the blood velocity at the same site.

PATEL, Dali J. and Janicki, Joseph S.
CATALOGUE OF SOME DYNAMIC ANALOGIES USED IN PULMONARY AND VASCULAR MECHANICS
Med. Res. Engr. 5: 30-33, 1966

Abstract: Mechanical models consisting of various combinations of mass-spring-dashpot are discussed. Many of these models are used in pulmonary and vascular mechanics. The steady-state response to sinusoidal forcing is described in some detail since it can be studied in living animal or man.

Patel, Dali, J., Janicki, Joseph S., Vaishnav, Ramesh N. and Young, JOHN T.
Dynamic Anisotropic Viscoelastic Properties of the Aorta in living Dogs.
Circulation Research, Vol.32, 93-107, Jan.1973

Abstract: The purpose of this paper is to describe the incremental dynamic anisotropic viscoelastic properties of the middle descending thoracic aorta in ten living dogs. A segment of the middle descending thoracic aorta was isolated in situ and connected to a reservoir filled with oxygenated blood. The pressure, longitudinal force and length of the segment were monitored continuously. From these data, the incremental elastic and viscous moduli were calculated. The results indicated that the vessel wall was anisotropic, having its greatest values of moduli were higher in the in vivo than the in vitro experiments.

PATEL, DALI J., Tucker, William K. and Janicki, Joseph S.
Dynamic Elastic Properties of the Aorta in Radial Direction
J. Appl. Physiol. 28(5): 578-582. 1970.

Abstract: The purpose of this study was to directly evaluate the viscoelastic properties of the aorta in the radial direction. A specially designed instrument capable of superimposing small sinusoidal strains on an initially strained tissue was used. The upper, middle, and lower thoracic aorta and the abdominal aorta were studied around the physiologic thickness in eight dogs. The local viscoelastic behavior was linear as long as the superimposed sinusoidal strain remained below 4%. Edge effects were found negligible, and the data were reproducible up to 16 hr following removal of the tissue. The storage (E') and the loss (E'') moduli were calculated as functions of frequency (ω) and initial strain. At a given site, E' increased and E'' decreased as the initial strain was increased. E' also increased as one proceeded from the upper descending thoracic aorta down to the abdominal aorta. A simple linear model consisting of a spring and dashpot in parallel (Voigt model) approximated the experimental data in the frequency range of 2-40 Hz. For such a model E' represents the dynamic elastic modulus and E''/ω the viscous modulus.

Patel, D. J., and Fry, D. L.
The Elastic Symmetry of Arterial Segments in Dogs
Circulation Research, Vol. 24, pp. 1-8, 1969

ABSTRACT: Elastic symmetry was studied in the middle descending thoracic aorta, abdominal aorta, and left common carotid artery under physiologic ranges of loading in ten dogs. A segment of the blood vessel was isolated and hung vertically. As the segment was pressurized, the radius, length, and the rotation of the lower end of the vessel were measured with respect to the fixed upper end. In addition, the angular displacement of a glass whisker initially placed perpendicularly through the wall was measured. From these data it was possible to calculate the values of shearing strains and elongating strains associated with pressurization and various imposed longitudinal stresses. The values of shearing strain varied from 0.0003 to 0.115 over pressure ranges of 3 to 270 cm. H₂O. In all instances the values of shearing strain were much smaller than the corresponding elongation strains. It was concluded that the vessel has elastic properties that are nearly symmetrical about the planes perpendicular to principal stresses under physiologic loading, i.e., the vessel may be treated as a cylindrically orthotropic tube.

orthotropic elastic properties elastic symmetry in arteries shearing strain
in arteries

55 581 B

PATEL, D.J., Austen, W.G., Greenfield, J.C., Jr. and Tindall, O.T.
Impedance of certain large blood vessels in man.
Ann. N.Y. Acad Sci, 115: 1129-1139, 1964.

Abstract: Instantaneous pressure-flow and pressure-radius relationships have been studied in human subjects undergoing various therapeutic surgical procedures. Standard digital computer techniques were utilized for steady state analysis of these data. The respective pressure, flow, and radius contours were subjected to harmonic analysis not only to determine the significant harmonic content of these functions, but also to permit calculation of impedance functions

Patel, D.J., J.C. Greenfield, Jr., and Fry, D.L.
In Vivo Pressure-Length-Radius Relationship of Certain Blood Vessels in Man
and Dog
In Pulsatile Blood Flow, edited by E. O. Attinger, New York: McGraw, p293-305, 1963

Abstract: It is the purpose of this report to summarize a series of studies which we have carried out in both man and dog to explore the mechanical behavior of certain blood vessels throughout the cardiac cycle [6,8,12,14]. The instantaneous lateral intravascular pressure was measured, in vivo, simultaneously with one or more of the following variables: circumferential wall strain, longitudinal wall strain, longitudinal wall motion, and radial wall motion. It is of major importance that these measurements be obtained in vivo, since the mechanical properties of a blood vessel are influenced by its natural length, its coupling to surrounding tissues, and the presence of a normal metabolic milieu [3,11].

PATEL, Dali, J.
Mechanical Properties of Large Blood Vessels
The Pulmonary Circulation and Intersitial Space, edited by Alfred P. Fishman
and Hans H. Hecht, 1969

ABSTRACT: The purpose of this communication is to summarize the work done in our laboratory on the mechanical properties of the main pulmonary artery and the descending thoracic aorta in dogs. The latter is included here since this vessel has been studied in much greater detail and some of the ideas, with appropriate modifications, could be adapted for the pulmonary vessels.

Some of the salient features of mechanical properties of the large blood vessels are described. The anisotropic elastic behavior of the pulmonary artery has not been investigated to date. It is hoped that the approach used in the aortic studies will prove useful in this regard.

PATEL, Dali J., Greenfield, Jr., Joseph C., Austen, W. Gerald, Morrow, Andrew G. and Fry, Donald L.
Pressure-flow Relationships in the Ascending Aorta and Femoral Artery of Man
J. Appl. Physiol. 20(3):459-463, 1965.

Abstract: Using a Kolin-Kado electromagnetic flowmeter and a 20-gauge needle connected to a Statham transducer, instantaneous blood flow and pressure were measured in the ascending aorta of 3 patients and in the common femoral artery of 11 patients. From the data obtained in the ascending aorta the peak blood flow, cardiac output, peak power, and stroke work were calculated. Harmonic analysis of the pressure and flow curves was carried out and the hydraulic input impedance series was calculated for each subject. The constant term (peripheral vascular resistance) was found to be about 12 times as large as the largest time-dependent impedance term. Similar analysis of the femoral artery data indicated: 1) the moduli of the hydraulic input impedance series dropped with frequency from an initially high constant term, and then varied slightly with frequency thereafter; and 2) the vascular resistance decreased to 75% of the control value during reactive hyperemia and increased to 232% of the control value following norepinephrine administration.

hydraulic input impedance

PAUL, John P.
Load Actions on the Human Femur in Walking and Some Resultant Stresses
Experimental Mechanics, March 1971 pp. 1-4.

Abstract: From experimental measurements of ground-to-foot force actions and limb configurations, resultant load actions at junctions of leg segments can be calculated. From a knowledge of the phasic activity of muscles and their anatomical location, the tension in relevant muscles and ligaments may be inferred, and the joint forces obtained. From the measured geometry of the femur, calculations are made of the stresses on the basis of simplifying assumptions of material disposition and behavior.

Pennington, Claude L.

External Trauma of the Larynx and Trachea. Immediate Treatment and Management
Ann.Otol.Rhinol.Laryngol. 81:546-54,1972

Abstract:Laryngeal crush injuries have a predictable injury mechanism and pattern of injury. the knowledge of which aids in an orderly repair by the surgeon.

Open repair of the larynx within eight days in severe crush injury allows microscopically accurate anatomic reconstruction of the larynx with maximum preservation of laryngeal functions.

Peterson, L.H.
Measurement of Displacement and Strain.
In Methods in Medical Research, R.F. Rushmer, Editor-in-Chief,
Chicago; Year Book, 1966 Vol.II, p.1-23.

Peterson, Lysle H., M.D., Jensen, Roderick E., Ph.D., and Parnell, John, M.S.
Mechanical Properties of Arteries in Vivo
Circulation Research, Volume VIII, pp. 622-639, 1960

ABSTRACT: Simultaneous, instantaneous in vivo recordings of intra-arterial pressure and arterial diameter have been obtained from a variety of sites along the arterial tree in 10 dogs. Analysis of the data established the fact that the mechanical properties of arteries can be described by a linear, first order differential equation where coefficients can be described as the moduli of elasticity and viscosity. It is established that the circumferential motion of arteries may be characterized as small strain.

The harmonic content comprising the pressure and diameter pulsations have been evaluated by Fourier Analysis. The effects of epinephrine, norepinephrine, acetylcholine and nerve stimulation on the mechanical properties of arteries are discussed.

An analytical discussion is developed and mathematical equations are derived which relate pressure, wall tension, radius, strain, elasticity, viscosity and inertia in a tube which has been shown to be a reliable model of the living artery.

It is concluded that the concept that the arteries function as a "peripheral heart," i.e., rhythmically contract in synchrony with the heart is not justified.

Probable relationships of these properties to the structure and functions of the arterial system are discussed.

Peterson, L.H.

Vessel Wall Stress-Strain Relationship

In Pulsatile Blood Flow, edited by E.O. Attinger. New York: McGraw, p.263-274, 1963

Abstract:

Pieper, Heinz P. and Paul, Lawrence T.
Responses of Aortic Smooth Muscle Studied in Intact Dogs
American Journal of Physiology
Vol. 217, N. 1, July 1969

ABSTRACT: A method of obtaining the pressure-diameter relationship (PDR) of the aorta in intact dogs is described. The relationship is linear in most animals (71%); at large aortic diameters this relationship tends to become curvilinear. The analysis of these PDR curves clearly demonstrates the responsiveness of aortic smooth muscle to experimental manipulations. During hemorrhage the aortic diameter for any given pressure in general decreases, whereas on reinfusion of the blood the diameter returns toward the control condition. This response of the smooth muscle persisted after bilateral vagotomy and stabilization of carotid sinus pressure. Elasticity moduli were calculated from the PDR curves; these moduli vary greatly but do not necessarily indicate the direction of the aortic smooth muscle response as seen in the PDR curves. Pulse-wave velocities were also calculated but not measured. Very little variation occurred in these pulse-wave velocities and it appeared that changes in slope and position of the PDR curves due to aortic smooth muscle activity moved in a direction so as to minimize alteration of pulse-wave velocities.

PINTO, JOHN G. and FUNG, Y.C.
Mechanical Properties of the Heart Muscle in the Passive State
J. Biomechanics, 6:6, 597-616, 1973

ABSTRACT: The viscoelastic behaviour of the heart muscle (papillary muscle) in the passive unstimulated state is studied by such methods as stress relaxation, creep, vibration and stress-strain testing. The tests are conducted on a newly developed electromechanical muscle testing device which is suitable for conducting active and passive tests on biological materials.

PINTO, John G. and Fung, Y.C.
Mechanical Properties of the Stimulated Papillary Muscle in Quick-Release
Experiments
J.Biomechanics, Vol.6 No.6, pp 617-630, 1973

Abstract: The behavior of heart muscle in the stimulated state is a subject of much controversy. A brief summary of the conclusions drawn by some investigators is given to bring the conflicts to focus. In 1970 Fung formulated the general problem incorporating Hill's three-elements model and Huxley's sliding element theory. This formalism is of general validity and is adopted here to study the papillary muscle behavior. Preliminary results obtained using quick-release technique are presented.

PODOLSKY, Richard J.
Mechanochemical Basis of Muscular Contraction
Fedr.Proc. 21:6, 964-974, 1962.

Pollack, Gerald H., Huntsman, Lee L. and Verdugo, Pedro
Circulation Research, Vol. XXXI, pp. 569-579, 1972

Cardiac Muscle Models An Overextension of Series Elasticity?

ABSTRACT: Quick-stretch and quick-release experiments were performed on right ventricular cat papillary muscles to test the applicability of the Hill model to cardiac mechanics. Series elastic component (SEC) force-length curves were calculated from stretches and releases carried out at various times during the contractile cycle. At any SEC force, the SEC elastic modulus depended on the time during the contractile cycle at which it was measured. When measured at the same time and at the same SEC force, elastic moduli obtained by releases of less than 1% of muscle length differed from those obtained by corresponding stretches. Larger stretches, in fact, appeared to yield negative elastic moduli. Thus, a unique SEC modulus could not be identified at any level of SEC force. It is concluded that the concept of the SEC as a passive elasticity appears unsatisfactory and, as a consequence, that the quantitative validity of the Hill model for cardiac muscle is questionable. Moreover, since an anatomical counterpart of the SEC has not been identified, the Hill model also appears unsatisfactory from a structural point of view.

POOL, Peter E., Chandler, Brian M., Seagren, Shirley C. and Sonnenblick, Edmund
Mechanochemistry of Cardiac Muscle, II. The Isotonic Contraction
Circulation Research, Vol. 22, 465-472, 1968.

Abstract: The aim of this study was to evaluate utilization of chemical energy in relation to myocardial mechanics in variably afterloaded contractions of cardiac muscle by determining total energy utilization in the absence of energy production. Right ventricular papillary muscles of cats were equilibrated at 26°C in a myograph in Krebs's solution while contracting isometrically (12/min)

These findings provide a demonstration of the Fenn effect in cardiac muscle and explain the well-known discrepancy in energy cost when cardiac work is increased by increasing pressure load as opposed to increasing volume load.

cat papillary muscle, muscle mechanics, creatine phosphate, energetics, adenosine triphosphate

Porje, I.G.
Hemodynamics of the Ascending Aorta
In Pulsatile Blood Flow, edited by E.O. Attinger, New York: McGraw, p.237-245, 1963

Abstract:

Pudenz, Robert H. and Sheldon, C. Hunter
The Lucite Calvarium--A Method for Direct Observation of the Brain
Neurosurg. 3, 487-505. 1946

Abstract: In a previous report an experimental surgical technic in which the convex portion of the monkey skull is replaced by a transparent lucite calvarium was described. Because a large area of both cerebral hemispheres is exposed through the lucite window, the method is ideally suited for the study of intracranial phenomena under "closed box" conditions. It may be of interest to mention that the technic was developed primarily to study the effects of cranial trauma on the underlying brain. The patterns of brain motion resulting from blows to both the freely movable and the immobile head were recorded by high-speed cinematography.

