Contents

Chapter 1. Electrocardiogram: The Basics **1**

- Parts of the Electrical System 3
- Waves of the Electrocardiogram 3
- Electrocardiogram Representation of Systole and Diastole 3
- Electrocardiogram Tracing 4

Chapter 2. Electrocardiogram Lead Placement and Standardization **5**

- Electrode Placement 7
- Limb Leads 7
- Augmented Limb Leads 8
- Precordial (Chest) Leads 8
- Standardization of Voltage and Timing Intervals 9

Chapter 3. Interpretation and Identification of Different Waves in Electrocardiogram and Calculation of Heart Rate **13**

- P Wave 14
  - » Characteristics of Normal P Wave 16
- PR Interval 16
  - » Causes of Prolonged PR interval 17
  - » Causes of Short PR interval 17
- PR Segment 17
- QRS Complex 18
- J-Point 19
- ST Segment 19
  - » Common Causes of ST Segment Elevation 19
  - » Less Common Causes of ST Segment Elevation 20
  - » Rare Causes of ST Segment Elevation 20
  - » Common Causes of ST Segment Depression 20
  - » Uncommon Causes of ST Segment Depression 21
- T Wave 22
  - » Patterns of Different "T" Waves 23
  - » Causes of T Wave Inversion 24
- QT interval 27
  - » Causes of Prolonged QT_c 29
  - » Drugs Causing QT Prolongation 30
  - » Causes of Short QT_c 31
- U Wave 32
  - » Causes of Prominent U Waves 32
- TP Segment 32
- Calculation of Heart Rate 32
- Sinus Bradycardia 34
- Sinus Tachycardia 35

Chapter 4. Axis Determination and Rotation of the Heart **39**

- Normal and Abnormal Axis on Electrocardiogram 41
- Axis Determination from QRS Configuration in LI, LII, and LIII 41
- Axis Calculation from Lead I and aVF 41
- Rotation of Heart 43
- Interpretation of QRS Axis 45
- Axis Determination by Isoelectric (Equiphasic) Lead Method 45
- Quick and Easy Determination of Electrocardiogram Axis 45

Chapter 5. Normal Variant Electrocardiogram **55**

- Sinus Arrhythmia 55
- Inverted P Waves 55
- PR Interval Variation 55
- QRS Duration: Bundle Branch Block Pattern 55
- Axis Deviation 58
- Q-Wave Abnormality 58
- Early Repolarization Pattern 58
- Nonspecific T-Wave Inversion 61
- Persistent Juvenile Pattern 64
- Wandering Pacemaker 64
- Tall R in V1 64

Chapter 6. Chamber Enlargement **68**

- Electrocardiographic Criteria for the Diagnosis of Left Ventricular Hypertrophy 68
  - » Increased QRS Amplitude (Voltage Criteria) 68
  - » Delayed Intrinsicoid Deflection (Increased Ventricular Activation Time) 70
  - » Widened QRS/T Angle 70
  - » Left Axis Deviation 70
  - » Secondary ST-T Abnormalities 70
  - » Left Atrial Abnormalities 73
- Diagnostic Criteria of Left Ventricular Hypertrophy Based on QRS Voltage 73
  - » Factors Influencing QRS Voltage 74
  - » Sokolow–Lyon Criteria 74
  - » Cornell Criteria to Detect Left Ventricular Hypertrophy 75
  - » Romhilt–Estes Score 75
  - » Perugia Score 75
  - » Framingham Electrocardiographic Score and Other System 75
  - » Left Ventricular Strain Pattern 76
  - » Differentiation Between Left Ventricular Hypertrophy with Strain and Ischemia 76
  - » Diagnosis of Left Ventricular Hypertrophy in the Presence of Left Bundle Branch Block 77
  - » Electrocardiographic Diagnosis of Left Ventricular Hypertrophy in Presence of Right Bundle Branch Block 77
  - » Left Ventricular Hypertrophy in Presence of Left Anterior Fascicular Block 77
  - » Left Ventricular Hypertrophy Pressure Versus Volume Overload 78

