BIOMECHANICS—AN INTRODUCTION

Biomechanics is the application of mechanical principles to living organisms. This includes bioengineering, the research and analysis of the mechanics of living organisms and the application of engineering principles to and from biological systems. This research and analysis can be carried forth on multiple levels, from the molecular, wherein biomaterials such as collagen and elastin are considered, all the way up to the tissue and organ level. Some simple applications of Newtonian mechanics can supply correct approximations on each level, but precise details demand the use of continuum mechanics.

Chinstrap Penguin Aristotle wrote the first book on biomechanics, De Motu Animalium, or On the Movement of Animals. He not only saw animals' bodies as mechanical systems, but pursued questions such as the physiological difference between imagining performing an action and actually doing it. Some simple examples of biomechanics research include the investigation of the forces that act on limbs, the aerodynamics of bird and insect flight, the hydrodynamics of swimming in fish, and locomotion in general across all forms of life, from individual cells to whole organisms. The biomechanics of human beings is a core part of kinesiology.

The application of biomechanical principles to plants and plant organs has developed into the sister field of Plant biomechanics. The many strands of plant biomechanics are described in a text book on the subject
by Karl Niklas Plant Biomechanics: An Engineering Approach to Plant Form and Function.

Applied mechanics, most notably thermodynamics and continuum mechanics, and mechanical engineering disciplines such as fluid mechanics and solid mechanics, play prominent roles in the study of biomechanics. By applying the laws and concepts of physics, biomechanical mechanisms and structures can be simulated and studied. Such concepts are found in the field of Sports Biomechanics where we apply the laws of mechanics and physics to human performance in order to gain a greater understanding of performance in athletic events through modeling, computer simulation, stimulation, gesticulation, mastication and measurement. Elements of Mechanical Engineering (e.g. strain gauges), Electrical Engineering (e.g. digital filtering), Physics/Dynamics (e.g. moments of inertia), Computer Science (e.g. numerical methods) and Clinical Neurophysiology (e.g. surface EMG) are common methods used for the analysis.

Relevant mathematical tools include linear algebra, differential equations, vector and tensor calculus, numerics and computational techniques such as the finite element method.

The study of biomaterials is of crucial importance to biomechanics. For example, the various tissues within the body's organs, such as skin, bone, and arteries each possess unique material properties. The passive mechanical response of a particular tissue can be attributed to characteristics of the various proteins, such as elastin and collagen, living cells, ground substances such as proteoglycans, and the orientations of fibers within the tissue. For example, if human skin were largely composed of a protein other than collagen, many of its mechanical properties, such as its elastic modulus, would
be different.

It has been shown that applied loads and deformations can affect the properties of living tissue. There is much research in the field of growth and remodeling as a response to applied loads. For example, the effects of elevated blood pressure on the mechanics of the arterial wall, the behavior of cardiomyocytes within a heart with a cardiac infarct, and bone growth in response to exercise, and the acclimative growth of plants in response to wind movement, have been widely regarded as instances in which living tissue is remodelled as a direct consequence of applied loads.

Chemistry, molecular biology, and cell biology have much to offer in the way of explaining the active and passive properties of living tissues. For example, in muscle contractions, the binding of myosin to actin is based on a biochemical reaction involving calcium ions and ATP.

Applications

The study of biomechanics ranges from the inner workings of a cell to the movement and development of limbs, to the mechanical properties of soft tissue, and bones. As we develop a greater understanding of the physiological behavior of living tissues, researchers are able to advance the field of tissue engineering, as well as develop improved treatments for a wide array of pathologies.

Continuum Mechanics

It is often appropriate to model living tissues as continuous media. For example, at the tissue level, the arterial wall can be modeled as a continuum. This assumption breaks down when the length scales of interest approach the order of the micro structural details
of the material. The basic postulates of continuum mechanics are conservation of linear and angular momentum, conservation of mass, conservation of energy, and the entropy inequality. Solids are usually modeled using "reference" or "Lagrangian" coordinates, whereas fluids are often modeled using "spatial" or "Eulerian" coordinates. Using these postulates and some assumptions regarding the particular problem at hand, a set of equilibrium equations can be established. The kinematics and constitutive relations are also needed to model a continuum.

Second and fourth order tensors are crucial in representing many quantities in electromechanical. In practice, however, the full tensor form of a fourth-order constitutive matrix is rarely used. Instead, simplifications such as isotropy, transverse isotropy, and incompressibility reduce the number of independent components. Commonly-used second-order tensors include the Cauchy stress tensor, the second Piola-Kirchhoff stress tensor, the deformation gradient tensor, and the Green strain tensor. A reader of the mechanic's literature would be well-advised to note precisely the definitions of the various tensors which are being used in a particular work.

Circulation

Red blood cells Under most circumstances, blood flow can be modeled by the Navier-Stokes equations. Whole blood can often be assumed to be an incompressible Newtonian fluid. However, this assumption fails when considering flows within arterioles. At this scale, the effects of individual red blood cells becomes significant, and whole blood can no longer be modeled as a continuum. When the diameter of the blood vessel is slightly larger than the diameter of the red blood cell the
Fahraeus–Lindquist effect occurs and there is a decrease in wall shear stress. However, as the diameter of the blood vessel decreases further, the red blood cells have to squeeze through the vessel and often can only pass in single file. In this case, the inverse Fahraeus–Lindquist effect occurs and the wall shear stress increases.

**Bones**

Bones are anisotropic but are approximately transversely isotropic. In other words, bones are stronger along one axis than across that axis, and are approximately the same strength no matter how they are rotated around that axis.

The stress-strain relations of bones can be modeled using Hooke’s law, in which they are related by elastic moduli, e.g. Young’s modulus, Poisson’s ratio or the Lamé parameters. The constitutive matrix, a fourth order tensor, depends on the isotropy of the bone.

**Muscle**

There are three main types of muscles:

Skeletal muscle (striated): Unlike cardiac muscle, skeletal muscle can develop a sustained condition known as tetany through high frequency stimulation, resulting in overlapping twitches and a phenomenon known as wave summation. At a sufficiently high frequency, tetany occurs, and the contractile force appears constant through time. This allows skeletal muscle to develop a wide variety of forces. This muscle type can be voluntary controlled. Hill’s Model is the most popular model used to study muscle.

Cardiac muscle (striated): Cardiomyocytes are a highly specialized cell type. These involuntarily contracted cells are located in the heart wall and operate in concert