It is stressed that these experiments were conducted to study the motion patterns of the cerebral mass and any other visible physical change. It is not a study of cerebral concussion. Although brain movement and concussion are probably closely interrelated the mechanism of concussion is not explainable in the light of our findings. It is hoped, however, that this study may furnish additional data toward the eventual solution of the problem of cerebral concussion.

Rackley, Charles E., Hood, Jr., William P. Cleveland, Linda and Stacy, Ralph W.
Derivation of Cardiac Mechanical Parameters from Serial Biplane Angiocardiograms
J. Appl. Physiol. 24(2), 254-258, 1968.

Abstract: Data-handling methods and algorithms have been developed for removing the tedious task of hand calculation of left ventricular volumes and weight, stress-tension relations, circumference, and work from biplane angiocardio-graphic data. These methods have been so planned and arranged that they can be carried out on a small, laboratory-oriented digital computer. In effect, they have reduced the information availability time to less than 3 hr so that the procedure becomes feasible for clinical evaluation of patient status.

heart volume, cardiac output, cardiac muscle; computers in biology

RADIN, Eric L., Paul, Igor L. and Lowy, Martin
A Comparison of the Dynamic Force Transmitting Properties of Subchondral Bone and Articular Cartilage
J. Bone Joint Surg. (Amer) 52:444-56, Apr.70

Abstract: The development of wear changes in joints is in part related to their ability to withstand compressive force. Activity applies forces across joints, and it is the ability of a joint to withstand these forces that to some extent determines how long its articular surfaces last. Since the marked compliance of articular cartilage was established experimentally, it has been assumed that the compressive forces to which a joint is subjected are attenuated mainly by the cartilage and to some extent by the viscous synovial fluid. This paper will discuss the reaction of articular cartilage and subchondral bone to compression and the relative ability of the subchondral bone to decrease the dynamic peak forces produced by impact loading.

26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
RADIN, Eric L. and Paul, Igor L.
Does Cartilage Compliance Reduce Skeletal Impact Loads?
The Relative Force-Attenuating Properties of Articular Cartilage, Synovial Fluid,
Periarticular Soft Tissues and Bone
Arthritis and Rheumatism, Vol.13, No.2 (March-April) 1970

Abstract: Joint wear is related to the pressure exerted at the articular cartilage interface. The largest loads an animal joint experiences in life will be brief and will result from impact. Compliance in the system will decrease the peak value of such impulsive loadings at the expense, probably unimportant, of increasing their duration. The ability of synovial fluid, supporting bone and periarticular soft tissues to provide this compliance and attenuate peak forces might spare the articular cartilage and prevent wear. Measurements were made of the relative attenuation of longitudinally applied, external impulsive force by these major joint elements of adult bovine interphalangeal joints. The effect of the various elements, independently, upon the over-all compliance of the joint was measured in nonimpulsive experiments and found to correlate quite well with their ability to reduce the peak load in the impulsive experiments. Only the periarticular soft tissues (capsule, ligaments and synovial tissue) and bone have significant force-attenuating properties. Articular cartilage and synovial fluid have little effect. These results support the contention that the integrity of bone could well be important in prolonging joint life.

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
RADIN, ERIC L. and PAUL, IGOR L.
Importance of Bone in Sparing Articular Cartilage from Impact
Clin. Ortho. No.78, pp.342-44, Jul-Aug 1971

Abstract: The etiology of degenerative joint disease may well be related to either an abnormal increase in intra-articular pressures or a decrease in the ability of joints to handle normal loads. Bovine middle phalanges from 3 to 4 year old healthy cows were fresh frozen and thawed just before testing. These phalanges were subjected to longitudinal impact loads to measure the peak dynamic force transmission and deformation. Removal of 40 to 50 percent of their bony shafts decreased these parameters far more than did removal of articular cartilage.

Rahn, Hermann
The Relationship Between Thora^X and Lung: a Review.
U.S.A.F School of Aerospace Medicine 1-14, Jan.1970.

RAMSEY, R.H.
THE ANATOMY OF THE LIGAMENTA FLAVA
Clin. Orthop. 44, pp.129-140, 1966

Abstract: The purpose of this study is to make a detailed investigation into the gross, microscopic and functional anatomy of the ligamenta flava. A detailed gross and microscopic description of the interlaminal yellow ligaments, or ligamenta flava, of the human has been presented. Their elastic tissue composition substitutes the physical property of elasticity for the shear strength of ligaments of dense collagenous tissue. The clinical and surgical significance of the ligamenta flava is also considered.

RAMSEY, R. W.
Dynamics of single muscle fibers.
Ann. N. Y. Acad. Sci. 47: 675-695, 1946

Remington, John W.
Introduction to Muscle Mechanics, with a Glossary of Terms
Fedr. Proc. 21:6, 954-973, 1962

Remington, J. W. and Alexander, R. S.
Relation of Tissue Extensibility to Smooth Muscle Tone
Am. J. Physiol. Vol. 185: 302-308, 1956

ABSTRACT: Isolated specimens of rabbit gut or bladder were subjected to fixed loads, length changes being recorded kymographically. The elongation curves showed two essential phases. First there was a rapid visco-elastic extension whose amount was directly related to load. Second, there was a sustained creep whose slope was less clearly dependent upon load. This creep appeared not to develop until a critical load value was exceeded. The stretch reduced the viscosity, as reflected in the initial extension of a succeeding stretch. This change could be reversed with long recovery intervals allowed after load removal. Load removal was followed by a brief viscoelastic recoil, and then a long term length retraction which had the same slope regardless of the amount of prior extension. The recoil was always less in amount than the previous visco-elastic extension. The recovery of the initial viscosity, with time, could not be related to the recovery in length. While acetylcholine or epinephrine could change the tissue length, they had no effect upon the amount or rate of initial extension, upon the late creep, or upon the late length retraction upon load release. The contractile elements of the muscle would seem to be in series with visco-elastic elements, and the elongation pattern of the latter

Remington, J. W. and R. S. Alexander
Relation of Tissue Extensibility to Smooth Muscle Tone
Am. J. Physiol, Vol. 185, pp. 302-308, 1956

ABSTRACT (continued): dominantly controls the over-all tissue extensibility. Only in a few cases can the tissue extensibility be related to the amount of muscle contraction.

Remington, J.W. and Alexander, R.S.
Stretch Behavior of the Bladder as an Approach to Vascular Distensibility
Am. J. Physiol. 181: 240-248, 1955

Abstract: The effect of the rate of stretch, and of the time intervals allowed at the end of a stretch or of a stretch release, on the stretch behavior of kitten bladders was studied. A strong time-dependent factor was clear, so that the peak tension and the hysteresis loop width decreased with successive, equal stretches made in close sequence. This factor was studied by measuring the rates of tension decay and of tension recovery, at fixed bladder volumes. Both rates related to the previous tension level. After the bladder was killed by application of NaCN, the rates of tension decay remained unchanged, but the tension recovery became very small. This dead bladder showed an increased distensibility. The living bladder showed a direct relation between peak tension reached with a stretch and the rate of that stretch. With successive stretches, this rate dependency disappeared. It was seldom seen in the dead bladder. When the muscle was stimulated electrically, the tension rise was small and of brief duration. Except for the period in which the tension was actually rising, the elasticity of the bladder was not measurably altered. These results are discussed with reference to a simple mechanical model.

Rigby, Bernard J., Hirai, Nishio, Spikes, John D. and Eyring, Henry
The Mechanical Properties of Rat Tail Tendon
J. gen. Physiol. 43: pp 265-283, 1959/60

Abstract: The load-strain and stress-relaxation behavior of wet rat tail tendon has been examined with respect to the parameters strain, rate of straining, and temperature. It is found that this mechanical behavior is reproducible after resting the tendon for a few minutes after each extension so long as the strain does not exceed about 4 per cent. If this strain is exceeded, the tendon becomes progressively easier to extend but its length still returns to the original value after each extension. Extensions of over 35 per cent can be reached in this way. Temperature has no effect upon the mechanical behavior over the range 0-37°C. Just above this temperature, important changes take place in the mechanical properties of the tendon which may have biological significance. The application of the techniques used here to studies of connective tissue disorders is suggested. Some of the mechanical properties of tendon have been interpreted with a simple model.

ROBARD, Simon
Physical Factors in Arterial Sclerosis and Stenosis
Angiology 22:267-84, May, 1971.

ABSTRACT: (Summary) The role of physical factors on vascular structure is reviewed. Vessels are generally adapted to the mechanical stresses which they must bear. We suggest that the cells of the vascular system sense these stresses, and that they respond with specific negative feedback mechanisms which relieve them of the stress.

Roach, Margot R. and Burton, Alan C.
The Effect of Age on the Elasticity of Human Iliac Arteries
Can. J. Biochem. Physiol., Vol. 37, pp. 557-570, 1959

ABSTRACT: Autopsy specimens of iliac arteries of 63 individuals of ages between birth and 91 years have been used to measure pressure-volume curves from which elastic diagrams, i.e. tension vs. elongation, and 'elastances' were deduced. For a smaller number of specimens, the longitudinal elastance was also measured. The resistance to deformation was also derived from the amount of excess pressure outside, which was required to empty the vessel (collapse pressure). The mean curves of tension vs. stretch for the different age groups showed a remarkable increase in resistance to stretch with age for both circumferential and longitudinal elastance. The incidence of atherosclerosis, shown by the independent grading of the histologist, increased with age, but vessels not showing atherosclerosis also showed a significant increase in 'elastance' with age. The thickness of the arterial wall was increased from birth to age 20 (about 3 times) but did not change significantly thereafter. There was a significant trend for the diameter of the lumen to decrease after age 30. This was not accounted for by intimal thickening, found in some specimens of greater age. Biophysical analysis in terms of the quantity of collagen fibers present in the wall suggests that not only does the quantity of collagenous material increase with age, but more importantly, the unstretched length of these fibers decreases with age, as the

Roach, Margo R. and Burton Alan
The Effect of Age on the Elasticity of Human Iliac Arteries
Can. J. Biochem. Physiol., Vol. 37, pp. 557-570, 1959

ABSTRACT: (continued) 'slack' in them is taken up, possibly by cross-linkages or adhesions.

Roddy, William T.
The Dry Strength of Collage Fiber Aggregates: Part II. The effect of Sodium Sulfide
J. Am. Leath Chem Ass. 47: 98-110, 1952

Abstract: The dry strength of collagen fiber aggregates can be used to obtain an indication of the influence of pretanning and tanning operations. Mitton reported that tannage did not decrease the dry strength of the fiber while Compton reported that tannage decreased the dry strength. Mao and Roddy found that the dry strength of the fiber aggregates was not altered by the treatment they used. This data was in agreement with the work of Mitton on fibers teased from hide or leather and indicates that tendon fiber aggregates give results that are similar to those obtained when using hide fiber aggregates.

Additional experiments have been conducted using fiber aggregates from tendon, hide and finished leather. In using the tendon material a modification in technique was made in some cases and the changes are reported,

ROGERS, R.T.
A Phantom Material to Represent Lungs
Brit J. Radiol 43:441-4, Jul 70

Abstract: A phantom material to represent lungs radiologically is described. The material consists of an open-cell, plastic foam the density of which may be varied over a wide range by adjustment of the amount of blowing agent used. Details of the chemical procedure are given. The process is simple and requires a maximum processing temperature of only 115°C and the material can be shaped easily by the use of moulds. The effective atomic number of the plastic was calculated and measured and details are given. The unexpanded material has a density of 1.06 gcm⁻³, an effective atomic number of 7.55 and 3.42 electrons per gram. Tissue-equivalence is considered satisfactory and is compared with data for other tissue-equivalent substances. A review of other materials which have been used to simulate lungs is given.

ROBERTS, Jay, Ehrreich, S. and Levitt, B.
Some aspects of the cardiac actions of reserpine and pronethalol
Fedr.Proc.24:6, 1421-27,1965

Abstract:

ROMAN, James A., Coermann, Rolf, and Ziegenruecker, Gerd
Vibration, Buffeting and Impact Research
Aerospace Medicine, 30, 118-125, Feb. 1959

Abstract: The field of biological vibration research encompasses several areas, prominent among which is the study of the effects on animals and humans severe whole body vibration. This is a report of our studies of whole body motion. This study was conducted on rats and/or rabbits and humans. Prediction of the effects of mechanical forces upon the human body, and protection against these effects hinges largely upon our ability to describe body structures in terms which are susceptible to analyses. The chest abdomen system has been described by a stringently simplified mechanical model.

Rosenhamer, Gunnar
Influence of Increased Gravitational Stress on the Adaptation of Cardiovascular and Pulmonary Function to Exercise
Acta Physiologica Scandinavica, Vol.68, Suppl.276, 1967

Abstract:

Rupprecht, A.
Mechanochemical Study of Wet-Spun Lithium-DNA Fibers
Biopolymers, Vol. 9, pp. 825-842, 1970

Abstract: Uniform LiDNA fiber specimens of nearly 20 m length have been prepared with a wet-spinning method developed by the author. Samples immersed in the spinning bath (80% ethyl alcohol containing 0.4M LiCl) have been subjected to mechanochemical study involving stretching, relaxation, and contraction measurements. A special technique was developed to transfer the sample from the Teflon-coated cylinder used in spinning the sample column of the mechanochemical apparatus without stretching or removing the sample from the spinning bath. Force-strain curves of samples consisting of two fiber bundles showed an initial region of low slope followed by a region of high slope and a second region of low slope up to rupture. Some thicker specimens showed an aging effect which abolished the initial low-slope region and was interpreted as indicative of crystallization. Force-strain curves of two-bundle samples showed a strong influence of temperature with a complete loss of tensile strength of the LiDNA fibers in the spinning bath at about 55°C. Furthermore, samples at zero strain exhibited a contractile force when subjected to temperatures above about 40°C.; the contractile process was pronounced with samples kept above 48°C. On contraction these samples obtained a zero-force

Rupprecht, A.
Mechanochemical Study of Wet-Spun Lithium-DNA Fibers
Biopolymers, Vol. 9, pp. 825-842, 1970

Abstract (continued): length 20-30% of the original. These data are taken as evidence for a helix-to-coil transition occurring in the DNA, the low melting temperature being caused by the chemical influence of the ambient aqueous alcohol-LiCl Bath.

