

Cardiovascular Physiology Concepts

SECOND
EDITION



Richard E. Klabunde

 Wolters Kluwer Health | Lippincott
Williams & Wilkins

CONTENTS

Preface.....	v
Acknowledgments.....	v

1	Introduction to the Cardiovascular System.....	1
	THE NEED FOR A CIRCULATORY SYSTEM.....	1
	THE ARRANGEMENT OF THE CARDIOVASCULAR SYSTEM.....	2
	THE FUNCTIONS OF THE HEART AND BLOOD VESSELS.....	4
	Heart.....	4
	Vascular System.....	5
	Interdependence of Circulatory and Organ Function.....	5
	THE REGULATION OF CARDIAC AND VASCULAR FUNCTION.....	5
	THE CONTENT OF THE FOLLOWING CHAPTERS.....	6
	SUMMARY OF IMPORTANT CONCEPTS.....	7
	REVIEW QUESTIONS.....	7
	ANSWERS TO REVIEW QUESTIONS.....	8
2	Electrical Activity of the Heart.....	9
	INTRODUCTION.....	10
	CELL MEMBRANE POTENTIALS.....	10
	Resting Membrane Potentials.....	10
	Maintenance of Ionic Gradients.....	12
	Ion Channels.....	14
	Action Potentials.....	16
	Arrhythmias Caused by Abnormal Action Potential Generation.....	21
	CONDUCTION OF ACTION POTENTIALS WITHIN THE HEART.....	21
	Electrical Conduction within the Heart.....	21
	Regulation of Conduction Velocity.....	23
	Abnormal Conduction.....	24
	Tachycardia Caused by Reentry.....	24
	THE ELECTROCARDIOGRAM.....	26
	ECG Tracing.....	26
	Interpretation of Normal and Abnormal Cardiac Rhythms.....	28
	from the ECG.....	28
	volume Conductor Principles and ECG Rules of Interpretation.....	30
	ECG Leads: Placement of Recording Electrodes.....	32
	ELECTROPHYSIOLOGICAL CHANGES DURING CARDIAC ISCHEMIA.....	35
	SUMMARY OF IMPORTANT CONCEPTS.....	36
	REVIEW QUESTIONS.....	37
	ANSWERS TO REVIEW QUESTIONS.....	38
	ANSWERS TO PROBLEMS AND CASES.....	39
	SUGGESTED RESOURCES.....	40

3	Cellular Structure and Function	41
	INTRODUCTION.....	41
	CARDIAC CELL STRUCTURE AND FUNCTION.....	41
	Myocytes and Sarcomeres.....	41
	Excitation–Contraction Coupling.....	43
	Regulation of Contraction (Inotropy).....	45
	Regulation of Relaxation (Lusitropy).....	49
	Cardiac Myocyte Metabolism.....	49
	VASCULAR STRUCTURE AND FUNCTION.....	49
	Vascular Smooth Muscle Cells.....	50
	Vascular Endothelial Cells.....	54
	SUMMARY OF IMPORTANT CONCEPTS.....	55
	REVIEW QUESTIONS.....	56
	ANSWERS TO REVIEW QUESTIONS.....	57
	ANSWERS TO PROBLEMS AND CASES.....	58
	SUGGESTED RESOURCES.....	59
4	Cardiac Function	60
	INTRODUCTION.....	60
	CARDIAC ANATOMY.....	60
	Functional Anatomy of the Heart.....	60
	Autonomic Innervation.....	61
	THE CARDIAC CYCLE.....	62
	Cardiac Cycle Diagram.....	62
	Phase 1. Atrial Systole.....	62
	Phase 2. Isovolumetric Contraction.....	64
	Phase 3. Rapid Ejection.....	65
	Phase 4. Reduced Ejection.....	65
	Phase 5. Isovolumetric Relaxation.....	65
	Phase 6. Rapid Filling.....	66
	Phase 7. Reduced Filling.....	66
	Summary of Intracardiac Pressures.....	66
	Ventricular Pressure–Volume Relationship.....	67
	CARDIAC OUTPUT.....	67
	Measurement of Cardiac Output.....	68
	Influence of Heart Rate and Stroke Volume on Cardiac Output.....	68
	EFFECTS OF PRELOAD ON STROKE VOLUME.....	69
	Effects of Ventricular Compliance on Preload.....	69
	Effects of Preload on Tension Development (Length–Tension Relationship).....	71
	Effects of Venous Return on Stroke Volume (Frank–Starling Mechanism).....	74
	Factors Determining Ventricular Preload.....	75
	EFFECTS OF AFTERLOAD ON STROKE VOLUME.....	77
	Effects of Afterload on the Velocity of Fiber Shortening (Force–Velocity Relationship).....	77
	Effects of Afterload on Frank–Starling Curves.....	79
	Effects of Afterload on Pressure–Volume Loops.....	79

