# Contents

## SECTION ONE
## Physiological Mechanisms Governing Electrocardiographic Deflections


**1. Fundamentals of Electrocardiography ..... 3**
- Electrocardiogram—An Introduction ..... 3
- Einthoven Theory of Electrical Activity ..... 4
- Anatomy and Physiology of Conduction Tissues of the Heart ..... 4
- Applied Physiology ..... 5
- Modes of Activation of the Heart (Atria and Ventricles) ..... 5

**2. The Electrode and the Lead System ..... 7**
- Electrodes ..... 7
- Lead System ..... 7
- Arbitrary Orientation of Different Leads ..... 9
- Continuous Monitoring System Used in Coronary Care Unit (CCU) ..... 10
- Special or Unconventional Leads for Recording Atrial Activity from Back of the Heart ..... 11

**3. Action Potentials and Waveforms ..... 12**
- Charged or Polarized or Resting Membrane ..... 12
- Generation of Action Potential in Pacemaker Cells ..... 12
- Recording of Depolarization and Repolarization as Waveforms (P-QRS-T Complex) on ECG ..... 14
- Waveforms of Electrocardiogram ..... 15
- Atrial Depolarization Wave (Atrial Complex—P wave) ..... 15
- Ventricular Activation Complex (Depolarization) ..... 15
- Intrinsic or Intrinsicoid Deflections ..... 20
- Physiology of R Wave Progression ..... 20

**4. The Cardiac Vector and the Electrical Axis ..... 23**
- Electrical Field of the Heart ..... 23
- Axial Reference Systems ..... 24
- Ventricular Depolarization, Instantaneous QRS Vectors and the Mean Manifest Electrical Axis ..... 24
- Axis Deviation ..... 29
- Abnormal P wave Axis and Associated Clinical Conditions ..... 36

**5. The Electrical Rotation of the Heart ..... 37**
- Positions of the Heart ..... 37
- Effect of Deep Respiration on the Rotational Patterns ..... 41

## Section Two
## The Electrocardiogram


**6. Normal Electrocardiogram ..... 45**
- Electrocardiographic (ECG) Paper ..... 45
- Heart Rate ..... 46
- Natural Pacemakers and Heart Rates ..... 47
- Prerequisite for Good Electrocardiogram Recording ..... 48
- Normal Electrocardiogram in Adults ..... 49
- Normal Electrocardiographic Intervals ..... 54
- Normal Segments and Junctions on ECG ..... 59
- Voltage Measurement ..... 59
- Electrocardiogram in Infants ..... 60
- Electrocardiogram in Children ..... 60

**7. Normal Electrocardiographic Variants in Adults ..... 62**
- Normal Electrocardiographic Variants in Adults—General Aspects ..... 62
- Conditions Associated with Well Recognized Electrocardiographic Variants ..... 64


## Section Three
## Chamber Hypertrophy or Enlargement


**8. Atrial Hypertrophy/Enlargement ..... 71**
- Anatomy and Electrophysiology of Human Heart ..... 71
- Chamber Enlargement ..... 71
- Atrial Hypertrophy and Enlargement ..... 72
- Left Atrial Hypertrophy or Enlargement ..... 73
- Combined Right and Left Atrial Hypertrophy (Biatrial Hypertrophy) ..... 77
- Review at Glance ..... 80

**9. Ventricular Hypertrophy/Enlargement ..... 82**
- Left Ventricular Hypertrophy (LVH) ..... 84
- Review at Glance ..... 90
- Right Ventricular Hypertrophy (RVH) ..... 91
- Biventricular (Combined Right and Left Ventricles) Hypertrophy ..... 95


## Section Four
## Conduction Defects


**10. Intracardiac Conduction Defects ..... 101**
- Basic Concepts of Conduction ..... 103

**11. Sinus Node Dysfunction ..... 105**
- Sinus Node Dysfunction and Structural Nodal Disease ..... 105
- Sinoatrial Blocks (SA Blocks) ..... 106
- Sick Sinus (Lazy Sinus, Unstable Sinus) Syndrome—The Structural Nodal Disease ..... 107
- Hypersensitive Carotid Sinus Syndrome ..... 115

**12. Atrioventricular (AV) Blocks ..... 116**
- Incomplete AV Blocks ..... 116
- Complete (Third Degree) AV Block ..... 121
- Clinical Significance of Second Degree AV Block and Complete AV Block ..... 124