Rushmer, Robert F.
Pressure-Circumference Relations of Left Ventricle
Am. J. Physiol., Vol. 186, pp. 115-121, 1956

ABSTRACT: Changes in left ventricular pressure and left ventricular circumference of intact animals have been recorded simultaneously during spontaneous and induced cardiovascular responses. Mechanisms by which the left ventricular myocardium alters its 'work output' are indicated by pressure-circumference loops displayed on a cathode ray oscilloscope. Evidence is presented that the external work of the heart is not necessarily related to the diastolic dimensions in accordance with Starling's law of the heart. Instead, changes in both myocardial contractility and distensibility may play important roles in cardiac adaptation to various conditions.

Ryan, G. Anthony
A Study of Seat Belts and Injuries
17th Stapp Car Crash Conference, SAE Paper No. 730965, pp. 67-79

ABSTRACT: This paper studies the effects of wearing seat belts in severe crash impacts in Victoria, Australia. In the study, it was found that there were some injuries associated with wearing seat belts, but most of these were minor. There was an association between incorrect adjustment of seat belts and the occurrence of injury. There is a need for seat belt systems to be foolproof so that they can only be worn correctly.

Sandblom, P.H., Peterson, P., and Muren, A.
Determination of the Tensile Strength of the Healing Wound as a Clinical Test.
Acta Chir Scand. 105: 252-257, 1953

Abstract: Determination of the tensile strength of the healing wound has been adapted for clinical use in order to make possible an estimation of the patient's healing power preoperatively.

An apparatus constructed for the purpose is described and the results obtained in a limited series are presented.

SANDLER, H. and H. T. Dodge
Left Ventricular Tension and Stress in Man
Circulation Res. 13: 91-104, 1963

ABSTRACT

SASS, Donald J.

Roentgenographic Study of Relative Heart Motion During Vibration in Water-Immersed Cats

J. Biomechanics, 6:3, 219-226, 1973

Abstract: Anesthetized cats were subjected to constant-amplitude (10mm peak-to-peak) whole-body vibration in either the prone (+Gx), left lateral decubitus (+Gy), or upright positions (+Gz) to determine whether or not the heart could be forced to undergo large-amplitude translational motion relative to other intrathoracic structures and show resonance phenomena as described by others. The animals were totally immersed in water within a rigid transparent assembly to minimize vibratory motion of the chest wall and abdominal viscera which could transmit translational forces to the heart. With the animal thus tightly coupled to the vibration table motion of the heart would be due only to its inertia and to the mechanical properties of its intrathoracic supports. Radiopaque 2 mm beads were implanted in the cardiac apex, domes of the diaphragm, and in the chest wall, and the amplitude of motion of each bead was measured in serial roentgenograms as the frequency and peak acceleration of the vibration were increased stepwise from 3 Hz(+0.2g) to 20 Hz(+8g). In contrast to the results of roentgenographic studies of heart motion due to vibration reported by others in animals less well restrained, in the present study, motion of the heart due to whole-body vibration was minimal, less than 3 mm at the cardiac

Abstract (Cont'd):

apex, and resonance was not detected.

SCHOENBERG, MARK and PODOLSKY, Richard J.
Length-Force Relation of Calcium Activated Muscle Fibers
Science, Vol.176, 52-54, 7 Apr.1972

ABSTRACT: Calcium activated skinned frog muscle fibers develop a large relative force at a sarcomere length of 1.0 micrometer. Since the normal myofilament lattice is perturbed at this length, regularity of the lattice does not appear to be an important factor in the contraction mechanism.

Seller, P.C., Wright, V., Sikorski, J, Dowson, D. and Longfield, M.D.
Wear of Cartilage Bio-Engineering and Scanning Electron Microscope Study
Calc. Tiss.Res.4 (Suppl.:128 , 1970

Osteoarthritis is a degenerative joint disease, being manifested by a softening of the cartilage — chondromalacia, or a loss of ground substance, thus exposing the underlying fibrous network — fibrillation.

The authors have studied normal and osteoarthrotic cartilage using a stylus tracing method and by scanning electron microscopy.

Evidence for the existence of two types of damage will be shown, namely, fibrillation and damage whereby the surface layer has become detached, in parts, from the underlying cartilage.

An analysis of the stresses imposed on cartilage due to loading and sliding has been made and, by using information obtained from other studies, a prediction of the cause of the damage can be made.

On this basis, it is postulated that, provided the degeneration of the cartilage is not too severe, i.e., Grade 2 osteoarthritis, it may be possible to relieve some of the pain and stiffness and retard further degradation of the cartilage by lubrication with an artificial fluid.

Sellier, Von K.
Biomechanics of Trauma
Beitr Gerichtl Rfd V29, 1972 Ger.

Setnikar, I and Meschia, G.
Proprieta Elastiche Del Polmone e di Modelli Meccanici
Arch. fisiol. 52: 288-374, 1952.

SHAMARINA, N.M.
Synaptic Transmission in Different Fibers of Tonic Frog Skeletal Muscle
Fedr.25:4, T589-T594, 1966. Fedr.Proc.

Shimosato, Shiro, Herpfer, Guenther E. and Etsten, Benjamin E.
Static and Dynamic Performance of Walton Strain Gauge Arches
J. Appl. Physiol, Vol. 21, No. 6, pp. 1892-1896, 1966

ABSTRACT: The total performance characteristics of six Walton strain-gauge arches were evaluated. The effects of changes in the direction of applied force and the effects of temperature variation on static accuracy and dynamic accuracy were measured. The gauges proved to be linear in response to static loads ranging from 20 to 300 g. When the direction of force was altered by rotating a gauge in the plane including the surface of its two legs, the recorded response at an angle θ was a function of the response at 0° rotation times the cosine of the angle θ . Increases of environmental temperature produced a fall in base line in four gauges and an increase in one. The gauges showed uniform ($\pm 5\%$) response to 45 cycles/sec with a maximum frequency-phase angle lag of 1° /cycle per sec. It was concluded that the uniformity of the amplitude-frequency relationship is significantly affected by both environmental temperature and the direction of the applied force.

measurement of myocardial contractile force; temperature; direction of applied force

Sillar, P., Czoboly, E. and Kery, L.
Deformations of the Articular Cartilage of the Head of Femur and Humerus under
Mechanical Stress
Arch.orthop.Unfall-Chir. 74, 231-236,1972

Abstract: The authors have made comparative biomechanical tests with the articular surface of load bearing heads of femora and heads of humeri bearing no load. They studied the elastic and permanent deformations of the articular cartilage under mechanical stress, by using an "Instron" tensile strength machine. They conclude that at first the degree of elastic deformation exceeds that of permanent deformation but increasing the load permanent deformation becomes more prominent. The elasticity and deformative capacity of a load bearing joint is higher than that of a joint bearing no load.

SIMON, B.R., KOBAYASHI, A.S., WIEDERHIELM, C.A. and STRANDNESS, D.E.
Deformation of the Arterial Vasa Vasorum at Normal and Hypertensive Arterial
Pressure
J. Biomechanics, 6:4, 349-359, 1973

Abstract: In a previous paper, a numerical procedure (the finite element method) was presented for the structural analysis of soft biological structures possessing complex geometry and mechanical properties and undergoing large deformations. This method was used here to model a vas vasorum in an arterial cross-section subjected to physiological and hypertension mean arterial pressure levels. The deformation of the lumen of the model vas vasorum was determined for two cases: an arteriole and a venule. Estimates of hydraulic resistance and flow rate for these model vasa vasorum were calculated and compared with experimental total flow rates in the vasa vasorum reported in the literature. The results indicate that prolonged abnormally elevated arterial pressure could constrict venules of the vasa vasorum thereby impairing arterial wall tissue nourishment. If no compensatory mechanisms exist, tissue degeneration and/or atherogenesis could occur.

Simon, B.R., Kobayashi, A.S., Strandness, D.E. & Wiederhielm, C.A.
Large Deformation Analysis of the Arterial Cross Section
J. Basic Eng. Trans., ASME paper no. 70-WA/BHF-15, ASME 93.138-146. 1971

Abstract: Possible relations between arterial wall stresses and deformations and mechanisms contributing to atherosclerosis are discussed. Necessary material properties are determined experimentally and from available data in the literature by assuming the arterial response to be a static finite deformation of a thick-walled cylinder constrained in a state of plane strain and composed of an incompressible, nonlinear elastic, transversely isotropic material. Experimental justification from the literature and supporting theoretical considerations are presented for each assumption. The partial derivative of the strain energy density function

w_1 , necessary for in-plane stress calculation, is determined

to be of exponential form using in situ biaxial test results from the canine abdominal aorta. An axisymmetric numerical integration solution is developed and used as a check for finite element results. The large deformation finite element theory of Oden is modified to include aortic material nonlinearity and directional properties is used for a structural analysis of the aortic cross

Simon, B.R., Kobayashi, A.S., Strandness, D.E. & Wiederhielm, C.A.
Large Deformation Analysis of the Arterial Cross Section
J. Basic Eng. Trans. ASME 93, 138-146, 1971

Abstract continued. Results of this investigation are: (a) Fung's exponential form for the strain energy density function of soft tissues is found to be valid for the aorta in the biaxial states considered; (b) finite deformation analyses by the finite element method and numerical integration solution reveal that significant tangential stress gradients are present in arteries commonly assumed to be "thin-walled" tubes using linear theory.

Simon, B. R., Kobayashi, A. S., Strandness, D. E., and Wiederhielm, C. A.
Mechanical Response of an Arterial Cross Section
Presented at the 4th Symposium on Composite Materials, International, Tokyo,
Japan, August 23-25, 1971

ABSTRACT: A brief discussion of a theoretical procedure based on finite elasticity and a numerical procedure based on finite element analysis which can be used effectively to analyze the structural response of an arterial cross section are given. The developed procedure can also be applied in analyzing other problems involving finite elasticity such as a plane structure composed of Mooney material subjected to plane strain deformation. The procedure is then used to predict the deformation of vasa vasorum in an arterial wall and subjected to normal and hypertensive lumen pressure.

SIMON, Bruce R., Kobayashi, A.S., Strandness, D.E. and Wiederhielm, C.A.

Reevaluation of Arterial Constitutive Relations - A Finite-deformation approach
Circulation Research, Vol. XXX, 491-500, Apr. 1972

Abstract: The purpose of this investigation was to use the finite-deformation theory of elasticity to interpret pressure-diameter data for in situ canine aortas and other arterial response data reported in the literature. A meaningful mechanical property for arterial tissue was identified as $\partial W_1 / \partial I_1$, the partial derivative of the strain-energy density function with respect to the first strain invariant. An exponential function was found to characterize the mechanical property $\partial W_1 / \partial I_1$ for all arteries considered. Thin-walled tube stress approximations were found to result in inaccurate values for arterial stresses and incremental elastic mechanical properties. Wave speeds calculated using $\partial W_1 / \partial I_1$ for these arterial tissues agreed well with experimental measurements of wave speeds reported in the literature. Elevated values for strain-energy density were found in the inner arterial tissue layers. These high value for strain energy may contribute to atherogenesis in relatively straight arteries (e.g., the abdominal aorta) subjected to hypertension.

SIMON, William H.

Scale Effects in Animal Joints, II. Thickness and Elasticity in the Deformability of Articular Cartilage

Arthritis and Rheumatism, 14:4, 493-502, 1971

Abstract: The deformability of articular cartilage was studied in vitro in 64 bovine, canine and human joints with an indenting compressometer. Two factors contributed to the depth of the indentation: the thickness of the cartilage and its intrinsic elasticity. Within a given species, there was in general a consistent curvilinear relationship between the magnitude of the deformation and the thickness of the articular cartilage under a given level of static loading (usually 106 pounds per square inch). Although it was not possible to establish a satisfactory Young's modulus, differences in intrinsic elasticity were demonstrated by variations in the indentations produced in cartilages of comparable thickness, when subjected to the same compressive stress. These species differences corresponded roughly to variations in the water content of the articular cartilages (bovine, 87; canine, 80; human, 79%). The data are consistent with the hypothesis that deformability of articular cartilage serves to increase the congruence to joints and thereby reduce the stresses on their surfaces. A frequently postulated senescent thinning of articular cartilage received no support from measurements of 28 intact human patellas through the fifth decade of life.

SIMON, William H.

Wear Properties of Articular Cartilage in Vitro

J. of Biomechanics, 4:5, 379-389, 1971.

Abstract: The wear of articular cartilage (human patellar and canine humeral head) was studied in vitro with a rotating steel abrader. With saline lubrication at 37°C, the cartilage was more resistant to abrasion than neoprene rubber (Shore durometer 50), oak and balsa wood, but less than a series of plastics (nylon, high and low density polyethylenes, polycarbonate and polytetrafluoroethylene). Synovial fluid had a distinct wear-protecting effect; this was eliminated by digestion of the mucin with trypsin but not by testicular hyaluronidase. The viscosity of the synovial fluid therefore did not account for its protective effect. Fibrillated cartilage was abraded more readily than intact tissue, but age otherwise had no effect. It is concluded that surface friction as well as intrinsic properties of the cartilage (strength and stiffness) are major determinants of its wear properties.

Snyder, Roger W.
Large Deformation of Isotropic Biological Tissue
J. Biomechanics, 5:6, 601-606, 1972

Abstract: The requirements for the development of a general potential function describing the behavior of homogeneous, isotropic biological tissue are discussed and such a function is proposed. It is shown that this function yields both tensile and torsional results compatible with existing data.

Snyder, M.F. and Rideout, V.C.
Computer Modeling of the Human Systemic Arterial Tree
Jr. of Biomechanics, Vol.1 No.4, 341-353, 1968.

Abstract: A model of the human systemic arterial tree has been devised, based on a lumped-parameter-circuit approximate form. This model has been set up and studied on an analog computer. A feature of this simulation is the division of the arterial system into sections whose lengths are inversely proportional (approximately) to their cross-sectional area--or what is termed 'equal-volume' modeling.

Great care was exercised in the determination of the model parameters, using expressions for these parameters from a recent paper by Rideout and Dick on fluid flow in distensible tubes, with numerical values based on measurements reported in the medical literature.