- Right Ventricular Hypertrophy 79
- Biventricular Hypertrophy 82
  - » Katz–Wachtel Sign 83
- Atrial Abnormalities 84
  - » Left Atrial Abnormality/Enlargement 84
  - » Right Atrial Abnormality/Enlargement 85
  - » Pseudo-P Pulmonale 85
  - » Biatrial Abnormality/Enlargement 85

Chapter 7. Myocardial Ischemia 98

- ECG Features of Stable Angina 98
- ECG Features of Acute Coronary Syndromes 98
- ST-Segment Depression 99
  - » Causes of ST Depression 99
  - » Patterns of ST-Segment Depression 99
  - » Primary and Secondary ST Depression 100
  - » Reciprocal ST-Segment Depression 103
- True Posterior ST-Segment Elevation Myocardial Infarction 104
- Wellens' Syndrome 104
- Nonspecific ST- and T-Wave Changes 104
- Diffuse ST-Segment Depression 108
- Prinzmetal Angina 111
- MINOCA (Myocardial Infarction with Nonobstructive Coronary Arteries) 112

Chapter 8. ECG Diagnosis of ST-Elevation Myocardial Infarction (STEMI) 117

- Hyperacute T Waves 117
- ST-Segment Elevation 119
  - » Causes of ST Elevation with Convexity Upward 121
  - » Causes of ST Elevation with Concavity Upward 121
  - » Causes of Saddle-Shaped ST Elevation in Leads V1–V3 121
- Appearance of Pathological Q-Waves 121
- T-Waves Inversion 122
- Normalization of the ST-Segment 122
- Significance of Reciprocal ST-Segment Depression in STEMI 125
- Localization of Site of Infarction 125
  - » ECG Criteria of Acute Anterior Myocardial Infarction 126
  - » ECG Criteria of Acute Inferior Myocardial Infarction 127
  - » ECG Criteria of Right Ventricular Infarction 129
  - » ECG Criteria of Posterior Infarction 131
- High Lateral ST-Elevation Myocardial Infarction 131
- Tombstone ST Elevation 134
- Diagnosis of ST-Elevation Myocardial Infarction in Presence of Bundle-Branch Block 134
  - » ECG Diagnosis of ST-Elevation Myocardial Infarction in Presence of Left Bundle-Branch Block 134
  - » Sgarbossa Scoring System for Diagnosis of ST-Elevation Myocardial Infarction in Presence of Left Bundle Branch Block 136
  - » ECG Diagnosis of ST-Elevation Myocardial Infarction in Presence of Right Bundle Branch Block 138
- Differential Diagnosis of ST-Segment Elevation 138

- Causes of ST-Segment Elevation Other Than ST-Elevation Myocardial Infarction 138
- Identification of the Exact Site of the Infarct-Related Artery 140
  - » ECG Criteria of Left Main Coronary Artery Occlusion 140
  - » ECG Criteria of Left Anterior Descending Artery Occlusion 141
  - » ECG Signs of Different Sites of Left Anterior Descending Artery Occlusion in the Context of Anterior ST-Elevation Myocardial Infarction 142
  - » Electrocardiogram Criteria of Left Circumflex Artery Occlusion 143
  - » ECG Criteria of Right Coronary Artery Occlusion 143
  - » de Winter's T Wave 143
  - » ECG Distinction Between Right Coronary Artery Versus Left Circumflex Coronary Artery Related Acute Inferior Myocardial Infarction 145
- Atrial Infarction 149
- Arrhythmias and Conduction Disturbances in the Acute Phase of STEMI 150
- ECG Evidence of Prior Myocardial Infarction 151
- Poor R-Wave Progression 151
- Significance of Persistently Elevated ST Segment After STEMI 151

Chapter 9. Electrocardiogram Documentation of Reperfusion in ST-Elevation Myocardial Infarction 161

- Electrocardiogram Assessment of Resolution of ST Elevation 164
  - » Sum ST-Segment Resolution 164
  - » Single-Lead ST-Segment Resolution 164
  - » Max ST-Segment Elevation 164
- Appearance of Early T-Wave inversion 166
- Arrhythmias Following ST Elevation Myocardial Infarction 168
- Resolution of ST-Segment Depression 169
- ECG Criteria of Successful Reperfusion 170
- Calculation of ST-Segment Change 170