- High Grade AV Block ..... 125
- Diagnosing AV Blocks at Glance ..... 126

**13. Bundle Branch Blocks ..... 128**

- Disorders of Intraventricular Conduction ..... 128
- Bundle Branch Blocks ..... 128
- Right Bundle Branch Block Pattern ..... 130
- Review at a Glance ..... 133
- Right Bundle Branch Block with Left Ventricular Hypertrophy ..... 133
- Intermittent Right Bundle Branch Block ..... 133
- Right Bundle Branch Block with Right Ventricular Hypertrophy ..... 134
- Left Bundle Branch Block (LBBB) Pattern ..... 137
- Left Bundle Branch with Left Anterior Fascicular Block ..... 140
- Left Bundle Branch Block with Left Posterior Fascicular Block ..... 142
- Left Bundle Branch Block with Left Ventricular Hypertrophy ..... 142
- Review at Glance ..... 143
- Alternating Right and Left Bundle Branch Block (Intermittent Bilateral Bundle Branch Block) ..... 144
- Masquerading Bundle Branch Block ..... 144
- Bundle Branch Block Alternans ..... 144
- Nonspecific or Indeterminate Intraventricular Conduction Defect ..... 144

**14. The Fascicular Blocks or Hemiblocks ..... 146**

- Fascicular Blocks ..... 146
- The Left Anterior Fascicular Block (Left Anterior Hemiblock) ..... 147
- Left Anterior Fascicular or Hemiblock (LAH) Block with Left Ventricular Hypertrophy ..... 149
- Left Posterior Fascicular Block or Left Posterior Hemiblock (LPH) ..... 150
- Left Septal Fascicular Block ..... 153
- Peri-infarction Block ..... 153
- Review at a Glance ..... 153
- Combined Fascicular Blocks ..... 153
- Bifascicular Blocks ..... 154
- Trifascicular Block ..... 156

**15. The $S_I$, $S_{II}$, $S_{III}$ Syndrome ..... 158**

- Definition ..... 158
- Mechanisms ..... 158
- Etiology ..... 159

## Section Five
## Stress Electrocardiography

**16. Stress Electrocardiography ..... 163**

- Exercise Electrocardiography ..... 163
- Pharmacological Methods of Stress Testing ..... 178
- Pharmacological Methods of Stress Testing ..... 180

## Section Six
## Continuous Ambulatory Electrocardiographic Recording

**17. Continuous Ambulatory Electrocardiographic Recording ..... 183**

- Continuous Ambulatory (Holter) Monitoring ..... 183
- Superiority of Ambulatory Electrocardiography Over Exercise Testing ..... 187

## SECTION SEVEN
## Coronary Artery Disease


**18. Myocardial Ischemia ..... 193**
- Pseudodepression and Pseudoelevation of ST Segment VS True (Ischemic) ST Depression and Elevation ..... 198
- Acute versus Chronic Change ..... 201
- Angina in a Patient with Infarction ..... 201
- Nonspecific ST Segment and T Wave Changes ..... 201
- Clinical and Electrocardiographic Correlation in Angina Pectoris ..... 204
- Variant Angina (Prinzmetal's Angina) Syndrome ..... 204
- Asymptomatic Electrocardiographic Abnormalities ..... 209

**19. Myocardial Infarction ..... 211**
- Hyperacute Myocardial Infarction ..... 221
- Evolution of Acute Myocardial Infarction ..... 223
- Subtle, Atypical or Nonspecific Pattern of Infarction ..... 225
- Chronic Established Changes ..... 230
- Localization of Myocardial Infarction by Electrocardiographic Patterns ..... 232
- Infarction of Left Ventricle ..... 232
- Right Ventricular Infarction ..... 249
- Subendocardial Infarction ..... 250
- Interventricular Septal Infarction ..... 251
- Atrial Infarction ..... 251
- ECG Features of Atrial Infarction ..... 252
- Myocardial Infarction with Conduction Disturbance ..... 252
- Ventricular Aneurysm ..... 262


## SECTION EIGHT
## Congenital and Heredofamilial Disorders


**20. Congenital Heart Disease ..... 267**
- Congenital Pulmonary Stenosis with Intact Septum ..... 267
- Primary Pulmonary Hypertension ..... 269
- Atrial Septal Defect (ASD) ..... 269
- Atrial Septal Defect with Reversed Shunt—The Eisenmenger's Syndrome ..... 273
- Common Atrium ..... 274
- Ventricular Septal Defect (VSD) ..... 274
- Malposition and Malformation of the Heart ..... 276
- Dextrocardia (True or Mirror Image versus Technical) ..... 277
- Patent Ductus Arteriosus (PDA) ..... 280
- Corrected Transposition of Great Vessels ..... 282
- Tetralogy of Fallot ..... 284
- Pentalogy of Fallot ..... 286
- Triology of Fallot ..... 286
- Ebstein's Anomaly ..... 287
- Persistent Truncus Arteriosus ..... 288
- Aortopulmonary Communication (Window) ..... 289
- Tricuspid Atresia ..... 289
- Congenital Aortic Stenosis ..... 290