The simulated pressure and flow waveforms obtained with the model compare favorably with data recorded from the normal adult human, and exhibit such well-known features as distal delay and peaking of pressure pulses. The aortic input impedance vs. frequency curve checks well against measurements on the human. The model also provides a simple means for determination of cardiac output, cardiac work and cardiac power under various assumed conditions such as variation of heart rate.

SNYDER, Richard G.
Impact Injury Tolerances of Infants and Children in Free-Fall
Proc. 13th Annual Conf. American Assoc. for Auto. Med., 131-164, Oct. 1969

Abstract: Accidental trauma received in free-fall impacts by infants and children offer one means of assessing the full range of tolerance to abrupt deceleration unavailable by either clinical, experimental, or modeling studies alone; providing each case is intensively investigated for both physical factors and resulting medical sequelae.

Sobin, Sidney S., Fung, Y. C., Tremer, Herta M., and Rosenquist, Thomas H.
Elasticity of the Pulmonary Alveolar Microvascular Sheet in the Cat
Circulation Research, Vol. 30, pp. 440-450, 1972

ABSTRACT: The pulmonary interalveolar capillary bed of the cat has previously been shown to be consistent with a sheet-like endothelium-lined space bridged by avascular endothelium-covered posts. This was termed the sheet-flow model, and blood flow through that space is termed sheet flow. The initial formulation of the sheet-flow theory and model required that sheet thickness be the independent variable. Sheet thickness (h) was measured in vertical and horizontal silicone-elastometer-perfused cat lungs over the transmural (alveolar-capillary) pressure (Δp) range of 6.3 to 27 cm H₂O. A plot of h vs Δp for 2753 individual measurements is linear over the measured pressure range. The regression line is described by $h = 4.28 + 0.2191 \Delta p$. Sheet thickness of 4.28 μ at zero pressure is an extrapolated value. The value 0.2191 μ /cm H₂O is the compliance coefficient (α) of the pulmonary capillary bed. Electron microscopic studies demonstrated that the capillary posts have a highly organized internal structure with abundant collagen and an elastin or elastinlike core. Collagen fibers originate from the alveolar-capillary basement membrane, emerge in a herringbone pattern and sweep toward the center of the post in a helical array around the elastinlike amorphous and fibrillar core. The unusual compliance of the microvascular blood vessels in the lung can be correlated with the architectural organization within the posts.

Sonnenblick, Edmund H.
Correlation of Myocardial Ultrastructure and Function
Circulation, Volume 38, pp. 29-44, 1968

ABSTRACT: The electron microscopic structure of heart muscle and the ultrastructural basis of cardiac contraction have been reviewed. The relation between muscle length and developed tension has been explained in terms of the structure of the sarcomere, which is the basis unit of contraction. Using the derived length-tension curve of the sarcomere, developed tension has been attributed to the overlap of thick and thin filaments within the sarcomere, lending support to the "sliding" mechanism in heart muscle.

It has been shown that initial sarcomere length is a function of ventricular filling pressure and that this relation explains the normal limits of the heart as a pump, including: (1) the Starling mechanism whereby increased diastolic volume (EDV) engenders an increased stroke volume (SV), (2) the upper limits to ventricular filling pressure and volume and (3) the normal range to the ventricular ejection fraction (SV/EDV). Further, ultrastructure helps to define the processes which occur with acute and chronic ventricular dilatation. In this regard, the importance of sarcomere dispersion and "fiber slippage," which may lead to disordered ventricular function, have been discussed.

Sonnenblick, Edmund H., Parmley, W.W. and Urschel, Charles W.
The Contractile State of the Heart as Expressed by Force-Velocity Relations
The Am. Jr. of Cardiology, Vol. 23, 488-503, 1969.

Abstract: This is a theoretical analysis of the contractile state of the heart in terms of bone mechanics apart from the function of the ventricle as a pump. The authors have attempted to define the principles of muscle mechanics in isolated heart muscle upon which the measurement of cardiac contractibility in the intact heart can be based.

A consideration of the heart as a muscle rather than a pump offers insights into the mechanisms which control ventricular contractility and function. These concepts are not only of use in understanding normal cardiac physiology but provide insight into ventricular performance with either abnormal overloads or failure. Thus, the principles of muscle mechanics offer a sensitive and reproducible method for analysis of cardiac function which can ultimately be integrated into over-all circulatory systems.

The analysis of isovolumic systole provides an estimate of the intrinsic speed of myocardial contraction (V_{max}) and thus a measure of contractility. Although the extension of these V_{max} methods to clinical problems is as yet embryonic, these principles and methods do provide a rational framework for such studies.

SONNENBLICK, Edmund H.
Determinants of Active State in Heart Muscle: force, velocity, instantaneous
muscle length, time.
Fedn.Proc. 24, 1396-1409., 1965.

Abstract:

SONNENBLICK, Edmund H.
Force-Velocity Relations in Mammalian Heart Muscle
Am. J. Physiol., 202(5): 931-939, 1962

ABSTRACT: Force-velocity relations were studied in the cat papillary muscle. As with skeletal muscle, a characteristic relation has been demonstrated between the velocity of shortening (V) and the force developed (P_0). Two generalities have been shown to pertain. First, increasing initial muscle length increases the maximal developed force (P_0) without a change in the maximal velocity of shortening (V_{max}). Secondly, at any one muscle length, changes in frequency of contraction and chemical environment (increased calcium and norepinephrine) increase V_{max} with a variable change in P_0 . Changes in V_{max} thus help to characterize an inotropic intervention (altered contractility). Work and power, at any one muscle length, are functions of afterload, with maxima when the load is approximately 40% of isometric tension. With increasing initial muscle length, the work and power at any one afterload as well as the maximal work and power of the muscle are both increased. At constant initial length, positive inotropic interventions (increased frequency, increased calcium, and norepinephrine) increase the work at any one afterload as well as shift the maximal work potential to a higher afterload. Work performance

SONNENBLICK, Edmund H.
Force-Velocity Relations in Mammalian Heart Muscle
Am. J. Physiol., 202(5): 931-939, 1962

ABSTRACT (continued): thus depends on muscle length, the prevailing force-velocity curve, and the afterload at which the muscle is operating.

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 R25 R26 R27 R28 R29 R30 R31 R32 R33 R34 R35 R36 R37 R38 R39 R40 R41 R42 R43 R44 R45 R46 R47 R48 R49 R50 R51 R52 R53 R54 R55 R56 R57 R58 R59 R60 R61 R62 R63 R64 R65 R66 R67 R68 R69 R70 R71 R72 R73 R74 R75 R76 R77 R78 R79 R80 R81 R82 R83 R84 R85 R86 R87 R88 R89 R90 R91 R92 R93 R94 R95 R96 R97 R98 R99 R100

Sonnenblick, E.H.
Implications of Muscle Mechanics in the Heart
Fedr. Proc., 21:6,975-990, 1962.

35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 R25 R26 R27 R28 R29 R30 R31 R32 R33 R34 R35 R36 R37 R38 R39 R40 R41 R42 R43 R44 R45 R46 R47 R48 R49 R50 R51 R52 R53 R54 R55 R56 R57 R58 R59 R60 R61 R62 R63 R64 R65 R66 R67 R68 R69 R70 R71 R72 R73 R74 R75 R76 R77 R78 R79 R80 R81 R82 R83 R84 R85 R86 R87 R88 R89 R90 R91 R92 R93 R94 R95 R96 R97 R98 R99 R100

Sonnenblick, Edmund H., M.D.
Instantaneous Force-Velocity-Length Determinants in the Contraction of Heart
Muscle
Circulation Research, Vol. XVI, pp. 441-451, 1965

ABSTRACT: The purpose of this report is to present data obtained from the cat papillary muscle which supports the view that the force-velocity relation is of value not only in describing shortening of heart muscle at a given initial muscle length, but by applying the force-velocity relation appropriate to a changing muscle length at any instant during contraction, this relation may be shown to pertain throughout muscle shortening. Thus, in heart muscle, the course of contraction has been found to be uniquely described by the instantaneous relations of force, velocity, and muscle length during shortening. This application of instantaneous force-velocity-length relations allows for a more generalized analysis of contraction in heart muscle than is afforded by the use of initial muscle length relative to force and velocity alone.

SONNENBLICK, Edmund H.

Series Elastic and Contractile Element Interactions in Generation of Myocardial Force. Effects of Changing Muscle Length, Norepinephrine and Strophanthidin
Fedn. Proc. 23, p.118, Abstract #104

Abstract only no paper: Using the cat papillary muscle, active cardiac muscle has been analyzed in terms of a contractile element (CE) in series with an elastic element (SE) after Hill. Force (P) and displacement (L) were recorded. The CE force-velocity and SE length-extension curves were evaluated under varying conditions of length and contractility. The modulus of elasticity (stiffness) of the SE (dp/dl) was obtained by measuring the instantaneous rate of force development (dp/dt) and velocity of isotonic shortening (dl/dt) as functions of load (P), since $dp/dl = \frac{dp/dt}{dl/dt}$ at P. The dp/dl was found a linear function of load ($dp/dl =$

$k \cdot P$), where $k = 3.2 \pm .4$. Thus, the load-extension curve of the SE is exponential. The SE was also measured by integrating dl/dt as a function of time after stimulation and by isometric quick release. This dl/dt -time relation is independent of muscle length and unique for a given state of contractility. During isometric force development, the SE is extended 7 to 9% of over-all muscle length with approximately 600 g/cm^2 tension. The modulus of elasticity of the SE, 4 to 5 times that of frog sartorius, is independent of changing muscle length and inotropic agents, norepinephrine or strophanthidin. These results allow

Abstract (Cont'd):

calculation of CE work in isometric contraction and analysis of myocardial force generation.

SOONG, T. T. and HUANG, W. N.

A Stochastic Model for Biological Tissue Elasticity in Simple Elongation
J. Biomechanics, 6:5, 451-458, 1973

Abstract: A mathematical model is described which predicts the effective tangent moduli of biological tissues at each deformed state, which accounts for the contributions of two major load-bearing components--collagen and elastin. The problem is studied from a stochastic point of view based upon the theory of composite materials. It is shown that a simple stochastic model is possible and it can be expressed simply in terms of the volume fractions of collagen and elastin fibers and of the 'collagen arrival density.' The model is then used in the discussion of stress-strain relationships of the alveolar wall in simple elongation.

Spitzka, Anthony

A note on the true weight of the lungs.
Amer.J. Anat.3:V, 1904

In six criminals executed by electricity, the weight of the lungs was found to be much below the averages generally given in the text-books. The differences due to two peculiar conditions attending this mode of death, namely, non-coagulation of the blood and contraction of the vessel walls. With this the sudden closure of the glottis, the contraction of the thoracic cavity, and other phenomena all help to bring about a nearly bloodless condition of the lungs, so that we are enabled to ascertain the actual weight of lung tissue only, not, as in ordinary death, of a variable amount of blood and serum as well.

The table follows:

	Age.	Grams.		Ounces	
		L	R	L	R
Czolgosz	29	220	241	7.75	8.5
Turckofski	41	230	260	8.5	9.5
W. V. W.....	27	320	356	11.3	12.5
B. V. W.....	23	280	310	9.9	10.9
Gamari	31	216	248	7.6	8.7
Ennis	30	...	269	..	9.5

The weight of the lungs themselves then more nearly approximate 7 and 8 ounces respectively than 20 and 22 ounces as usually given.

Stacy, R.W., Zarzman, M., Randall, J. and Eberstein, A.
Time course of stress relaxation in isolated arterial segments.
Am. J. Physiol. 177: 299-302, 1954

ABSTRACT: Experiments have been performed to study the time course of stress relaxation in isolated arterial segments, and to determine the arterial structures involved in this phenomenon. A comparison of stress relaxation in carotid arteries (containing considerable parallel elastic elements) and umbilical arteries (nearly all smooth muscle) indicates that the stress relaxation is a phenomenon associated with the smooth muscle component of the artery.

Stress relaxation was shown to be nonexponential. A successful plot was obtained when pressure (or wall tension) was plotted vs. logarithm of time. On such a plot, the time course followed a straight line relationship over two or more log cycles of time. The stress relaxation was about 80% complete within 10 seconds.

The time course curves are discussed in the light of a theory propounded for the explanation of similar curves in natural and artificial materials. Although such theories (based on a box-like distribution of relaxation times) fit the data reasonably well, it is considered that a more natural theory would be advisable.

Sten-Knudsen, Ove
Torsional Elasticity of the Isolated Cross Striated Muscle Fibre
Acta Physiol.Scand. 28: Suppl. 104, 1953

Stalnaker, R. L., V. L. Roberts and J. H. McElhanev
Side Impact Tolerance to Blunt Trauma
17th Stapp Car Crash Conference, Paper No. SAE 730979, pp. 377-408

ABSTRACT: The object of this research program has been to extend the scope of earlier work to include long-duration head impacts and to develop new scaling relationships to allow extrapolation of impact data from infrahuman primates to living humans.

A series of living primate side impacts to the head and torso was conducted in parallel with a series of impacts to human cadavers. Dimensional analysis techniques were employed to estimate in vivo human tolerance to side injury.

The threshold of closed brain injury to humans was found to be 76 g for a pulse duration of 20 ms and an impact velocity of 43 ft/s (13.2 m/s). The maximum tolerable penetration to the chest was found to be 2.65 in (6.72 cm) for both the left and right sides.

Scaling of abdominal injuries to humans was accomplished by employing a factor that relates impact contact area, animal mass, impact force, and pulse duration to injury severity. The maximum tolerable contact pressure to the upper abdomen of a human was found to be 32 lbf/in² (220 kPa).

STEPHENS, Frederick O., Hunt, Thomas K. and Dunphy, J. Englebert
Study of Traditional Methods of Care on the Tensile Strength of Skin Wounds in Rats
Am J Surg 122:78-80 Jul 1971

Abstract: The earliest records of wound closure by the use of surgical sutures and adhesive tapes are found in ancient Egyptian writings dating from 3000 B.C. Today an experimental study in rats indicates that sutures, dressings, and immobilization impair tensile strength in primarily closed skin wounds. Some practical applications of these observations, in the care of wounds in man, are discussed.