EFFECTS OF INOTROPY ON STROKE VOLUME.....	80
Effects of Inotropy on Length-Tension Relationship.....	80
Effects of Inotropy on Force-Velocity Relationship.....	81
Effects of Inotropy on Frank-Starling Curves.....	81
Effects of Inotropy on Pressure-Volume Loops.....	81
Factors Influencing Inotropic State.....	82
Cellular Mechanisms of Inotropy.....	82
INTERDEPENDENCE OF PRELOAD, AFTERLOAD, AND INOTROPY.....	83
MYOCARDIAL OXYGEN CONSUMPTION.....	84
How Myocardial Oxygen Consumption is Determined.....	85
Factors Influencing Myocardial Oxygen Consumption.....	86
SUMMARY OF IMPORTANT CONCEPTS.....	87
REVIEW QUESTIONS.....	89
ANSWERS TO REVIEW QUESTIONS.....	89
ANSWERS TO PROBLEMS AND CASES.....	91
SUGGESTED RESOURCES.....	92
5 Vascular Function.....	93
INTRODUCTION.....	93
ANATOMY AND FUNCTION.....	93
Vascular Network.....	93
Distribution of Pressures and Volumes.....	95
ARTERIAL BLOOD PRESSURE.....	97
Mean Arterial Pressure.....	97
Aortic Pulse Pressure.....	98
HEMODYNAMICS (PRESSURE, FLOW, AND RESISTANCE).....	100
Effects of Vessel Length, Radius, and Blood Viscosity on Resistance to Blood Flow.....	100
Laminar versus Turbulent Flow.....	102
Series and Parallel Arrangement of the Vasculature.....	103
REGULATION OF SYSTEMIC VASCULAR RESISTANCE.....	106
Calculation of Systemic Vascular Resistance.....	106
Vascular Tone.....	107
VENOUS BLOOD PRESSURE.....	107
Venous Blood Volume and Compliance.....	107
Mechanical Factors Affecting Central Venous Pressure and Venous Return.....	109
Summary of Factors Affecting Central Venous Pressure.....	112
VENOUS RETURN AND CARDIAC OUTPUT.....	113
The Balance between Venous Return and Cardiac Output.....	113
Systemic Vascular Function Curves.....	113
Cardiac Function Curves.....	116
Interactions between Cardiac and Systemic Vascular Function Curves.....	116
SUMMARY OF IMPORTANT CONCEPTS.....	118
REVIEW QUESTIONS.....	119
ANSWERS TO REVIEW QUESTIONS.....	121
ANSWERS TO PROBLEMS AND CASES.....	122
SUGGESTED RESOURCES.....	123

