

# Contents

Preface to the Second Edition	vii
Preface to the First Edition	ix
<b>Chapter 1</b>	
<b>Introduction: A Sketch of the History and Scope of the Field</b>	<b>1</b>
1.1 What Is Biomechanics?	1
1.2 Historical Background	2
1.3 What's in a Name?	6
1.4 Mechanics in Physiology	7
1.5 What Contributions Has Biomechanics Made to Health Science?	10
1.6 Our Method of Approach	11
1.7 Tools of Investigation	12
1.8 What Contributions Has Biomechanics Made to Mechanics?	14
1.9 On the Law of Laplace	14
Problems	17
References	22
<b>Chapter 2</b>	
<b>The Meaning of the Constitutive Equation</b>	<b>23</b>
2.1 Introduction	23
2.2 Stress	25
2.3 Strain	29
2.4 Strain Rate	34
2.5 Constitutive Equations	35

2.6	The Nonviscous Fluid	35
2.7	The Newtonian Viscous Fluid	36
2.8	The Hookean Elastic Solid	38
2.9	The Effect of Temperature	40
2.10	Materials with More Complex Mechanical Behavior	40
2.11	Viscoelasticity	41
2.12	Response of a Viscoelastic Body to Harmonic Excitation	48
2.13	Use of Viscoelastic Models	50
2.14	Methods of Testing	52
2.15	Mathematical Development of Constitutive Equations	57
	Problems	58
	References	65

### Chapter 3

	The Flow Properties of Blood	66
3.1	Blood Rheology: An Outline	66
3.2	The Constitutive Equation of Blood Based on Viscometric Data and Casson's Equation	72
3.3	Laminar Flow of Blood in a Tube	76
3.4	Speculation on Why Blood Viscosity Is the Way It Is	82
3.5	Fluid-Mechanical Interaction of Red Blood Cells with a Solid Wall	91
3.6	Thrombus Formation and Dissolution	93
3.7	Medical Applications of Blood Rheology	96
	Problems	99
	References	105

### Chapter 4

	Mechanics of Erythrocytes, Leukocytes, and Other Cells	109
4.1	Introduction	109
4.2	Human Red Cell Dimensions and Shape	112
4.3	The Extreme-Value Distribution	117
4.4	The Deformability of Red Blood Cells (RBC)	120
4.5	Theoretical Considerations of the Elasticity of Red Cells	122
4.6	Cell Membrane Experiments	128
4.7	Elasticity of the Red Cell Membrane	140
4.8	The Red Cell Membrane Model	144
4.9	The Effects of Red Cell Deformability on Turbulence in Blood Flow	146
4.10	Passive Deformation of Leukocytes	147
4.11	Cell Adhesion: Multipipets Experiments	151
4.12	Topics of Cell Mechanics	151
	Problems	156
	References to Erythrocytes	158
	References to Leukocytes and Other Cells	162

Chapter 5	
Interaction of Red Cells with Vessel Wall, and Wall Shear with Endothelium	165
5.1 Introduction	165
5.2 Apparent Viscosity and Relative Viscosity	166
5.3 Effect of Size of the Blood Vessel on the Apparent Viscosity of Blood: The Fahraeus–Lindqvist Effect	172
5.4 The Distribution of Suspended Particles in Fairly Narrow Rigid Tubes	176
5.5 The Motion of Red Cells in Tightly Fitting Tubes	176
5.6 Inversion of the Fahraeus–Lindqvist Effect in Very Narrow Tubes	182
5.7 Hematocrit in Very Narrow Tubes	186
5.8 Theoretical Investigations	194
5.9 The Vascular Endothelium	196
5.10 Blood Shear Load Acting on the Endothelium	198
5.11 Tension Field in Endothelial Cell Membranes Under the Fluid Interior Hypothesis	199
5.12 The Shape of Endothelial Cell Nucleus Under the Fluid Interior Hypothesis	201
5.13 Transmission of the Tension in the Upper Endothelial Cell Membrane to the Basal Lamina through the Sidewalls	203
5.14 The Hypothesis of a Solid-Like Cell Content	210
5.15 The Effect of Turbulent Flow on Cell Stress Problems	211
References to Blood Cells in Microcirculation	213
References to Endothelial Cells	215
	217
Chapter 6	
Bioviscoelastic Fluids	220
6.1 Introduction	220
6.2 Methods of Testing and Data Presentation	222
6.3 Protoplasm	226
6.4 Mucus from the Respiratory Tract	227
6.5 Saliva	231
6.6 Cervical Mucus and Semen	232
6.7 Synovial Fluid	233
Problems	238
References	240
Chapter 7	
Bioviscoelastic Solids	242
7.1 Introduction	242
7.2 Some Elastic Materials	243