STERN, Jack T., Jr.
Investigations Concerning the Theory of 'Spurt' and 'Shunt' Muscles
J. of Biomechanics 4:5, 437-453, 1971

Abstract: The object of this study is to examine in some detail the theory of 'spurt' and 'shunt' muscles as proposed by MacConaill (1946,1949) and MacConaill and Basmajian (1969). The prime application of the theory is to the flexors of the forearm, and the greater portion of this analysis concerns these muscles. The centripetal force required in rapid movements of the forearm is calculated. An electromyographic experiment demonstrated that the brachioradialis is not active in resisting a force of this magnitude tending to separate the bones forming the elbow joint. The theoretical ability of the brachioradialis to supply the required force is then determined. It is shown that, of the various muscles able to provide shunt force, the brachioradialis is not the best. Finally, the application of the theory of 'spurt' and 'shunt' muscles to other anatomical regions is analyzed and found to be unsupported by evidence.

Streeter, Daniel D., Spotnitz, Henry M., Patel, Dali P., Ross, John, Sonnenblick, Edmund M.
Fiber Orientation in the Canine Left Ventricle during Diastole and Systole
Circulation Research, Vol. 24, pp. 339-347, 1969

ABSTRACT: Fiber orientation across the left ventricular myocardial wall has been studied. Specimens were obtained from 18 dog hearts rapidly fixed in situ in systole, in diastole, and in dilated diastole. Fiber orientation was determined across the free wall at eight sites from a T-shaped specimen by measurements with light microscopy in serial paraffin sections. Results indicate: (1) The wall has a well-ordered distribution of fiber angles varying from about 60° (from the circumferential direction) at the inner surface to about -60° on the outer surface. The greatest change in angle with respect to wall thickness occurs at the two surfaces (endocardial and epicardial). (2) Fiber angles did not change significantly during the transition from diastole to systole, despite a 28% increase in wall thickness (except in the papillary muscle root region). (3) The proportion of fibers lying in the sector of fiber angles oriented circumferentially ($0 \pm 22.5^\circ$) to those oriented longitudinally (67.5 to 90° and -67.5 to -90°) is approximately 10:1. This ratio increases toward the base and diminishes toward the apex of the left ventricle. (4) All fiber angles in the lateral wall of hearts in systole increased through the wall by approximately 7° near the base and 19° near the apex relative to their counterparts in diastole, indicating bending or torsion of the left ventricle during contraction.

STREETER, Daniel D., Vaishnav, Ramesh N., Patel, Dali J., Spotnitz, Henry M. Ross, John and Sonnenblick, Edmund H.

Stress Distribution in the Canine Left Ventricle During Diastole and Systole
Biophys.J., 10:345:63, Apr.1970

Abstract: A model is proposed for stress analysis of the left ventricular wall (LV wall) based on the realistic assumption that the myocardium is essentially composed of fiber elements which carry only axial tension and vary in orientation through the wall. Stress analysis based on such a model requires an extensive study of muscle fiber orientation and curvature through the myocardium.

Accordingly, the principal curvatures were studied at a local site near the equator in ten dog hearts rapidly fixed in situ at end diastole and end systole; the fiber orientation for these hearts had already been established in a previous study.

STROMBERG, Don D. and Wiederhielm, Curt A.

Viscoelastic Description of a Collagenous Tissue in Simple Elongation
J. Appl. Physiol. 26(6), 857-862, 1969

Abstract: Primary tendon bundles about 100 μ in diameter and 3 cm long from tail tendons of young adult male mice were subjected to step loads and strain was measured with a differential transformer. Stress was computed from the applied load and initial cross section. After attachment with Eastman 910 adhesive, tendon bundles were immersed in a temperature controlled (37 C), Tris-buffered (pH 7.1), Ringer bath. Instantaneous elastic response was less than 2% of the initial length. Creep over several hundred seconds was less than 0.1%. Linearity of the plot of log stress vs. instantaneous strain over three decades of applied stress implies a simple linear relationship of the tangent modulus to applied stress, as outlined by Fung, 1967. Data in the literature suggest that Fung's modulus for a collagenous tissue is related to the organization of collagen fibrils in that tissue. Network analysis of the stress distribution among fibrils may provide a means for relating properties of fibrillar elements such as primary tendon bundles to behavior of whole collagenous tissues.

series elastic element of primary tendon bundle; fibrillar recruitment; macromolecular recruitment; network analysis; creep of primary tendon bundle; creep of collagenous tissues; viscoelasticity of connective tissue

Sugihara, T., Hildebrandt, J, and Martin, C. J.
Viscoelastic Properties of Alveolar Wall
J. Appl. Physiol., Vol. 33, No. 1, pp. 93-98, 1972

ABSTRACT: Viscoelastic properties of human lung tissue were estimated using: 1) the hysteresis ratio (HR) or the ratio of the area of hysteresis to the area beneath the extension curve measured from a length-tension curve obtained by methods previously reported (Fukaya, et. al., J. Appl. Physiol. 25:689-695, 1968), and 2) stress relaxation (SR), i.e., the percentage of stress decrement between the peak stress and that present 5 and 30 sec after a sudden stretch. HR and SR are greater on the first stretch than in subsequent stretches (adapted). Both HR and SR in the adapted state are relatively unchanged over a wide range of strain covering the whole physiological range. Neither age, sex, nor disease-related changes in HR or SR were observed. Biological materials may show deformation of the loading curve with diminished peak force on subsequent retentions without alteration of the resting length (permanent set).

viscoelasticity; hysteresis; stress relaxation; adapted state; permanent deformation; length-tension curves

TKACZUK, Henryk
Tensile Properties of Human Lumbar Longitudinal Ligaments
Acta. Orthop Scand. Suppl. 115, 69 p. 1968

TAYLOR, M.G.

An Experimental Determination of the Propagation of Fluid Oscillations in a tube with a Visco-elastic Wall; together with an Analysis of the Characteristics Required in an Eletrical Analogue
Physics Med. Biol. 4: 63-82, 1959.

Abstract:

TAKISHIMA, Tamotsu and Mead, Jere
Tests of a Model of Pulmonary Elasticity
J. Appl. Physiol. 33(5), 576-581, 1972.

Abstract: Mead et al (J. Appl. Physiol. 28:596-608, 1972) have observed that regions in lungs which are restricted in their expansion should be subjected to increased expanding stresses normal to the external surfaces of the region in proportion to A_0/A , where A_0 is the external surface area the region would have attained if the lung had expanded homogeneously, and A its area when restricted. To test this prediction, we used two approaches. First we measured volume-pressure relationships of lobules of goat and cow lungs by wedging catheters in airways and measuring pressures within as we changed lobular volumes at different fixed transpulmonary pressures. To estimate changes in lobular surface area, we assumed $A_{lob} = V_{lob}^{2/3}$. Second, we glued discs to the pleural surface of excised dog lobes in the unexpanded state and then expanded the lobes. The discs were pulled slightly into the substance of the lobe, and we measured the force necessary to reestablish the normal surface configuration and compared this force with the one predicted from the degree of restriction. We found that the observed changes somewhat exceeded the predictions in the first instance, but scattered around them in the second, and we attempt to interpret these differences.

ABSTRACT (Cont'd):

mechanics of breathing; respiratory mechanics; tissue force; pleural surface; lobular pressure and volume; lung elasticity

TAYLOR, M.G.

The Input Impedance of an Assembly of Randomly Branching Elastic Tubes
Biophys. J. 6, 29-51, 1966

Abstract: Computations are presented of the input impedance of assemblies of randomly bifurcating elastic tubes, as a generalized model of the arterial system. Account is taken of the viscosity of the fluid, the viscoelastic properties of the walls, the variation of elasticity in the different orders of branches, and the variation in cross-sectional area at the bifurcations. The results show that the distributed and scattered nature of the terminations of such an assembly greatly reduces the influence of reflections upon the behavior of the input impedance. The variation of impedance with frequency is very similar in form to that found in animal experiments for the input impedance of the aorta. The architecture of the arterial system may thus be considered to play an important part in determining the favorably low impedance presented to the heart by the aorta.

Theis, E.R. and Steinhardt, R.G., Jr.
Protein Axial Movement Studies
II. Data Obtained Through Use of Dynamic and Strain Gage Shrinkage Meters
J. Am. Leather Chems. Assoc. 45:591-610, 1950.

ABSTRACT:

Tickner, E. Glenn and Sacks, Alvin H.
A Theory for the Static Elastic Behavior of Blood Vessels
Biorheology, Vol. 4, pp. 151-168, 1967

ABSTRACT: A theory is presented for determining all of the parameters required to describe the elastic behavior of blood vessels under any static loading. Selected specimens of fresh excised human and canine arteries have been tested in the laboratory and their elastic behavior determined by the theory presented.

The results indicate that for all specimens tested, the arterial wall behaves as a nonlinear homogeneous anisotropic compressible material and can be described by six elastic constants for each level of strain. Both the circumferential and the axial stiffness are found to increase with internal pressure, and both approach the value for the collagenous fibres at very high internal pressure and axial weight, respectively. The radial stiffness is the smallest of the three and is found to be essentially independent of either internal pressure or axial loading.

Tipton, Charles, M., James Stanley L., Mergner, Wolfgang and Tcheng, Tse-Kia
Influence of Exercise on Strength of Medial Collateral Knee Ligaments of Dogs
Am. J. of Physiol., Vol. 218, No. 3, 1970. pp. 894-901

ABSTRACT: Strength measures were recorded from intact and repaired ligaments obtained from animals assigned to groups designated as nontrained or controls, trained, immobilized, sham operated, repaired, reattached, and combinations thereof. The experimental period for most groups was 6 weeks. The strength results from the animals with intact ligaments showed that the most inactive animals (leg immobilized) had the lowest values whereas the most active animals (trained) had the highest values. This same trend occurred with the animals with the repaired ligaments but their absolute strength measures were markedly lower. Hydroxyproline concentrations of intact ligaments from trained, nontrained, and immobilized dogs showed that the animals in the trained group had significantly higher collagen contents than the animals from the other groups. Histological measurements of fiber bundles demonstrated that the trained group had the largest diameters and that the immobilized group had the smallest diameters. Other than the fact that increased periods of tension were experienced by the ligaments the mechanism(s) responsible for these changes are obscure.

Tipton, C. M., Schild, R. J., and Tomanek, R. J.
Influence of Physical Activity on the Strength of Knee Ligaments in Rats
Am. J. Physiol. Vol. 212, No. 4, pp. 783-787, 1967

ABSTRACT: The relationship between physical activity and the strength of the medial collateral ligament was investigated with normal and hypophysectomized rats. Animals were assigned to groups designated as controls, single exercise period, repeated exercise periods (trained), trained-detrained, immobilized, tenectomized, hypophysectomized-trained, and hypophysectomized-trained plus Growth hormone. Results were expressed in units of separation force (SF), separation force-to-body weight ratio (SFR), and centimeters of ligamentous elongation. The findings indicated that a single exercise bout had no appreciable influence on SF results, but that repeated periods of exercise will significantly strengthen the knee ligaments. The same tendency prevailed with the detrained group. Ligaments from tenectomized and immobilized animals had SF values lower than their controls; however, only the latter finding had statistical significance. Force-elongation curves showed that the normal trained animals had more elongation at a given force than nontrained animals. It was postulated that the changes associated with training were occurring at the attachment site between the ligament and the bone.

Tipton, Charles M., Tchong, Tse-Kia and Mergner, Wolfgang
Ligamentous Strength Measurements from Hypophysectomized Rats
Am. Jr. of Physiology, Vol. 221, No. 4, 1144-1150, Oct. 1971

Abstract: Medial collateral knee ligamentous strength measures were obtained from hypophysectomized ($n = 342$) rats assigned to various (21) experimental groups concerned with the influence of physical activity, surgical repair, and/or exogenous hormones. Results indicated that increased activity (training) will increase the strength of intact or repaired preparations, whereas inactivity (immobilization) with or without surgical repair will decrease this measure. For all groups, the lowest strength values were obtained from animals with repaired and immobilized ligaments. Daily injections for 6 weeks of either ICSH, TSH, or testosterone were associated with stronger ligaments in the intact preparations. ICSH and testosterone also enhanced the strength measures from repaired ligaments, whereas ACTH, TSH, orthyroxine injections were associated with weaker ligaments. Surprisingly, the influence of GH was apparent only in the histological measurements. When the thickness of the fiber bundles was recorded, the repaired and immobilized ligaments had the lowest values. Force-elongation results for intact and repaired preparations were evaluated, and marked elongation pattern were observed for the immobilized, repaired, and the repaired-plus-ACTH groups. It was concluded that mechanical stresses can act independently of pituitary influence to modify ligamentous strength.

Torri, G., Damia, G. and Ravagnan R.
Analisi grafica della meccanica toracica durante respirazione controllata
Clinica Chirurgica dell'Universita di Milano
Minerva Anestesiologica, pp557-59, 1965

TOWNSEND, M.A.

A Relationship between Muscle Performance when Producing and Absorbing Work
J. Biomechanics, 6:3, 261-266, 1973

Abstract: A relationship between muscle efficiency when producing work and energy expenditure characteristics when contracted muscle is stretched by an external load (negative work) is developed based upon the energies involved in these activities. By considering the system performance in its normal and energized reverse operation (negative work) modes, a theoretical maximum muscle efficiency of 50 per cent is indicated. The experimental results of A.V. Hill and others are used in guiding the development. A general approach is used.

Trollope, M.L., R.L. Stalnaker, Mc Elhaney, J.H. & Frey, C.
Injury Tolerance Levels in Blunt Abdominal Trauma
Proc. International Conference on the Biokinetics of Impacts, Amsterdam, Jun 26-27,
1973

There is a positive correlation between the degree of abdominal injury produced in blunt abdominal trauma and the force, surface area, animal mass and duration of impact in pigs and three species of primates. Only a small percent of the force applied to the abdomen of an experimental animal in these experiments, and presumably to a human in an auto accident, is actually transmitted directly to the liver. When the location of impact and the mass of the subject are taken into account, a composite function, $ESI \text{ Log ft}^2/m a$, relates well to the degree of injury produced in an impact. This formula might be expected to apply to man for the following reasons: 1) the visceral weights of the pigs approximate those of man, 2) the other species studied were primates, and 3) the mass of the subject was taken into account in the formula.