**21. Heredofamilial Prolonged Q-T Syndromes ..... 292**
- Acquired Prolonged Q-T Syndrome ..... 293
- Clinical Significance ..... 294

**22. Accelerated Conduction or Pre-excitation ..... 295**
- Wolff-Parkinson-White (WPW) Syndrome ..... 295
- WPW Variants ..... 304

**23. Hypertrophic Cardiomyopathy ..... 308**
- Etiology ..... 308
- Macroscopic Subtypes ..... 309
- The Electrocardiogram ..... 309
- Clinical Significance ..... 313

## SECTION NINE
## Acquired Heart Disease

**24. Rheumatic Heart Disease ..... 317**
- Acute Rheumatic Carditis ..... 317
- Chronic Rheumatic Valvular Heart Disease ..... 318
- Floppy Mitral Valve (Mitral Valve Prolapse) Syndrome ..... 327

**25. Myocarditis and Cardiomyopathies ..... 330**
- Myocarditis ..... 330
- Chagas' Myocarditis ..... 332
- Review At Glance ..... 333
- Cardiomyopathies ..... 333

**26. Pericarditis ..... 339**
- Pericarditis with Effusion ..... 343
- Chronic Constrictive Pericarditis ..... 345

**27. Acute Pulmonary Thromboembolism (Acute Cor Pulmonale) ..... 347**
- Pathogenesis ..... 347
- Electrocardiographic Manifestations ..... 347
- Electrocardiogram ..... 347
- Frontal Plane Leads (I, II, III, aVR, aVL and aVF) ..... 347
- Horizontal Plane Leads ($V_1$ to $V_6$) ..... 348
- Diagnosis and Differential Diagnosis ..... 349
- Review at Glance ..... 351
- ECG Changes in Acute Cor Pulmonale ..... 351

**28. Chronic Obstructive Pulmonary Disease (COPD) and Chronic Cor Pulmonale ..... 352**
- Chronic Cor Pulmonale ..... 352
- Chronic Cor Pulmonale without Obstructive Disease of the Airways ..... 356

**29. Systemic Hypertension ..... 360**
- Hemodynamic Alterations ..... 360
- Electrocardiogram ..... 360
- Hypertension Associated with Other Conditions ..... 362
- Effect of Treatment ..... 362

## SECTION TEN
## The Disorders of Cardiac Rhythm


**30. Basic Physiopathologic Considerations ..... 367**
- Anatomy and Physiology of Conduction System ..... 367
- Classification of Cardiac Arrhythmias ..... 368
- Basic Approach for Analysis of Cardiac Rhythm ..... 369
- Arrhythmogenesis ..... 370
- Other Electrophysiological Abnormalities Leading to Cardiac Arrhythmias ..... 372
- Review at a Glance ..... 375

**31. Sinus Rhythm and its Manifestations ..... 376**
- Sinus Rhythm ..... 376
- Sinus Arrhythmia ..... 376
- Types ..... 377
- Sinus Bradycardia ..... 378
- Sinus Tachycardia ..... 379
- Sinus Nodal Re-entrant Tachycardia ..... 379

**32. Abnormal Atrial Rhythm (Atrial Arrhythmias or Dysarrhythmias) ..... 382**
- Atrial Arrhythmias ..... 382
- Atrial Ectopics (Extrasystoles or Premature Beats) ..... 382
- Atrial Bigeminy / Trigeminy ..... 385
- Atrial Interpolated Beat ..... 385
- Atrial Escape Beat ..... 385
- Ectopic Low Atrial Rhythm ..... 385
- Atrial Parasystole ..... 386
- Wandering Atrial Pacemaker Rhythm ..... 386
- Atrial Tachycardias ..... 387
- Review at Glance ..... 390
- Atrial Re-entrant Tachycardia ..... 390
- Multifocal Atrial Tachycardia (MAT) ..... 390
- Chaotic Atrial Rhythm ..... 391
- Atrial Flutter ..... 391
- Review at a Glance ..... 394
- Atrial Fibrillation (AF) ..... 394
- Review at Glance ..... 397

**33. Atrioventricular (AV) Nodal Disturbances ..... 398**
- AV Nodal (Junctional) Escape Beats (Read Chapter 40—Escape Rhythm) ..... 400
- Premature AV Nodal (Junctional) Complexes / AV Nodal Extrasystoles or Ectopics ..... 402
- AV Nodal (Junctional) Rhythm ..... 403
- Acceleration of AV Nodal Rhythm (Accelerated AV Nodal Rhythm or Idionodal Tachycardia) ..... 403

