

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