Truong, X. T., Walker, S. M. and Wall, B. J.
The Use of Velocity of Elastic Waves in the Determination of Elastic Constants in Frog Muscle
The Physiologist, Vol. 6 p. 289, 1963

ABSTRACT: Measurements of velocity of propagation of elastic waves were used to study the elasticity of leg muscles in the frog under various conditions of stretch and contraction. The isolated muscle was mounted on an isometric myograph to allow the recording of resting and isometric tensions. An electrodynamic transducer was used to produce low frequency mechanical pulses at one end of the muscle and a piezoelectric transducer was used to pick up the propagated electric waves at the other end. Both sending and receiving signals were displayed on a double-beam oscilloscope and the traveling time measured. Measurements were made in the resting and contracting states at various muscle lengths from 80% to 130% of resting length. The linear longitudinal moduli of elasticity were calculated from the velocity equation. Comparison with constants derived from the length-tension data showed good correlations.

Truong, Xuan T.
Visco-Elastic Propagation of Longitudinal Waves in Skeletal Muscle
J. Biomechanics, 5:1, 1-10, 1972

Abstract: A method for obtaining the relaxation spectrum of isolated frog skeletal muscle from measurements of phase velocity and attenuation of longitudinal waves, was derived from conventional linear theory of visco-elastic wave propagation. The experimental method for measuring wave velocity and attenuation is described. An approximation method for obtaining the relaxation spectrum from wave velocity alone was developed from theoretical considerations. Experimental results from both the conventional and the approximation methods are presented and compared. Wave propagation measurements appeared to be of value in visco-elastic studies of skeletal muscle, especially when the use of other traditional methods is not practical.

TUCKER, William K., Janicki, Joseph S., Plowman, Fred and Patel, Dali J.
A Device to Test Mechanical Properties of Tissues and Transducers
J. Appl. Physiol. 26(5): 656-658, 1969.

Abstract: A device designed to determine the dynamic mechanical properties of tissues and various transducers is described. Elastic properties of polyurethane, Hevea rubber, and descending thoracic aorta were evaluated using this device. Results agreed with 6% with those obtained independently using other methods.

mechanical impedance; dynamic elastic modulus

Turgeon, Robert and Webb, J.A.
Growth Inhibition by Mechanical Stress
Science 174:961-2, 26 Nov.71

TURNER, James M., Mead, Jere and Wohl, Mary Ellen
Elasticity of Human Lungs in Relation to Age
J. Appl. Physiol. 25(6), 664-671, 1968

Abstract: We reinvestigated the relationship between age and lung elasticity with an improved technique for measuring esophageal pressure and found reductions of static recoil pressures throughout the age range of 20 - 60 years. We also found an increase in functional residual capacity/total lung capacity (FRC/TLC) ratio with increasing age, which we believe can be accounted for almost entirely by the changes in lung elasticity. We discuss the possibility that the changes in lung elasticity are primarily the result of alterations in the contribution of elastin to the overall volume-pressure behavior of lungs.

pulmonary mechanics; static recoil of lungs; volume-pressure behavior of lungs; aging

Ulrick, William C.
Characteristic force-velocity equation of rat heart muscle.
Am. J. Physiol., Vol. 206, No. 6, pp. 1285-1290, 1964

ABSTRACT: Shortening velocities were measured for in vitro rat left ventricular trabeculae carneaee preparations stimulated to contract isotonically with different loads, and at temperatures from 20 C to 35 C. The data obtained were used to derive the heat of shortening constant, a , the velocity constant, b , and the maximum isometric tetanic tension term, P_0 , of the characteristic force-velocity equation. The study showed that the derived constants a and P_0 statistically did not vary with temperature, but that the velocity constant b increased linearly as temperature increased. Differences between cardiac and skeletal muscle are discussed.

VAISHNAV, Ramesh N., Young, John T. Janicki, Joseph S. and Patel, Dali J.
Nonlinear Anisotropic Elastic Properties of the Canine Aorta
Biophysical Journal Vol.12, 1008-1027, 1972

Abstract: A nonlinear theory of large elastic deformations of the aortic tissue has been developed. The wall tissue has been considered to be incompressible and curvilinearly orthotropic. The strain energy density function for the tissue is expressed as a polynomial in the circumferential and longitudinal Green-St. Venant strains. Limiting application to states of strains wherein the geometric axes are the principal axes and truncating the energy expression to include terms with highest degrees 2,3, and 4, three expressions with 3, 7, and 12 constitutive constants are obtained. Results of application of these expressions to data from three series of in vitro and in vivo experiments involving 31 dogs have been presented. Whereas all the three expressions are found to be applicable to various degrees, the third-degree expression for the strain energy density function with seven constitutive constants is particularly recommended for general use.

Van Kirk, D. J. and Lange, W. A.
A Detailed Injury Scale for Accident Investigation
12th Stapp Car Crash Conf. 1968 SAE 680781

Abstract: A program of investigating frontal force accidents has been underway for approximately 2 years at Wayne State Univ. It differs from most investigations in that each accident was analyzed in detail. Accidents in which the cause of injury could not be accurately ascertained were eliminated. Thus, a limited number of cases were investigated in detail rather than depending on statistics from a large number of accidents.

A series of cases are presented with the injury rating quantitatively correlated with vehicle interior and exterior deformation up to 2 in. with bruises on the chest to fatal cases where the whole steering assembly and rim are grossly deformed.

VERDOUW, P.D.
Mechanical Properties of arteries.
Physics Lab., Univ. of Utrecht Int. Rep. No. V. 1649, 1961

Veronda, D. R. and Westmann, R. A.
Mechanical Characterization of Skin - Finite Deformations
Journal of Biomechanics, Vol. 3, No. 1., pp. 111-124, 1970

Abstract: The mechanical characterization of skin tissue is examined employing the principles of finite elasticity. A strain energy or work function is employed to develop time independent stress-strain relations valid for large deformations. Results from uniaxial tests on cat skin are presented. Comparing the experimentally determined force-extension curves with the analytical stress-strain relations permits the determination of suitable strain energy functions.

Veith, Frank J., Hagstrom, Jack W.C., Nehlsen, Sandra L. Karl, Richard C. and
Deysine, Maximo
Functional, Hemodynamic, and Anatomic Changes in Isolated Perfused Dog Lungs: The
Importance of Perfusate Characteristics
Ann.Surg. 165: 267-278, 1967.

Verzar, F.
Aging of the collagen fiber
Int. Rev. of Conn. Tissue Res. 2, 1964

Abstract:(Summary) At present the best founded theory for the aging of collagen seems to be that in the stable and nonmetabolizing mature collagen macromolecule the number of hydrogen bonds increases possibly through physical factors associated with the Brownian molecular movement. In addition substances may exist which speed up the process of aging by increasing the cross-linking, perhaps by the formation of ester cross-links. These might be either of intrinsic metabolic origin or extrinsic factors.

Present research is aimed at determining whether such factors, in addition to increasing the velocity of aging, are also responsible for the collagen diseases of old age. It is similarly of importance to decide whether factors exist which may lead not to cross-linking, but to dissolution of the collagen macromolecule.

Viidik, A.
An Apparatus for the Measurement of Small Tensions
Experientia 24: 861-2, 15 Aug.68

Abstract:

Viidik, A. and R. Ekholm
Light and Electron Microscopic Studies of Collagen Fibers under Strain
Zeitschrift fur Anatomie un Entwicklungsgeschichte 127, 154-164, 1968

Abstract: The correlation of the mechanical properties and the morphological behaviour of collagenous tissue during strain was investigated. Relaxed and strained tendons were examined by incidental and transmitted polarized light microscopy and electron microscopy. It was concluded that the wavy pattern seen at the semi-microscopic level of the collagen fibers vanished at relatively low loads. The direction of birefringence in transmitted light microscopy varied in the relaxed preparations but became even in the strained. The electron microscopy showed that the fibrils had the same periodicity as calculated from X-ray diffraction patterns of moist collagen, i.e. 680 Å, and that straining increased the period lengths of some fibrils. The correlation of these findings to a mechanical analogy of the tissue was discussed.

key words: collagen -- Connective tissue -- Electron microscopy -- Polarization microscopy -- tendons

Viidik, A.
Rheology of Skin with Special Reference to Age-Related Parameters and their Possible Correlation to Structure. Rheology of Skin -- Age and Structure
Front. Matrix Biol., Vol. 1, pp. 157-189 (Karger, Basel 1973)

Abstract:

Viidik, A.
Simultaneous Mechanical and Light Microscopic Studies of Collagen Fibers
Z. Anat. Entwickl. Gesch. 136+p.204-212, 1972

Abstract: An apparatus that enables simultaneous stress-strain recording and morphological observation in incidental light microscopy of a specimen surface during tensile loading is reported and variations between behavior during the first tensile loading cycle and those in the steady-state cycles (when the plasticity and irreversible viscosity are exhausted) are described. It is found that the "toe" part of the stress-strain curve is longer from a morphological point of view than can be mechanically measured, which means that the waviness of the collagenous bundles is diminished before any measurable load is applied. The steady state means an even longer such "toe" part and a better parallel arrangement of the fibers but the waviness in the relaxed specimen cannot be disturbed by repeated loadings. The functional range of a tendon is also discussed as are the phenomenon of spraining and the possibility of pre-stress. key words: Biomechanics--Collagen--Connective tissue--Polarizing microscopy--Tendons.

Viidik, A.
Tensile Strength Properties of Achilles Tendon Systems in Trained and Untrained Rabbits
Acta orthop. Scandinav. 40, 261-272, 1969.

Abstract: 19 rabbits were trained in a running machine, while 17 rabbits of the same stock served as controls. At the end of the training period of 40 weeks the calcaneus-Achilles tendon-gastrocnemius muscle-femur systems were tested regarding their tensile strength. The shapes of the load-deformation curves were inspected and the following parameters calculated for the tendon until failure at the system's weakest point: (1) the slope of the linear portion of the load-deformation curve, (2) the failure energy, (3) the maximum load, (4) the elongation at the maximum load, (5) the point of load where the linear part of the load-deformation curve ends. The failure site was also recorded.

It was concluded that the slope tended to become steeper with training but that no other parameters were altered. The failure site proved to be the insertion of the Achilles tendon into the calcaneus. It was concluded that studies on the properties of isolated tendons were needed to ascertain whether tendons change their mechanical properties in response to training or not.

Viidik, A. and Magi, M.
Visco-Elastic Properties of Ligaments
7th Int. Conf. on medical and Biological Engng., Stockholm, 38-4, 1967

Abstract: Mechanical stresses in the human body are mainly resisted by the collagen fibres in both calcified and soft connective tissue. The well-defined collagen fibre system in the anterior cruciate ligament of the knee joint is well suited for studying the physical properties of these fibres. A mechanical model proposed satisfied the elastic and rheological behavior of ligaments, when the specimens are taken from a group of animals of the same age and in the same state of training. If the connective elements in the model (elastic-spring or viscus-dashpot) are altered it might correspond to the mechanical behavior of collagenous tissue in different ages and functional states.

VITO, Raymond
A Note on Arterial Elasticity
J. Biomechanics, 6:5, 561-564, 1973.

Abstract: In this note, an exponential form for the strain energy function characterizing arterial elasticity is suggested. The three parameter function used reduces, for small extensions, to that proposed by Mooney for vulcanized rubber. It is shown that the assumed function gives good agreement with experimental data for the case of simple elongation of dog aortae.

VLASBLOM, D. C.
Skin Elasticity In Vivo Measurement at Small Deformations
7th Int. Conf. on Medical and Biological Engng., Stockholm, 27-2, 1967

Abstract: A quantitative investigation of the elastic properties of human skin is desired because of its importance in dermatology and plastic surgery. A torsional method was used to investigate skin elasticity under physiological conditions and worked quite well. Measurements can be made on intact living skin and lead to reproducible results.

Vlasblom, D.C.
Skin elasticity.
Ph.D. Thesis, University of Utrecht, Netherlands 1967

Von Gierke, Henning E.
Biodynamic Models and Their Applications
The Journal of the Acoustical Society of America, Vol. 50, No. 6, pp 1397-1413
1971

ABSTRACT Progress in modeling the mechanical response of man exposed to various environmental forces is discussed. Starting with a mathematical description of the mechanical and physical characteristics of the integument, soft and hard tissue, the numerous approaches taken and the results obtained from modeling various integrated elements such as the human vertebral column under vibration and impact loads, the chest and respiratory system under vibratory and blast loads and of the whole body system for selected force input conditions and locations are reviewed. Generalized (five-degree and more) freedom models are best suited to understand the correlation between the models derived to understand anatomical and physiological mechanical events, and models used to explain the various injury mechanisms under environmental biodynamic loads (impact, blast, vibration, and noise). To derive a capability of modeling specific injury modes or experimentally observed probabilities of injury curves for various parenchymatous and hollow organs as a function of force input variables, more detailed and specialized models are being used such as, for example, the tissue behavior. The status and value of these models for studying the body's physical and physiological response, for understanding and predicting injury mechanisms

Von Gierke, Henning E.
Biodynamic Models and Their Applications
The Journal of the Acoustical Society of America, Vol. 50, No. 6, pp. 1397-1413,
1971

ABSTRACT (continued): and probability of injury, for scaling the results of animal experiments, and for applying the models in protection engineering, such as escape and restraint systems design are demonstrated. There is a need for further experimental as well as theoretical work in support of these practical biomedical as well as hardware requirements.