**34. Paroxysmal Supraventricular Tachycardias ..... 408**
Definition ..... 408
Mechanisms ..... 408
Atrioventricular (AV) Nodal Tachycardias ..... 409

**35. Ventricular Arrhythmias/Dysarrhythmias ..... 416**
- Ventricular Ectopics or Extrasystoles ..... 416
- Idioventricular Rhythms ..... 425

- Ventricular Tachycardia (VT) ..... 428
- Torsades De Pointes ..... 435
- Ventricular Flutter ..... 436
- Ventricular Fibrillation (VF) ..... 436
- Ventricular Asystole ..... 437
- Dying Heart (Agonal Rhythm) Pattern ..... 438
- Other Diagnostic Electrocardiographic Techniques for Arrhythmias ..... 438

**36. Reciprocal Rhythm and Reciprocal Tachycardia ..... 443**
- Reciprocal Rhythm ..... 443
- WPW Syndrome and Reciprocating Rhythm / Tachycardia ..... 448
- Tachycardia through Atrio-hisian Pathway (Lown-Ganong-Levine Syndrome with Tachycardia) ..... 452
- Tachycardias through Mahaim Fibers ..... 452

**37. Atrioventricular Dissociation ..... 455**
- Etiology ..... 456
- Mechanisms ..... 456

**38. Parasystole ..... 462**
- Parasystolic Ventricular Tachycardia ..... 464
- Atrial Parasystole and Parasystolic Atrial Tachycardia ..... 464
- Nodal Parasystole ..... 465

**39. Ventricular Aberrancy or Aberrant Intraventricular Conduction ..... 467**
- Phasic Aberrant Intraventricular Conduction ..... 467
- Ventricular Aberrancy ..... 473
- Atrial Fibrillation with Ventricular Aberration ..... 477
- Atrial Flutter with Ventricular Aberration ..... 480
- Ventricular Aberrancy versus Intermittent Bundle Branch Block ..... 482

**40. Escape Rhythm ..... 484**
Escape Beats and Escape Rhythm ..... 484

**41. Ventricular Fusion Beats ..... 490**
Ventricular Fusion Complexes or Beats ..... 490

**42. Ventricular Capture Beats ..... 493**
- Types of Ventricular Capture ..... 493
- Timing and Conduction of Capture Beats ..... 494
- Electrocardiographic Characteristics of a Capture Beat ..... 494
- Significance ..... 495


## SECTION ELEVEN
## Artificial Pacemakers


**43. Artificial Pacemakers ..... 499**
- Electrocardiographic Patterns of Paced Complexes ..... 509
- Malfunctioning of Pacemakers ..... 511
- Pacemaker Re-entrant Tachycardia (Endless Loop Tachycardia) ..... 516
- Pacemaker Syndrome ..... 517

## SECTION TWELVE
## Miscellaneous Disorders


**44. Heart in Endocrine Disorders and Injuries ..... 521**
- Hyperthyroidism (Thyrotoxicosis) ..... 521
- Hypothyroidism (Myxoedema) ..... 521
- Acromegaly ..... 523
- Cushing's Syndrome ..... 523
- Adrenal Insufficiency ..... 523
- Pheochromocytoma (Catecholamines Excess) ..... 524
- Parathyroid Disorders ..... 524
- Physical Injuries ..... 524
- Hypothermia ..... 524
- Electrical Injuries ..... 525
- Drowning ..... 525
- Trauma to the Heart ..... 525
- Tumors of the Heart ..... 525

**45. Drugs, Poisons and the Heart ..... 528**
- Drugs and the Heart ..... 528
- Phenothiazines and Other Antipsychotic Drugs ..... 534
- Antidepressants ..... 534
- Heart in Systemic Poisonings ..... 536
- Heart in Envenomation ..... 540

**46. The Electrolytes and the Heart ..... 544**
- Electrolyte Disturbances ..... 544
- Hypokalemia ..... 544
- Hyperkalemia ..... 547
- Hypercalcemia ..... 550
- Hypocalcemia ..... 551
- Hypomagnesemia ..... 552
- Hypermagnesemia ..... 552
- Uremia ..... 552

**47. Heart in Cerebrovascular and Neuromuscular Disorders ..... 554**
- Cerebrovascular Accident (CVA) ..... 554
- Hypokalemic and Hyperkalemic Periodic Paralysis ..... 554
- Neuromuscular Disorders ..... 556


## Appendices


**Appendix A**
- Normal 12-Lead Surface ECG and its Variations in Adults ..... 563

**Appendix B ..... 565**
- Analysis of an Arrhythmia ..... 565

**Appendix C ..... 567**
- Proforma for ECG Reporting ..... 567

***Index ..... 569***