CHAPTER 7

Bio-viscoelastic Solids

7.1 Introduction

Solids provide "body" to living organisms and are proper provinces of biomechanics. Some biosolids are more "elastic," others are more "viscous"; altogether they are viscoelastic.

The attention of this chapter is focused on soft tissues. We shall first consider some of the most elastic materials in the animal kingdom: abductin, resilin, elastin, and collagen. Collagen will be discussed in greater detail because of its extreme importance to human physiology. Then we shall consider the thermodynamics of elastic deformation, and make clear that there are two sources of elasticity: one associated with change of internal energy, and another associated with change of entropy. Following this, we shall consider the constitutive equations of soft tissues. Results of uniaxial tension experiments will be considered first, leading to the concept of quasi-linear viscoelasticity. Then we will discuss biaxial loading experiments on soft tissues, methods for describing three-dimensional stresses and strains in large deformation, and the meaning of the pseudo strain energy function.

In Sec. 7.10 we give an example: the constitutive equation of the skin. In Sec. 7.11 we present equations describing generalized viscoelastic relations. The chapter is concluded with a discussion of the method for computing strains from known stresses if the stress-strain relationship is given in the other way: stresses expressed as functions of strains.

In the chapters to follow, we consider in detail the blood vessels, skeletal muscle, heart muscle, and smooth muscles. Muscles are the materials that make biomechanics really different from any other mechanics. Finally, in Chapter 12, we discuss bone and cartilage.
7.2 Some Elastic Materials

Elastin is the most "linearly" elastic biosolid materials known. If a cylindrical specimen of elastin is prepared and subjected to uniaxial load in a tensile testing machine, a tension-elongation curve as shown in Fig. 7.2:1 is obtained. by the initial (unloaded) length of the specimen. The ordinate is the stress. Note that the loading curve is almost a straight line. Loading and unloading do lead to two different curves, showing the existence of an energy dissipation mechanism in the material; but the difference is small. Such elastic characteristics remain at least up to $\lambda = 1.6$.

Elastin is a protein found in vertebrates. It is present as thin strands in areolar connective tissue. It forms quite a large proportion of the material

![Figure 7.2:1 The stress-strain curve of elastin. The material is the ligamentum nuchae of cattle, which contains a small amount of collagen that was denatured by heating at 100°C for an hour. Such heating does not change the mechanical properties of elastin. The specimen is cylindrical with rectangular cross-section. Loading is uniaxial. The curve labeled “control” refers to native elastin. The curve labeled “10% formalin” refers to a specimen fixed in formalin solution for a week without initial strain. From the author’s laboratory in collaboration with Dr. Sobin.](image-url)