Von Gierke, Henning E.
Biodynamic Response of the Human Body
Applied Mechanics Review, Vol. 17, pp. 951-958, 1964

ABSTRACT: The word biodynamics has evolved as the unifying term describing the dynamic mechanical properties of living systems and the effects of various mechanical force environments on these systems. The breakdown of the force environments into sustained acceleration, hypodynamics, impact, vibration, blast, acoustics, etc., has its justification more in historical reasons, simulation techniques and practical requirements than in a basic systematic approach to the mechanisms involved. Notwithstanding obvious differences with respect to problems, techniques used and some apparent differences in biological reactions to the various forms of mechanical energy, this paper reports and reviews results of recent studies emphasizing the common background and the physical phenomena applying to the whole field. The status and value of mathematical models for studying the body's response to pressure (infrasonic noise, blast) as well as force changes (vibration, impact) are presented and the practical applications of such models for explaining physiological and pathological findings, for predicting the body's response to force environments not yet experienced, for protection engineering and biomedical problems in general is discussed.

von Gierke, Henning E.
Response of the Body to Mechanical Forces--an Overview
Annals of the New York Academy of Sciences, Vol 152, Article 1, 172-186, 28 Oct 1968

Abstract: It is the purpose of the paper to relate the body's mechanical response to blast to the response to other mechanical stress environments. The mechanical model of the human body has certainly proved to be extremely valuable for considering the dynamic effects caused by the various environments within the frame of one unifying concept and for explaining the relationships of some of the physiological phenomena observed. There are three practical applications of this model: (1) Once the validity is confirmed, it allows calculation of its response to very complex input functions by computer technique. (2) Model concept is useful in interpreting and planning animal experimentation and in extrapolating human safety criteria. (3) Model provides the capability to analyze numerically the mechanical effectiveness and detailed mode of action of a protection or restraint system coupled with a biological system.

Walinsky, Harvey
Response of the Rat Aortic Media to Hypertension
Circulation Research, Vol. 26, pp. 507-522, 1970

ABSTRACT: Clinical and experimental studies indicate that hypertension accelerates the development of arteriosclerosis. Morphological and chemical studies of the distended rat thoracic aorta were undertaken to define the structural and compositional alterations of the media which accompany hypertension and to relate these changes to increases in calculated medial stress. An 8-week period of hypertension was associated with significantly greater diameter, medial thickness, and cross-sectional area of the media of the thoracic aorta than in normotensive animals. Calculated wall tension was significantly higher in hypertensive animals, but the number of medial lamellar units was not greater than that usual in normotensive animals; this resulted in a strikingly elevated value for calculated tension per medial lamellar unit for the aortas of hypertensive animals. A highly significant linear relation was found between total tension and cross-sectional area of the media of the same segment. In addition, the absolute amounts of both medial elastin and collagen were increased in hypertensive animals; however, the percent of these elements remained essentially constant, indicating little change in the composition of aortic tissue. Increments in both fibrous proteins were linearly related to increases in calculated mural stress, and medial accumulations of elastin and collagen proceeded at similar rates. These findings demon-

Walinsky, Harvey
Response of the Rat Aortic Media to Hypertension
Circulation Research, Vol. 26, pp. 507-522, 1970

ABSTRACT (continued): strate a linear relation among vessel dimensions and amounts of medial elastin and collagen and calculated wall tension

structure-function relations elastin collagen smooth muscle vascular
disease cross-sectional wall area

Wang, Han Chou and Wineman, Alan S.
A Mathematical Model for the Determination of Viscoelastic Behavior of Brain
in vivo--II. Relaxation Response
J. of Biomechanics, 5:6, 571-580, 1972

Abstract: In a recent experiment for determining the mechanical response of brain in vivo, a probe, inserted through scalp, skull and dura, is placed in contact with and normal to the brain, given a prescribed motion, and the time variation of corresponding force is measured. In the corresponding continuum mechanical model, brain is idealized as a linear isotropic viscoelastic solid constrained by a rigid skull. At the mating surface, the shear stress and normal displacement vanish everywhere except under the probe which exerts a local radial displacement. This model introduces effective viscoelastic moduli in shear, which is unknown, and in dilatation, which is considered known from other sources. Part II of this study is concerned with stress relaxation induced by a small step displacement of the probe. From the solution of the corresponding quasi-static boundary value problem, a nonlinear Volterra integral equation is established from which the shear stress relaxation function can be solved in terms of measured probe displacement and force. A numerical method of solution is developed.

Wang, Han Chou and Wineman, Alan S.
A Mathematical Model for the Determination of Viscoelastic Behavior of Brain
in vivo--I Oscillatory Response
J. Biomechanics, 5:5 431-446, 1972

Abstract: In a recent experiment for determining the mechanical response of brain in vivo, a probe, inserted through scalp, skull and dura, is placed in contact with and normal to the brain, given a prescribed motion, and the time variation of corresponding force is measured. In the corresponding continuum mechanical model, brain is idealized as a linear isotropic viscoelastic solid constrained by a rigid skull. At the mating surface, the shear stress and normal displacement vanish everywhere except under the probe which exerts a local radial displacement. This model introduces effective viscoelastic moduli in shear, which is unknown, and in dilation, which is considered known from other sources. Part I of this study considers steady oscillations of the probe. A transcendental equation for the complex shear modulus is established in terms of probe displacement and force amplitude ratio and phase lag and is solved for specific test data. The corresponding stress and displacement fields are evaluated so that the probe influence may be assessed.

WATERS, R. L. and MORRIS, J. M.
An in Vitro study of Normal and Scoliotic Interspinous Ligaments
J. Biomechanics, 6:4,343-348, 1973

Abstract: The mechanical properties of specimens of spinal ligaments from 16 patients with idiopathic scoliosis and 10 patients with scoliosis resulting from connective-tissue disease or anomaly were compared. Stress was determined with an Instron Testor and strain with a modified Instron extensometer. Stress-strain values and percentages of stress relaxation were calculated. It was found that the mechanical properties of the two groups of specimens were essentially similar: The elastic moduli were 129 N/mm^2 and 113 N/mm^2 , and the percentages of stress relaxation were 5 and 4, respectively.

Weisfeldt, Myron L., Loeven, W.A. and Shock, N.W.
Resting and Active Mechanical Properties of Trabeculae Carneae from Aged Male Rats
Am. J. Physiol. 220(6):1921-1927, 1971.

Abstract: Trabeculae carneae from the left ventricles of 11- to 13- and 26- to 31-month-old male rats were examined in terms of the active and resting length-tension curves. No significant difference between the two groups was noted for the active length-tension curve. The resting length-tension curves showed that muscles from the older rats had significantly greater resting tension at lengths greater than 115% of L_0 . L_0 was defined as the shortest length with a resting tension above zero. The duration of contraction, time-to-peak tension, and relaxation time at maximum isometric tension were prolonged in muscles from the older group. Stress relaxation was studied using other trabeculae from rats of similar ages. Resting tension was found to decline linearly with the log of time from 0.3 to 240 sec after a rapid stretch. Less stress relaxation was exhibited by muscles from 25- to 29-month-old male rats than 11- to 12-month-old rats. This age-associated alteration in stress relaxation accounts in part for the age-associated changes in the resting length-tension curve.

Wellisch, Eric, Marker, Leon and Sweeting, Orville J.
Viscoelastic Properties of Regenerated Cellulose Sheet
Jr. of Appl. Polymer Sci. Vol.5, #18, pp 647-654, 1961.

Abstract: The durability properties of cellophane are measured at the present time by several physical tests, such as measurement of impact strength, flexing under stress, tenacity, elongation, tear and others and no correlation between these test data and the structure and interaction of the polymer chains exists. It has been shown by the tests in this article that at constant load the creep data for softened cellophane can be fitted to a four-element model consisting of a Voight unit and a Maxwell unit in series. The parameters of the Maxwell model depend on the total number of moles of softener added and the parameters of the Voight model depend on the internal pressure of the liquids carried by the cellulose.

WELSH, R. P., Macnab, Ian and Riley, V.
Biomechanical Studies of Rabbit Tendon
Clin. Ortho.No.81, pp.171-77, Nov-Dec.1971

Abstract: Tendon is a dynamic link between bone and muscle, vital to the efficient translation of the body's energy into effective action. In testing an intact rabbit musculotendinous system, complete with its bony attachments, the muscle belly was found to be the weakest unit. When the tendon-bone preparation was evaluated it broke at the bone - tendon junction, but tendons alone were found to fail at their points of clamping - sites of maximum stress concentration. Of extreme importance is the loading rate - high rate results in brittle fracture.

WESSELING, Karel H., Weber, Hans and de Wit, Ben
Estimated Five Component Viscoelastic Model Parameters for Human Arterial Walls
J. of Biomechanics, 6:1, 13-24, 1973

ABSTRACT: Parameter values in the Westerhof and Noordergraaf (1970) model for viscoelastic arterial wall behavior are obtained for the human thoracic and abdominal aorta and the iliac, femoral and carotid artery for "young" and "old" age groups, applying a computerized estimation technique to data published by Learoyd and Taylor (1966).

The asymptotic normalized Young modulus is defined as the Young modulus of the resulting model at very high frequency divided by that at zero frequency. Values are determined for each arterial segment. Results show the asymptotic modulus of the carotid artery to decrease and of the iliac and femoral artery to increase with increasing age. A possible explanation is presented. Characteristic frequencies are defined as those frequencies where the imaginary or viscous part of the model Young modulus reaches local maxima. These frequencies appear to attain higher values at high age for all segments.

WEST, John B.
Respiration
Annu.Rev.Physiol. 34:91-116,1972

Abstract: This review makes no attempt to cover all the papers on respiratory physiology published during the period May 1970 to May 1971 but rather concentrates on those that seem to the reviewer to be of particular interest. For convenience, the articles have been grouped under four headings: morphology, mechanics, blood flow, and gas exchange. Inevitably many important papers within these areas and indeed whole areas of pulmonary physiology, such as ventilatory control, have been completely omitted.

Wertheim, M.G.

Memoirs sur l'elasticite et la cohesion des principaux tissus du corps humain.
Ann.Chim. Phys. 3e Serie, 21, 385-414, 1947

WEST, John B. & Matthews, Frank L.

Stresses, strains, and surface pressures in the lung caused by its weight
J. Appl. Physiol. 32(3), 332-345, 1972

Abstract : In an effort to understand how the lung is deformed by its own weight we have analyzed the distribution of regional expansion, stresses, and surface pressures in a theoretical elastic lung-shaped model using the technique of finite elements. In the upright position, the parenchyma was most expanded at the apex and least at the base. Stresses in both the vertical and lateral directions were maximal at the apex. As the lung was inflated from very low volumes to total lung capacity, parenchymal expansion and stress at the apex first decreased, then increased. This behavior can be explained by the increasing rigidity of the expanded lung which enabled it to resist distortion by its own weight. At functional residual capacity, the stress at the apex was near its minimum. The differences in intrapleural pressure down the lung were volume dependent, increasing at very low volumes. In the inverted lung, the regional differences in stress, strain, and surface pressures were less marked because of the shape of the chest.

gravity; pleural pressure; distribution of ventilation

Westernof, Nicolaas, Bosman, Frederik, DeVries, Cornelis J. and Noordergraaf, Abraham

Analog Studies for the Human Systemic Arterial Tree

Journal of Biomechanics, Vol 2, No. 2, pp. 121-143, 1969

Abstract: The design, construction and evaluation of a linear passive model of the human systemic arterial tree are presented. The performance of this electrical model is compared extensively to its real counterpart in the following areas: magnitude and phase of input impedances, wave travel (amplitude and phase of pressure harmonics) along the aorta, and wave shapes of pressures and flows at different locations. These comparisons demonstrate that the model behaves very much like the real system.

A series of refinements in the modeling of a short segment of artery is discussed; although these refinements help to obtain better agreement with reality, none has a major effect on the behavior of the model as measured close to the heart.

Reflections play a major role in determining the behavior of the system and occur at all branch points. The largest reflection coefficients are found at the periphery. These reflection coefficients result mainly from the architecture of the arterial tree. It is shown how the nature of the input impedance and wave travel pattern can be explained in terms of these reflections.

Westernof, Nicolaas, Bosman, Frederik, DeVries, Cornelis J, and Noordergraaf, Abraham

Analog Studies of the Human Systemic Arterial Tree

Journal of Biomechanics, Vol. 2, No. 2., pp. 121-143, 1969

Abstract (Continued): The input impedance and wave travel in large vessels, for frequencies larger than 2 cps, are largely determined by the characteristics of these vessels themselves and not by the load. This is mainly due to the architecture of the system.

Alterations in peripheral resistance affect the input impedance of the system only for very low frequencies; the same holds for wave travel in the aorta; the high frequencies are virtually independent of the peripheral resistance.

Some clinical states are simulated and discussed.

Westerhof, Nicolaas, and Noordergraaf, Abraham
Arterial Viscoelasticity: A generalized Model
Journal of Biomechanics, Vol. 3, No. 3, pp. 357-379, 1970

Abstract: In the first part of this paper most of the reported results concerning measurements of the viscoelastic properties of the systemic arterial wall are discussed. The various mechanical models of the vessel wall that have been proposed and which usually account for a special aspect of viscoelastic properties are reviewed critically. From these discussions a new mathematical model for the wall properties emerges. It accounts in quantitative terms for the frequency dependence of the Young modulus, stress-relaxation, creep, and hysteresis. Hence this new description, which is in terms of the complex Young modulus, covers all the known aspects of the viscoelastic wall properties.

In the second part of this paper the complex Young modulus is incorporated in a model of the systemic arterial tree for the purpose of studying the effect of the viscous properties of the wall. Wave travel and input impedances are given for the case of a purely elastic wall and for the case of a realistic viscoelastic wall; the differences are compared. Addition of the viscous wall properties proves to have a significant effect on input impedance and wave travel.

WILLIAMS, M. L.
Structural Analysis of Viscoelastic Materials
AIAAJI, 2, 785-808, 1964.

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Whimster, William F.
Normal Lung Weights in Jamaicans
American Review of Respiratory Disease, Vol. 103, pp. 85-90

ABSTRACT: In a retrospective postmortem study of 1,019 adult Jamaicans of African extraction, 350 (17.2 percent) of the 2,038 lungs were classified as normal. The weights of these lungs were compared with weights of lungs in abnormal categories and considerable overlap was found. It was concluded, however, that lungs that were normal to inspection and palpation but that weighed less than the mean could be included in studies requiring normal lungs. In 70 men and 81 women, both lungs were normal.

Regressions of the normal total lung weights were calculated with age, height, weight, and surface area. These factors accounted for only 11 percent of the variation in total lung weights in men and 14 percent in women. Analysis of male and female lung weights showed that for any given height and weight there was no significant difference between the sexes. No adequate data were available to compare races, but it was concluded that lung weight was more closely related to stature than to sex or, probably, to race.

