

# Contents

Preface .....	vii
1. Historical Backgrounds and Book Contents	
1.1 Discoveries of the Circulation.....	1
1.2 Importance of the Vascular System .....	7
1.3 Modern Concepts .....	8
1.4 Book Contents.....	9
2. Vascular Biology, Structure and Function	
2.1 Anatomical Organization of the Vasculature .....	14
2.1.1 The Circulatory System .....	14
2.1.2 The Heart .....	14
2.1.3 The Arteries .....	18
2.1.4 The Veins.....	18
2.1.5 The Microvasculature .....	19
2.2 Mechanical Properties of Blood Vessels.....	20
2.2.1 Some Geometric Aspects of Blood Vessels.....	20
2.2.2 Vascular Stiffness and Elastic Properties.....	25
2.3 Functional Properties of Blood .....	30
2.3.1 Blood Plasma and Blood Gas.....	30
2.3.2 Oxygen Saturation Curves and Hemoglobin.....	31
2.3.3 Red Blood Cells, Hematocrit and Blood Volume .....	33
2.4 Control Aspects of the Vascular System.....	35
2.4.1 Control of the Central Cardiovascular System.....	36
2.4.2 Functions of the Baroreceptors .....	37
2.4.3 Arterial Chemoreceptors .....	39
3. Physical Concepts and Basic Fluid Mechanics	
3.1 Basic Mechanics and Dimensional Analysis .....	41
3.1.1 Mass, Length and Time System and the Pi-Theorem of Buckingham .....	41

3.1.2 Dimensional Matrix .....	43
3.1.3 Dynamic Similitude in Vascular Biology .....	44
3.1.4 Elastic and Viscoelastic Properties of Blood Vessels .....	46
3.2 Frequency Domain and Fourier Analysis .....	54
3.2.1 Periodic Functions .....	54
3.2.2 Trigonometric Fourier Series .....	55
3.2.3 Complex Form of Fourier Series.....	58
3.2.4 Other Aspects of Frequency Domain Analysis .....	60
3.2.4.1 Dirichlet Conditions .....	60
3.2.4.2 Line Spectrum and Nyquist Criterion .....	61
3.2.4.3 Correlation, Coherence and Power Spectrum .....	61
3.3 Fluid Mechanics and Rheology.....	63
3.3.1 Steady Flow and Poiseuille Equation.....	63
3.3.2 Bernoulli's Equation and Narrowing Vessel Lumen .....	67
3.3.3 Orifice Flow and Torricelli's Equation .....	68
3.3.4 The Gorlin Equation .....	69
3.3.5 Flow and Flow Acceleration.....	69
3.3.6 Newtonian Fluid, No-Slip, Boundary Conditions and Entry Length .....	72
3.3.6.1 Newtonian Fluid.....	72
3.3.6.2 No-Slip Boundary Conditions.....	73
3.3.6.3 Laminar and Turbulent Flow.....	73
3.3.6.4 Entry Length .....	75
4. Hemodynamics of Large Arteries	
4.1 Ventricular Outflow and the Aorta .....	76
4.1.1 Ventricular Ejection.....	76
4.1.2 Cardiac Muscle Contraction and Force-Length-Velocity Relation .....	78
4.1.3 The Pressure-Volume Curve and Contractility of the Heart .....	81
4.1.4 Ejection Fraction, Cardiac Performance, Preload and Afterload .....	82
4.1.5 Coupling of the Ventricle and the Arterial System .....	83
4.1.6 Dynamic of Heart-Arterial System Interactions.....	87
4.2 Pressure-Flow Relations and Vascular Impedance .....	89
4.2.1 Pressure and Flow Waveforms in Large and Small Arteries .....	89
4.2.2 Vascular Impedance to Blood Flow .....	94
4.3 Wave Propagation Phenomena .....	99
4.3.1 The Propagation Constant .....	99
4.3.2 Foot-to-Foot Velocity .....	100
4.3.3 Apparent Propagation Constant and Transfer Function.....	103
4.3.4 Determination of the Propagation Constant .....	107