6	Neurohumoral Control of the Heart and Circulation	124
	INTRODUCTION.....	124
	AUTONOMIC NEURAL CONTROL.....	124
	Autonomic Innervation of the Heart and Vasculature.....	124
	Baroreceptor Feedback Regulation of Arterial Pressure.....	130
	Chemoreceptors.....	134
	Other Autonomic Reflexes Affecting the Heart and Circulation.....	135
	HUMORAL CONTROL.....	135
	Circulating Catecholamines.....	135
	Renin-Angiotensin-Aldosterone System.....	137
	Atrial Natriuretic Peptide.....	139
	Vasopressin (Antidiuretic Hormone).....	140
	INTEGRATION OF NEUROHUMORAL MECHANISMS.....	141
	SUMMARY OF IMPORTANT CONCEPTS.....	142
	REVIEW QUESTIONS.....	143
	ANSWERS TO REVIEW QUESTIONS.....	145
	ANSWERS TO PROBLEMS AND CASES.....	146
	SUGGESTED RESOURCES.....	147
7	Organ Blood Flow	148
	INTRODUCTION.....	148
	DISTRIBUTION OF CARDIAC OUTPUT.....	148
	LOCAL REGULATION OF BLOOD FLOW.....	149
	Tissue Factors.....	149
	Endothelial Factors.....	152
	Smooth Muscle (Myogenic) Mechanisms.....	153
	Extravascular Compression.....	153
	Autoregulation of Blood Flow.....	154
	Reactive and Active Hyperemia.....	156
	SPECIAL CIRCULATIONS.....	157
	Coronary Circulation.....	157
	Cerebral Circulation.....	161
	Skeletal Muscle Circulation.....	164
	Cutaneous Circulation.....	168
	Splanchnic Circulation.....	169
	Renal Circulation.....	170
	Pulmonary Circulation.....	173
	Summary of Special Circulations.....	175
	SUMMARY OF IMPORTANT CONCEPTS.....	176
	REVIEW QUESTIONS.....	176
	ANSWERS TO REVIEW QUESTIONS.....	178
	ANSWERS TO PROBLEMS AND CASES.....	178
	SUGGESTED RESOURCES.....	178
8	Exchange Function of the Microcirculation	180
	INTRODUCTION.....	180
	MECHANISMS OF EXCHANGE.....	180
	Diffusion.....	181
	Bulk Flow.....	182
	Vesicular and Active Transport.....	182

EXCHANGE OF OXYGEN AND CARBON DIOXIDE.....	182
Oxygen Diffusion.....	182
Oxygen Delivery and Extraction.....	183
Carbon Dioxide Diffusion.....	186
TRANSCAPILLARY FLUID EXCHANGE.....	186
Physical Mechanisms Governing Fluid Exchange.....	187
Capillary Exchange Mode.....	192
EDEMA FORMATION.....	193
SUMMARY OF IMPORTANT CONCEPTS.....	194
REVIEW QUESTIONS.....	194
ANSWERS TO REVIEW QUESTIONS.....	195
ANSWERS TO PROBLEMS AND CASES.....	196
SUGGESTED RESOURCES.....	197
9 Cardiovascular Integration, Adaptation, and Pathophysiology.....	198
INTRODUCTION.....	198
CARDIOVASCULAR RESPONSES TO EXERCISE.....	198
Mechanisms Involved in Cardiovascular Response to Exercise.....	199
Steady-State Changes in Cardiovascular Function during Exercise.....	201
Factors Influencing Cardiovascular Response to Exercise.....	203
MATERNAL CHANGES IN CARDIOVASCULAR FUNCTION DURING PREGNANCY.....	205
HYPOTENSION.....	206
Causes of Hypotension.....	206
Compensatory Mechanisms during Hypotension.....	207
Decompensatory Mechanisms Following Severe and Prolonged Hypotension.....	210
Physiologic Basis for Therapeutic Intervention.....	212
HYPERTENSION.....	212
Essential (Primary) Hypertension.....	213
Secondary Hypertension.....	214
Physiologic Basis for Therapeutic Intervention.....	215
HEART FAILURE.....	216
Causes of Heart Failure.....	216
Systolic versus Diastolic Dysfunction.....	217
Systemic Compensatory Mechanisms in Heart Failure.....	219
Exercise Limitations Imposed by Heart Failure.....	221
Physiologic Basis for Therapeutic Intervention.....	222
VALVE DISEASE.....	223
Valve Stenosis.....	223
Valve Regurgitation.....	226
SUMMARY OF IMPORTANT CONCEPTS.....	229
REVIEW QUESTIONS.....	229
ANSWERS TO REVIEW QUESTIONS.....	231
ANSWERS TO CASES.....	233
SUGGESTED RESOURCES.....	234
Index.....	235