Chapter 10. Ectopic and Escape Beats 172

- Premature Atrial Complex 173
- Premature Junctional Complex 176
- Premature Ventricular Complex 176
  - » Electrocardiogram Criteria for Diagnosis of Premature Ventricular Complex 178
  - » Causes of Premature Ventricular Contraction 181
- R-On-T Phenomenon 182
- Interpolated Beat 182
- Parasystole 183
- Differentiation Between Aberrant Ventricular Conduction and Premature Ventricular Complex 186
- Escape Beats 190
- Differences Between Premature Atrial Complex and Premature Ventricular Complex 193
- Differences Between Ectopic Beat and Escape Beat 193

Chapter 11. Narrow Complex Tachycardia 195

- Sinus Tachycardia 195
- Sinus Node Reentrant Tachycardia 196
- Multifocal Atrial Tachycardia 196

- Atrial Fibrillation 197
  - » Mechanisms of Atrial Fibrillation 197
  - » Causes of Atrial Fibrillation 197
  - » Classification of Atrial Fibrillation Based on the Temporal Pattern of the Arrhythmia 199
  - » Lone Atrial Fibrillation 201
- Atrial Flutter 202
- Paroxysmal Supraventricular Tachycardia 206
- Atrioventricular Nodal Reentrant Tachycardia (AVNRT) 207
  - » Types of Atrioventricular Nodal Reentrant Tachycardia 208
  - » ECG Characteristics of Atrioventricular Nodal Reentrant Tachycardia 208
- Atrioventricular Reentrant Tachycardia (AVRT) 209
  - » ECG Difference Between Atrioventricular Nodal Reentrant Tachycardia and Atrioventricular Reentrant Tachycardia 210
- Atrial Tachycardia 211

Chapter 12. Broad Complex Tachycardia 217

- Causes of Broad Complex Tachycardia 217
- Ventricular Tachycardia 217
  - » Electrocardiogram Criteria of Ventricular Tachycardia 217
  - » Monomorphic Ventricular Tachycardia 220
  - » Polymorphic Ventricular Tachycardia 222
- Torsades de Pointes 222
- Ventricular Flutter 223
- Ventricular Fibrillation 224
- Fascicular Ventricular Tachycardia 225
- Right Ventricular Outflow Tract Tachycardia 226
- Bidirectional Ventricular Tachycardia 227
- Accelerated Idioventricular Rhythm 227
- Broad Complex Tachycardias of Supraventricular Origin 227
  - » Supraventricular Tachycardia with Aberrant Conduction 229
  - » Supraventricular Tachycardia with Accessory Pathway 229
- Broad Complex Tachycardias: Ventricular Tachycardia Versus Supraventricular Tachycardia with Aberrancy 229
- Fusion Beats 231
- Capture Beats 231
- Josephson's Sign 233
- Tachycardia QRS More Narrow Than Sinus QRS 233
- Newer Criteria to Differentiate Between Ventricular Tachycardia and Supraventricular Tachycardia with Aberrancy 233
  - » The Brugada Algorithm 235
  - » Vereckei "the AVR" Algorithm 236
  - » Griffith Algorithm 236
  - » The Bayesian Approach 236
  - » Ultra Simple Brugada Criterion: R Wave Peak Time 237

Chapter 13. Bundle-Branch Block 242

- Bundle-Branch Block: Basic Principles 242

- Types of Bundle-Branch Blocks 243
- Right Bundle Branch Block 244
  - » ECG Criteria of Complete Right Bundle Branch Block 244
  - » ECG Criteria of Incomplete Right Bundle Branch Block 245
- Left Bundle Branch Block 247
  - » ECG Criteria of Left Bundle Branch Block 249
- Hemiblock Concept 252
  - » Left Anterior Hemiblock (LAHB) 255
  - » Left Posterior Hemiblock (LPHB) 255
  - » Left Septal Hemiblock 255
- Bifascicular/Trifascicular Block 259
- Peri-infarction Block 265
- Nonspecific Intraventricular Conduction Disturbance 265