4.4 Wave Reflection Phenomena .....	110
4.4.1 Influence of Wave Reflections on Pressure and Flow Waveforms.....	110
4.4.2 The Reflection Coefficients .....	116
4.4.3 Augmentation Index.....	118
4.4.4 Wave Reflection Sites.....	119
4.5 Modeling Aspects of the Arterial System .....	120
4.5.1 Mathematical Formulations .....	120
4.5.2 Linear Theories of Oscillatory Blood Flow in Arteries .....	124
4.5.3 The Lumped Model of the Arterial System: The Windkessel.....	130
4.5.4 Nonlinear Aspects and Pressure-Dependent Arterial Compliance .....	136
5. Vascular Branching .....	
5.1 Branching Geometry .....	142
5.1.1 Complexity of Vascular Branching.....	142
5.1.2 Nonuniform Branching and 3-D Branching Structure .....	144
5.1.3 Space-Filling Properties and Modeling.....	146
5.2 Fluid Mechanics of Vascular Branching.....	148
5.2.1 Branching Geometry and Fluid Dynamic Considerations .....	148
5.2.2 Fluid Mechanics Associated with Atherosclerosis and Stenosis.....	154
5.3 Pulse Transmission Characteristics at Vascular Branching .....	157
5.3.1 Impedance Matching and Wave Reflections.....	157
5.3.2 Area Ratio Concept.....	160
5.3.3 Minimum Local Reflections at Vascular Branching Junctions .....	164
5.4 Optimization Aspects Applicable to Vascular Branching.....	166
5.4.1 Optimizing Vessel Radius and the Cube Law.....	166
5.4.2 Optimizing Branching Radii and Angles .....	170
6. The Venous System .....	
6.1 The Reservoir Properties and Venous Return .....	172
6.1.1 Venous Compliance and Reservoir Characteristics .....	172
6.1.2 Structural Properties of Veins .....	174
6.1.3 Venous Return .....	175
6.2 Pressure and Flow Waveforms in Vein.....	176
6.2.1 The Normal Pressure and Flow Waveforms in Veins .....	176
6.2.2 Respiration Effects on Venous Pressure and Flow Waveforms .....	178
6.2.3 Abnormal Venous Pressure and Flow Waveforms .....	180
6.3 Modeling and Collapsible Vessel Properties .....	182
6.3.1 Steady Flow in Collapsible Tubes.....	182
6.3.2 Flow Limitation and Model Experiments .....	184
6.3.3 Pulse Wave Transmission Characteristics in Veins .....	188

7. The Microcirculation	
7.1 Structure of the Microcirculation .....	192
7.1.1 Functional Organization of the Microvasculature.....	192
7.1.2 The Capillary Circulation.....	196
7.2 Pressure-Flow Relation and Microcirculatory Mechanics .....	200
7.2.1 Flow-Related Mechanical Characteristics of the Microcirculation.....	200
7.2.2 Some Pressure-Related Mechanical Characteristics .....	202
7.3 Pulse Transmission and Modeling Aspects.....	206
7.3.1 Pressure and Flow Waveforms in Arterioles and Capillaries.....	206
7.3.2 Pulse Transmission Characteristics in the Microcirculation .....	208
7.3.3 Modeling Aspects of the Microcirculation.....	210
8. Hemodynamic Measurements and Dynamics of the Assisted Circulation	
8.1 Pressure, Flow and Dimension Measurements .....	214
8.1.1 Invasive Blood Pressure Measurements.....	214
8.1.1.1 The Needle-Pressure Transducer System.....	214
8.1.1.2 The Catheter-Pressure Transducer Systems .....	217
8.1.2 Noninvasive Blood Pressure Measurements .....	222
8.1.2.1 Auscultatory Measurement of Blood Pressure .....	222
8.1.2.2 Blood Pressure Measurement with the Oscillometric Method .....	224
8.1.2.3 Noninvasive Blood Pressure Monitoring with Tonometer .....	225
8.1.3 Blood Flow Measurement.....	226
8.1.3.1 Electromagnetic Flowmeter .....	226
8.1.3.2 Ultrasound Doppler Velocimeters.....	227
8.1.3.3 Indicator Dilution Methods and Thermodilution .....	229
8.1.4 Measurement of Vascular Dimensions .....	233
8.2 The Assisted Circulation and the Intra-Aortic Balloon Pump.....	234
8.2.1 Mechanical Assist Devices and the Assisted Circulation .....	234
Bibliography .....	245
Index .....	253