WHITE, Augustus A.III & Raphael, Irving
The Effect of Quadriceps Loads and Knee Position on Strain Measurement of the Tibial Collateral Ligament - An Experimental Study on Human Amputation Specimens
Acta orthop. Scandinav. 43, 176-187, 1972

Abstract: (Summary) Strain measurements were made in the tibial (medial) collateral ligaments of five amputated legs using electrical devices and strain gages. The effect of several variables on the recorded strain of the ligaments was observed. These variables included the angle of knee flexion, simulated physiologic loading of the quadriceps mechanism, and abducting forces on the tibia. The following results were obtained: 1. Strain on the tibial collateral ligament is minimum at full flexion and increases as the knee extends. 2. The greater the load applied to the quadriceps mechanism, the less the strain in the ligament in various positions of flexion and extension. 3. The greater the abducting force on the tibia, the greater the strain in the ligament. 4. The greater the load on the quadriceps mechanism, the less the strain in the ligament due to the abducting force applied to the tibia.

A major conclusion supported by this investigation is that quadriceps mechanism can be shown experimentally to be a factor in decreasing strains on the tibial collateral ligament, both with and without abducting forces (valgus deformity) being imposed on the knee joint.

WILKIE, D.R.
MEASUREMENT OF THE SERIES ELASTIC COMPONENT AT VARIOUS TIMES DURING A SINGLE
MUSCLE TWITCH

J. Physiol. 134, 527-530, 1956

Abstract: (fm summary) A simple isotonic technique has been described for demonstrating the separate existence of two components in striated muscle, and for determining the stress-strain curve of the passive elastic component.

This technique has been used to show that the series component is present and has constant properties throughout a muscle twitch.

Wilkes, G.L. and Wildnauer, R.H.
Structure-Property Relationships of the Stratum Corneum of Human and Neonatal
Rat II. Dynamic Mechanical Studies

Biochim. Biophys. Acta. 304: 276-89, Apr 1973

Abstract: The stratum corneum from neonatal rat and human was investigated by the technique of dynamic mechanical spectroscopy. It was found that the corneum displayed a unique mechanical spectrum with temperature in that the modulus passed through two minima -- one being near the physiological region. The first is associated with the mobility and melting of water while the second is tentatively attributed to the melting and restructuring of the proteolipids. Overall the behavior of neonatal rat and human samples was similar.

WOLFRAM, Maria A., Wolejsza, Nancy F. and Laden, Karl
Biomechanical Properties of Delipidized Stratum Corneum
Jr. of Invest. Dermatol 59:6, pp 421-6, Dec.1972

Abstract: Alterations of the physical properties of stratum corneum induced by ether extraction were studied. In vitro changes measured included mechanical work to stretch (Instron extensometer), cross-sectional swelling, and expansion in the plane of the tissue when placed in water. Results showed that either extraction produced a pronounced weakening of the stratum corneum as shown by the work index when measured at 5% extension. This weakening was accompanied by an increase in the cross-sectional swelling and higher expansion in the plane of the tissue. In vivo observations using scanning electron microscopy of replicas of ether-extracted skin confirmed the pronounced swelling effects seen in vitro. The results suggest that removal of lipids from the surface of the skin produces a pronounced weakening and swelling when the skin is subsequently immersed in water. This may be reflected in the appearance of cracks and upturned stratum corneum cells.

Wolinsky, Harvy and Glagov, Seymour
Structural Basis for the Static Mechanical Properties of the Aortic Media
Circ. Res. 14, 400, 1964

Wong, Alan Y.K.

A Concentric Layer Model for Estimating the Energy Expenditure of the Left Ventricle.

Bulletin of Mathematical Biophysics, Vol.32, 581-598, 1970.

Abstract: The energy cost of the left ventricle is quantitatively analyzed on the basis of the following assumptions: (1) The left ventricle is assumed to be an isotropic, homogeneous elastic, thick, spherical shell. (2) The ventricular wall is made up of a finite number of thin concentric shells. (3) The energetics of the left ventricle is in accordance with the second law of thermodynamics. An expression for the work done during ventricular contraction is derived according to the definition of physical work. The energy liberation during isovolumic contraction is formulated parallel to the concepts of heat production in skeletal muscle during isometric contraction. This expression gives the total work done per stroke in terms of mean systolic pressure, and diastolic volume, stroke volume and wall thickness during diastolic phase.

WONG, Alan Y. K.

Mechanics of Cardiac Muscle, Based on Huxley's Model: Mathematical Simulation of Isometric Contraction

J. Biomechanics, 4:6, 529-540, 1971

Abstract: Hill's three-component model (Maxwell model) is used to represent the mechanical property of cardiac muscle. The parallel and series elastic elements of the fibres are described according to their non-linear exponential function; and Huxley's sliding-filaments model, together with the activating role of calcium, is applied to the contractile element.

With this composite model, the following responses can be simulated mathematically: isometric twitch at various muscle lengths, tension-length relationships, isometric contraction during quick stretch; and the Bowditch Treppe and tension velocity relationships of the contractile element.

Wong, Alan Y. K.
Mechanics of Cardiac Muscle, Based on Huxley's Model: Simulation of Active State
and Force-Velocity Relation
J. Biomechanics, 5:1, 107-117, 1972.

Abstract: Hill's three-component model for cardiac muscle, incorporating Huxley's sliding filament theory for the contractile element (CE) (Wong, 1971) is extended to study the force-velocity relation. At any defined contractile state, i.e. fixed time of contraction and CE length, force-velocity curve of CE can be described by Hill's characteristic equation. The hyperbolic relation is not found in force-velocity curve obtained by afterloaded isotonic contraction, but the curve can be fitted by Fung's equation (1970). Inconsistencies and discrepancies in force-velocity data reported in literature are discussed on the basis of the present model.

Wong, Alan Y.K. and Rautaharju, P.M.
Stress Distribution within the Left Ventricular Wall Approximated as a Thick
Ellipsoidal Shell.
American Heart J. 75:5, 649-662, May, 1968.

Abstract: A formula is derived for the stress distribution within the myocardium which is assumed to be an isotropic, homogeneous, elastic medium. This expression is generalized so that it is applicable for the left ventricle which is assumed as either a spherical thick shell, or an ellipsoidal shell, or a paraboloid of revolution. The patterns of stress distribution were computed for various phases of contraction of a simulated normal heart. In an ellipsoidal structure, the wall stress does not increase linearly with the radius of curvature. Although several simplifying assumptions were necessary to facilitate computing of the stress profiles, the results obtained are more realistic and accurate than can be expected from models which approximate the left ventricle as a sphere or a cylinder or a structure with a thin wall.

WOO, S. L-Y, Kobayashi, A.S., Lawrence, C. and Schlegel, W.A.
Mathematical Model of the Corneo-Scleral Shell as Applied to Intraocular
Pressure-Volume Relations and Applanation Tonometry
Annals of Biomedical Engineering 1,87-98,1972.

ABSTRACT: The nonlinear mechanical properties of the cornea, sclera, and optic disk determined previously are incorporated in a finite element mathematical model of a human corneo-scleral shell. This mathematical model is then used to calculate a nonlinear intraocular pressure-volume relation and the forces and volumes in applanation tonometry. These results are compared with experimental results obtained by other investigators. Friedenwald's coefficients of ocular rigidity were also calculated using the model and were found to decrease with increased intraocular pressure.

Woo, S.L.Y, Kobayashi, A.S., Lawrence, C. and Schlegel, W.A.
Nonlinear Material Properties of Intact Cornea and Sclera
Exp. Eye Res. 14:pp29-39, 1972.

Abstract: Enucleated human eyes, 1-3 days post mortem, were sectioned equatorially and the anterior or posterior segment of the corneoscleral shell was clamped on a metal chamber for pressurization. A flying spot scanner system was used to measure horizontal surface deformations while the pressure in the chamber was changed stepwise. Lateral deformations in directions 90° and 45° to the original horizontal direction were also measured to establish surface isotropy of the material when the eye specimens were pressurized in their natural geometries.

The finite element numerical method was then used to construct a mathematical model of the posterior segment of the eye mounted on the metal chamber. This model uses trilinear stress-strain relationships which were adjusted until the predicted surface deformations agreed with the experimental results. Using a similar procedure on the anterior segment, a trilinear stress-strain relation was obtained for the corneal stroma. The trilinear relations were then converted to exponential form by a least square method.

Woo, S.L.Y., Kobayshi, A.S., Lawrence, C. and Schlegel, W.A.
Nonlinear Material Properties of Intact Cornea and Sclera
Exp. Eye Res. 14: pp 29-39, 1972

Abstract continued: The finite element, axisymmetric mathematical model can assign these nonlinear material properties for different portions of the eye and specific variations in geometry such as central corneal or equatorial scleral thinning. Such geometric complexity and material heterogeneity and nonlinearity could not be modeled conveniently by previous mathematical models of the corneoscleral shell. The model will be useful in the analysis of stress and strain in portions of the eye, pressure-volume relations and tonometry.

Wood, T.E., McLeod, P., Anthonisen, N.R. and Macklem, P.T.
Mechanics of Breathing in Mitral Stenosis
Am. Rev. Resn. Disease, 104: 52-60, 1971

Abstract: The mechanical properties of the lungs of patients with mitral stenosis were studied using the esophageal balloon technique. Both the position and the volume of the balloon were systematically varied in an effort to detect artifacts in the pressure tracings ascribable to the heart and great vessels. No artifacts were found; variations in esophageal pressure induced by changing balloon position and volume were similar to those seen in normal subjects.

In patients with mitral stenosis, the static pressure-volume curve of the lung was abnormal in a unique way; at large lung volumes transpulmonary pressures were high, but at small lung volumes, recoil was diminished. It was suggested that vascular plethora accounted for loss of recoil at small lung volumes and pulmonary fibrosis caused increased recoil at larger volumes. This hypothesis was supported by studies on patients with atrial septal defects who showed loss of recoil at small lung volumes. Both static and dynamic compliances were sharply reduced in mitral stenosis. Although it was examined over a rather limited range, dynamic compliance did not decrease as breathing frequency increased. Airway resistance was approximately twice normal, and this abnormality tended to dominate the maximal expiratory flow-volume curve; expiratory flows were decreased at all lung volumes.

Wright, V., Dowson, D. and Seller, P.C.
Bio-Engineering Aspects of Synovial Fluid and Cartilage
Mod. Trends. Rheumatol. 2:21-9, 1971

Wright, V., Dowson, D. and Unsworth, A.
The Lubrication and Stiffness of Joints
Mod. Trends, Rheumatol. 2:30-45, 1971

Wurzel, M., Cowper, G. R. and McCook, James M.
Smooth Muscle Contraction and Viscoelasticity of Arterial Wall
Can. J. Physiol. Pharm, Vol. 48, pp. 510-521, 1970

ABSTRACT: Elasticity and viscosity, of fully relaxed and gradedly contracted arterial wall were measured on spirally cut rabbit aortic strips suspended in Ringer's solution. Pre-extended contracted tissue submitted to additional stretch shows an instantaneous and slow elongation. Only instantaneous elongation was observed on fully relaxed tissue. This behavior can be simulated by a mechanical model consisting of a spring in series with a dashpot, and a second spring in parallel with the first spring-dashpot component. The modulus of the first spring and the coefficient of viscosity both increase steadily with increasing contraction, while the modulus of the second spring decreases. The first spring-dashpot component is believed to represent the viscoelastic behavior of smooth muscle on its non-contractile network. The second spring probably represents the combined elastic properties of arterial elastin and collagen.

Yagnik, M.G., Kamidar, V.D., Kothari, D.L. and Kothari, Menna L.
Vertical Tensiometer for the Measurement of Tension of a Healing wound in vitro
J. Postgrad Med. 18:95-8, Apr. 72

Abstract: (fm summary) Eighteen cases of lymphoma of the gastro-intestinal tract are presented with their short clinical data and histological findings. A short review of the literature is also given.

Yeatman, Lawrence A., Jr., Parmley, William W. and Sonnenblick, Edmund H.
Effects of Temperature on Series Elasticity and Contractile Element Motion in
Heart Muscle
Am. Jr. of Physiology, Vol.217, No.4, 1030-1034, Oct.1969.

Abstract: The effects of changing temperature on myocardial force-velocity relations and series elasticity were studied in right ventricular papillary muscles of the cat. When temperature was increased from 24 to 34 C, maximum velocity of shortening at zero load (V_{max}) rose 150 ± 10% while maximum tension fell by 10 ± 6%. Stress-strain relations of the series-elastic component were determined for each muscle, with corrections for equipment compliance. The modulus of elasticity of the active muscle (dP/dl) was shown to be a function of the load (P), i.e., $dP/dl = KP + C$. The stiffness of the series-elastic component of active muscle decreased as temperature was increased, average K being .56/% L_0 at 24 C and .38/% L_0 at 34 C. Since the rate of tension development (dP/dt) is dependent on both the velocity of shortening of the CE (contractile element) and the stiffness of the SE (elastic element), this temperature dependence of SE stiffness helps to explain the anomalous fact that dP/dt may be only moderately altered by hypothermia despite a substantial fall in V_{max} .

Yin, F.C.P. and Fung, Y.C.
Mechanical Properties of Isolated Mammalian Ureteral Segments
Am. J. Physiol. 221(5): 1484-1493, 1971.

Abstract: Isolated ureteral segments from dog, rabbit, guinea pig, and human ureter were studied. Passive elasticity parameters under simple elongation were obtained. The resting tone of the ureter in situ was shown to be small. Hysteresis in loading-unloading cycles was found and was shown to have little significant dependence on strain rate. Stress relaxation and creep tests showed a dependence on the amount of stretch and amount of load on the specimen. For isometric contractions the maximum active tension was found to be attained at a length greater than the in situ length. The contractile behavior was found to be the same during loading and unloading. Finally, the mechanical properties of chronically dilated ureters were found to differ significantly from those of normal ureters.

ZUCKERMAN, S.,
EXPERIMENTAL STUDY OF BLAST INJUREIS TO THE LUNGS
Lancet 2:219-224, 1940

Abstract: This paper is a report of an experimental investigation carried out for the REsearch and Experiments Dept. of the Ministry of Home Security on the effects on the lungs of blast from high-explosive.

Mice, rats, guineapigs, rabbits, cats, monkeys and pigeons were exposed in the open to blast from the explosion of charges of 70 lb. of H.E. and from the explosion of hydrogen and oxygen in balloons.

It is concluded from these experiments that it is the pressure component of blast which bruises the lungs by its impact on the body wall.