Chapter 14. Sick Sinus Syndrome 271

- Sinus Bradycardia 271
- Sinus Arrest 271
- Escape Rhythms 271
- Tachycardia-Bradycardia Syndrome 272
- Sinoatrial Exit Block 279

Chapter 15. Atrioventricular Block 282

- First-Degree Atrioventricular Block 282
  - » Electrocardiogram Criteria of First-Degree Heart Block 285
- Second-Degree Atrioventricular Block 285
  - » Mobitz Type I Second-Degree Atrioventricular Block (Wenckebach Phenomenon) 285
  - » Mobitz Type II Second-Degree Atrioventricular Block (Hay Phenomenon) 286
  - » Site of Block 286
  - » Vagally-Mediated Atrioventricular Block and Atrioventricular Block in Athletes 293
- Third-Degree Atrioventricular Block (Complete Heart Block) 294

Chapter 16. Electrocardiographic Diagnosis of Cardiac Channelopathies 307

- Brugada Syndrome 307
  - » Types of Brugada Pattern Electrocardiograms 308
  - » Electrocardiographic Criteria for the Diagnosis of Brugada Syndrome 308
  - » Electrocardiogram Differentiation: Brugada Syndrome/Pattern Versus Right Bundle Branch Block 310
- Long QT Syndrome 312
  - » Different Varieties of Inherited Long QT Syndrome 313
  - » Acquired Long QT Syndrome 313
  - » QT and QTc Interval 314
  - » T-Wave Morphology in Long QT Syndrome 315
  - » Arrhythmias in Long QT Syndrome 315
  - » Drugs Associated with QTc Prolongation 315
- Short QT Syndrome 317
- Catecholaminergic Polymorphic Ventricular Tachycardia 317

Chapter 17. Preexcitation Syndromes 325

- Types of Preexcitation Syndromes 326
- Wolff–Parkinson–White Syndrome 326
- Concealed Accessory Pathways 328
- Arrhythmias in Wolff-Parkinson-White Syndrome 328
- Diagnosis of Coronary Artery Disease in Presence of Wolff-Parkinson-White Syndrome 331
- Localization of the Accessory Pathways 332
- Atrial Fibrillation in Wolff–Parkinson–White Syndrome 335
- Sudden Death in Wolff–Parkinson–White Syndrome 338
- Lown–Ganong–Levine Syndrome 338
- Mahaim-Type Preexcitation 338

Chapter 18. Electrocardiographic Diagnosis of Cardiomyopathies 345

- Hypertrophic Cardiomyopathy 345
  - » Basic Criteria for ECG Diagnosis of Hypertrophic Cardiomyopathy 351
  - » Anis-Baren ECG Triad 351
  - » Apical Cardiomyopathy 351
  - » Sudden Cardiac Death in Hypertrophic Cardiomyopathy 355
- Dilated Cardiomyopathy 361
  - » Goldberger's Triad 361
- Restrictive Cardiomyopathy 365
- Arrhythmogenic Right Ventricular Cardiomyopathy/Dysplasia 365
- Left Ventricular Noncompaction 367
- Takotsubo Cardiomyopathy 368
  - » Differentiation Between Acute Anterior Myocardial Infarction and Takotsubo Cardiomyopathy 368

Chapter 19. Electrocardiogram Diagnosis of Pericarditis and Other Cardiac Inflammatory Conditions 375

- Pericarditis 375
  - » Spodick's Sign 376
  - » Differentiation of Acute Pericarditis from Acute ST-Elevation Myocardial Infarction 378
  - » Differentiation of Acute Pericarditis from Early Repolarization Pattern 380
  - » Electrocardiogram Changes in Pericardial Effusion 382
  - » Cardiac Tamponade 383
- Electrocardiographic Diagnosis of Myocarditis 384
- Electrocardiographic Diagnosis of Endocarditis 387
- Electrocardiogram Changes in Rheumatic Carditis 387