7.3	Collagen	251
7.4	Thermodynamics of Elastic Deformation	265
7.5	Behavior of Soft Tissues Under Uniaxial Loading	269
7.6	Quasi-Linear Viscoelasticity of Soft Tissues	277
7.7	Incremental Laws	292
7.8	The Concept of Pseudo-Elasticity	293
7.9	Biaxial Loading Experiments on Soft Tissues	295
7.10	Description of Three-Dimensional Stress and Strain States	298
7.11	Strain-Energy Function	300
7.12	An Example: The Constitutive Equation of Skin	302
7.13	Generalized Viscoelastic Relations	306
7.14	The Complementary Energy Function: Inversion of the Stress–Strain Relationship	307
7.15	Constitutive Equation Derived According to Microstructure	310
	Problems	311
	References	314
Chapter 8		
Mechanical Properties and Active Remodeling of Blood Vessels		321
8.1	Introduction	321
8.2	Structure and Composition of Blood Vessels	322
8.3	Arterial Wall as a Membrane: Behavior Under Uniaxial Loading	326
8.4	Arterial Wall as a Membrane: Biaxial Loading and Torsion Experiments	336
8.5	Arterial Wall as a Membrane: Dynamic Modulus of Elasticity from Flexural Wave Propagation Measurements	343
8.6	Mathematical Representation of the Pseudo-Elastic Stress–Strain Relationship	345
8.7	Blood Vessel Wall as a Three-Dimensional Body: The Zero Stress State	349
8.8	Blood Vessel Wall as a Three-Dimensional Body: Stress and Strain, and Mechanical Properties of the Intima, Media, and Adventitia Layers	352
8.9	Arterioles. Mean Stress–Mean Diameter Relationship	357
8.10	Capillary Blood Vessels	360
8.11	Veins	363
8.12	Effect of Stress on Tissue Growth	369
8.13	Morphological and Structural Remodeling of Blood Vessels Due to Change of Blood Pressure	370
8.14	Remodeling the Zero Stress State of a Blood Vessel	373
8.15	Remodeling of Mechanical Properties	374
8.16	A Unified Interpretation of the Morphological, Structural, Zero Stress State, and Mechanical Properties Remodeling	376
	Problems	377
	References	384

Chapter 9	
Skeletal Muscle	392
9.1 Introduction	392
9.2 The Functional Arrangement of Muscles	393
9.3 The Structure of Skeletal Muscle	394
9.4 The Sliding Element Theory of Muscle Action	397
9.5 Single Twitch and Wave Summation	397
9.6 Contraction of Skeletal Muscle Bundles	398
9.7 Hill's Equation for Tetanized Muscle	399
9.8 Hill's Three-Element Model	405
9.9 Hypotheses of Cross-Bridge Theory	413
9.10 Evidences in Support of the Cross-Bridge Hypotheses	415
9.11 Mathematical Development of the Cross-Bridge Theory	418
9.12 Constitutive Equation of the Muscle as a Three-Dimensional Continuum	420
9.13 Partial Activation	422
Problems	423
References	424
 Chapter 10	
Heart Muscle	427
10.1 Introduction: The Difference Between Myocardial and Skeletal Muscle Cells	427
10.2 Use of the Papillary or Trabecular Muscles as Testing Specimens	431
10.3 Use of the Whole Ventricle to Determine Material Properties of the Heart Muscle	433
10.4 Properties of Unstimulated Heart Muscle	433
10.5 Force, Length, Velocity of Shortening, and Calcium Concentration Relationship for the Cardiac Muscle	441
10.6 The Behavior of Active Myocardium According to Hill's Equation and Its Modification	445
10.7 Pinto's Method	453
10.8 Micromechanical Derivation of the Constitutive Law for the Passive Myocardium	455
10.9 Other Topics	457
Problems	460
References	462
 Chapter 11	
Smooth Muscles	466
11.1 Types of Smooth Muscles	466
11.2 The Contractile Machinery	468
11.3 Rhythmic Contraction of Smooth Muscle	470
11.4 The Property of a Resting Smooth Muscle: Ureter	475

11.5 Active Contraction of Ureteral Segments	481
11.6 Resting Smooth Muscle: Taenia Coli	487
11.7 Other Smooth Muscle Organs	495
Problems	495
References	497
Chapter 12	
Bone and Cartilage	500
12.1 Introduction	500
12.2 Bone as a Living Organ	504
12.3 Blood Circulation in Bone	507
12.4 Elasticity and Strength of Bone	510
12.5 Viscoelastic Properties of Bone	513
12.6 Functional Adaptation of Bone	514
12.7 Cartilage	519
12.8 Viscoelastic Properties of Articular Cartilage	520
12.9 The Lubrication Quality of Articular Cartilage Surfaces	525
12.10 Constitutive Equations of Cartilage According to a Triphasic Theory	531
12.11 Tendons and Ligaments	535
Problems	536
References	538
Author Index	545
Subject Index	559