CONTENTS

Preface xi

1 RENAL FUNCTIONS, ANATOMY, AND BASIC PROCESSES 1

Objectives 1
Functions 2
Anatomy of the Kidneys and Urinary System 4
The Nephron 6
The Renal Corpuscle 7
The Tubule 8
Blood Supply to the Nephrons 11
Categories of Nephrons 13
Nephron Heterogeneity 13
The Juxtaglomerular Apparatus 14
Renal Innervation 14
Introduction to Basic Renal Processes 14
Glomerular Filtration 14
Tubular Reabsorption and Tubular Secretion 16
Metabolism by the Tubules 19
Intrarenal Chemical Messengers 20
Methods in Renal Physiology 20
Notes 22

2 RENAL BLOOD FLOW AND GLOMERULAR FILTRATION 24

Objectives 24
Flow, Resistance, and Pressure in the Kidneys 25
Glomerular Filtration 26
Formation of Glomerular Filtrate 26
Direct Determinants of GFR 28
K_f 30

P_{GC} 31
P_{BC} 33
Π_{GC} 33
Mean Arterial Pressure and Autoregulation 33
Renal Sympathetic Nerves 38
Reflexes Involving the Renal Sympathetic Nerves 39
Angiotensin II 41
Control of Renin Secretion 41
Intrarenal Baroreceptors 41
Macula Densa 41
Renal Sympathetic Nerves 43
Angiotensin II 44
Adaptive Value of Increased Renin Release 44
Prostaglandins 45
Other Factors 45
Notes 48

3 RENAL CLEARANCE 51

Objectives 51
Measurement of GFR 51
Definition of Clearance 54
Basic Clearance Formula 55
Quantitation of Tubular Reabsorption and Secretion Using Clearance 57
Plasma Creatinine and Urea Concentrations as Indicators af GFR Changes 58
Notes 60

4 BASIC MECHANISMS OF TUBULAR REABSORPTION AND SECRETION 62

Objectives 62
Classification of Transport Mechanisms 63
Diffusion 63
Facilitated Diffusion 63
Primary Active Transport 63
Secondary Active Transport (Cotransport and Countertransport) 64
Endocytosis 64
Solvent Drag 64

Transport Mechanisms in Reabsorption 64
Fluid Uptake by Peritubular Capillaries 69
Transport Maximum 71
Transport Mechanisms in Tubular Secretion 72
Bidirectional Transport 73
Regulation of Membrane Channels and Transporters 76
Tubular Division of Labor 77
Notes 77

5 **RENAL HANDLING OF ORGANIC SUBSTANCES** 79

Objectives 79
Active Proximal Reabsorption of Organic Nutrients: Glucose, Amino Acids, etc. 79
Proteins and Peptides 80
Urea 82
Active Proximal Secretion of Organic Anions 82
Urate 84
Active Proximal Secretion of Organic Cations 84
Passive Reabsorption or Secretion of Weak Organic Acids and Bases 85
Notes 88

6 **BASIC RENAL PROCESSES FOR SODIUM, CHLORIDE, AND WATER** 89

Objectives 89
Overview 91
Sodium Reabsorption 92
Chloride Reabsorption 94
Water Reabsorption 95
Individual Tubular Segments 97
Proximal Tubule 97
Henle's Loop 101
Distal Convoluted Tubule and Collecting-Duct System 102
Urinary Concentration: the Medullary Countercurrent Multiplier System 104
The Role of Interstitial Urea in Balancing Collecting-Duct Urea 109
Countercurrent Exchange: Vasa Recta 110
Summary 112
Notes 113

7 CONTROL OF SODIUM AND WATER EXCRETION: REGULATION OF PLASMA VOLUME AND OSMOLARITY 116

Objectives 116
Control of GFR in Response to Changes in Body Sodium Content and Extracellular Volume 120
Control of Tubular Sodium Reabsorption 120
Glomerulotubular Balance 122
Aldosterone 123
Control of Aldosterone Secretion 124
Peritubular-Capillary Starling Factors and the Role of Renal Interstitial Hydraulic Pressure 126
Direct Tubular Effects of Renal Sympathetic Nerves 129
Direct Tubular Effects of Angiotensin II 129
Pressure Natriuresis 130
Atrial Natriuretic Factor (ANF) 130
Antidiuretic Hormone 130
Other Hormones 131
Summary of the Control of Sodium Excretion 132
Abnormal Sodium Retention 133
Control of Water Excretion 134
Baroreceptor Control of ADH Secretion 135
Osmoreceptor Control of ADH Secretion 135
Thirst and Salt Appetite 139
Summary of the Effects of Angiotensin II 142
Notes 142

8 RENAL REGULATION OF POTASSIUM BALANCE 145

Objectives 145
Regulation of Internal Potassium Distribution 146
Basic Renal Mechanisms 147
Mechanism of Potassium Secretion in the Cortical Collecting Duct 149
Homeostatic Control of Potassium Secretion by the Cortical Collecting Duct 151
Potassium Secretion and Fluid Delivery to the Cortical Collecting Duct 154
Effects of Diuretics 154
ADH and Water Diuresis 157
The Effects of Acid-Base Changes on Potassium Secretion 157
Notes 160

9 RENAL REGULATION OF HYDROGEN-ION BALANCE 162

Objectives 162
Bicarbonate Excretion 166
Bicarbonate Filtration and Reabsorption 167
Bicarbonate Secretion 170
Addition of New Bicarbonate to the Blood (Renal Excretion of Hydrogen Ions) 171
Hydrogen-Ion Secretion and Excretion on Urinary Buffers 172
Phosphate and Organic Acids as Buffers 173
Qualitative Integration of Bicarbonate Reabsorption and Hydrogen-Ion Excretion on Nonbicarbonate Buffers 174
Glutamine Catabolism and NH_4^+ Excretion 176
Quantitation of Renal Acid-Base Compensation 177
Homeostatic Control of Renal Acid-Base Compensation 178
Control of Renal Glutamine Metabolism and NH_4^+ Excretion 179
Control of Tubular Hydrogen-Ion Secretion 179
Control of Bicarbonate Secretion 181
Specific Categories of Acid-Base Disorders 181
Renal Compensation for Respiratory Acidosis and Alkalosis 181
Renal Compensation for Metabolic Acidosis and Alkalosis 182
Factors Causing the Kidneys to Generate or Maintain a Metabolic Alkalosis 183
Influence of Extracellular-Volume Contraction 183
Influence of Chloride Depletion 184
Influence of Aldosterone Excess and Potassium Depletion 184
Notes 186

10 REGULATION OF CALCIUM AND PHOSPHATE BALANCE 190

Objectives 190
Effector Sites for Calcium Homeostasis 191
Gastrointestinal Tract 191
Kidneys 192
Bone 193

Hormonal Control of Effector Sites 194
Parathyroid Hormone 194
1,25-dihydroxyvitamin D_3 196
Calcitonin 197
Other Hormones 197
Overview of Renal Phosphate Handling 198
Notes 199

Study Questions 201

Appendix A

Table 1: Summary of Reabsorbtion and Secretion by Major Tubular Segments 217
Table 2: Major Functions of the Various Collecting-Duct Cells 218

Appendix B

Classes of Diuretics 219

Suggested Readings 220

Index 231