Chapter 20. Electrocardiographic Manifestations of Electrolyte Abnormalities 392

- Hyperkalemia 392
  - » Different Stages of Hyperkalemia 393
- Hypokalemia 394
- Hypercalcemia 398
- Hypocalcemia 401
- Hypermagnesemia 401
- Hypomagnesemia 401
- Electrocardiogram Features of Multiple Electrolyte Imbalances 401

Chapter 21. Electrocardiograms in Specific Clinical Conditions 404

- Chronic Obstructive Pulmonary Disease (COPD) 404
- Pulmonary Embolism 406
  - » McGinn-White Sign 407
- Hypothermia 409
- Thyrotoxicosis 409
- Hypothyroidism 411
- Electrocardiogram Features of Increased Intracranial Pressure 412
- Parkinson's Disease 415
- Electrocardiogram Changes in Neuromuscular Disorders 415
- Friedreich's Ataxia: Cerebellar Ataxia 415
- Electrocardiogram After Heart Transplantation 416
- Electrocardiogram Features of Primary Pulmonary Hypertension (PPH) 417

Chapter 22. Effects of Various Drugs on the Electrocardiogram 425

- Digitalis 425
  - » Digoxin Effect 425
  - » Reverse Tick Sign 425
  - » ECG Manifestations of Digitalis Toxicity 426
- Tricyclic Antidepressants 430
- Beta-Blockers 430
- Verapamil 431
- Fluoroquinolones 432
- Macrolide Antibiotics 432
- Antiarrhythmic Drugs 432

Chapter 23. Electrocardiogram Features of Congenital Heart Diseases 435

- Atrial Septal Defect (ASD) 435
  - » ECG Features of Secundum ASD 435
- Crochetage Sign 437
- ECG Features of Primum ASD 440
- ECG Features of Sinus Venosus Type ASD 440
- ECG Findings in Ventricular Septal Defect (VSD) 444
- Tetralogy of Fallot 444
- Ebstein's Anomaly 446
- Dextrocardia 446
- Technical Dextrocardia 450
- Patent Ductus Arteriosus 450
- Coarctation of Aorta 450
- Pulmonary Stenosis 450
- Eisenmenger Syndrome 450
- Transposition of the Great Arteries 453
- Tricuspid Atresia 453
- Mitral Valve Prolapse (MVP) 453

Chapter 24. Pacemaker Electrocardiogram Interpretation 459

- Indications for Permanent Pacing 459
- Atrial Pacing 460

- Ventricular Pacing 460
- Pacemaker Types 462
- Pacemaker Codes 462
- Pacemaker Terminology 465
  - » Interpretation of Pacemaker ECG 466
- Effects of Pacemaker on ECG 466
- Pacemaker Malfunctions/Complications 466
- Diagnosis of ST-Elevation Myocardial Infarction (STEMI) in Presence of Pacemaker 466
- Diagnosis of Hyperkalemia in Presence of Pacemaker 468
- Electrocardiogram Interpretation After Cardiac Resynchronization Therapy 469

Chapter 25. Pediatric Electrocardiogram Interpretation 473

- Heart Rate 473
- Age-related Changes in Ventricles and QRS Axis 473
- Variations from Sinus Rhythm 476
  - » High Grade AV Block in Children 478
  - » Extrasystoles 478
- Influence of Sex 480
- Complete Heart Block in Pediatric ECG 480

Chapter 26. Exercise Tolerance Test 484

- Safety 485
  - » Normal Electrocardiographic Changes During Exercise 485
- Criteria for a Positive Exercise Test 485
  - » ST-Segment Depression 485
  - » ST-Segment Elevation 486
- Significance of ST-Segment Depression Limited to the Recovery Phase of Exercise Stress Test 488
- J-Point Depression During Exercise Tolerance Test 489
- Blood Pressure Response During Exercise Tolerance Test 489
- False-Positive Test 491
- False-Negative Test 491
- Exercise-Induced Arrhythmias 491
- Limitations 491

Chapter 27. Ambulatory Electrocardiogram Monitoring (Holter Monitoring) 496

- Arrhythmia and Ambulatory Electrocardiogram Monitoring 496
- Continuous Monitors (Holter Technology) 496
- Indications for Holter Monitoring 496
- Diagnostic Value of Holter Monitoring 497

Index *503*