

Contents

List of Contributors *xxi*

Section I The ECG in Clinical Practice 1

1 The ECG in Clinical Medicine 3

Brian Kessen and Kelly Williamson

Introduction 3

The ECG as a Clinical Tool 3

Clinical Presentations and the ECG 4

Chest Pain 4

Dyspnea 5

Syncope 6

Toxicology 7

Electrolyte Abnormalities 7

Pacemakers 10

Conclusion 10

References 10

2 History of the Electrocardiogram 13

Trale Permar and Kelly Williamson

References 17

Section II ECG Changes in Myocardial Ischemia 19

1 The Cardiac Action Potential and Changes in the Setting of Acute Coronary Syndrome: How Ischemia and Infarction Impacts the ECG 21

Kirsti A. Campbell and Michael J. Lipinski

Introduction 21

Basic Electrophysiology 21

Action Potentials in Sodium-Dependent Depolarizers 21

Phase 0: The Upstroke 23

Phase 1: Early Repolarization 23

Phase 2: The Plateau 23

Phase 3: Rapid Repolarization 23

Phase 4: Maintenance and Transition 23

Excitation-Contraction Coupling 23

Action Potential in Calcium-Dependent Depolarizers 24

Phase 0 24

Phase 3 24

Phase 4 24

Anatomy of the Electrical Conduction System	24
Biochemical Impact of Ischemia	25
ST-Segment Deviation	25
QRS Complex	30
T Waves	31
P Waves	31
U Waves	34
Myocardial Ischemia: Causes Other than Acute Coronary Syndrome	34
Conclusion	34
References	36
2 Ischemic Electrocardiographic Changes and Correlation with Regions of the Myocardium	37
<i>Thibault Lhermusier and Michael J. Lipinski</i>	
Introduction	37
Coronary Anatomy	37
Definitions of STEMI and Non-ST Elevation ACS	38
Left Main Coronary Ischemia	39
Anterior STEMI	40
Wellens Syndrome	40
Inferior STEMI	41
Right Ventricular Infarction	41
Lateral STEMI	44
Posterior STEMI	44
Conduction Abnormalities in the Setting of Ischemia	46
Aneurysm of the Left Ventricle	49
ECG in Pharmacological and Mechanical Reperfusion	49
Conclusion	50
References	50
3 STEMI Mimics	53
<i>Peter M. Pollak</i>	
Introduction	53
Myocarditis and Myopericarditis	53
Early Repolarization	55
Left Ventricular Hypertrophy	57
Prior Infarction and Ventricular Aneurysm	58
Vasospasm (Prinzmetal or Variant Angina)	58
Apical Ballooning Syndrome (Takotsubo Cardiomyopathy)	61
Brugada Pattern and Idiopathic Ventricular Fibrillation	62
Hyperkalemia	62
Post-Cardioversion/Shock	62
Hypothermia and Osborn Waves	62
Pulmonary Embolism	63
Other Causes of ST Elevation	63
Conclusion	65
References	65
4 Confounders of ST-Elevation Myocardial Infarction	69
<i>Amy West Pollak</i>	
Introduction	69
Left Bundle Branch Block	69
Typical Pattern	69

	LBBB and Ischemic Heart Disease	69
	Left Ventricular Hypertrophy	71
	Ventricular Paced Rhythm	71
	Right Bundle Branch Block (RBBB)	73
	References	73
5	The Prognostic Value of the Electrocardiogram in Acute Coronary Syndromes	75
	<i>Benjamin Shepple and Robert Gibson</i>	
	Introduction	75
	The ECG in Acute Coronary Syndromes	75
	ST Elevation Myocardial Infarction (STEMI)	75
	The ECG during Myocardial Injury	76
	The ECG in Response to Therapy	80
	ECG after Completion of Infarction	81
	UA/NSTEMI	83
	ST-Segment Depression	83
	T-Wave Inversions	84
	Initial Normal ECG	86
	Takotsubo Cardiomyopathy	86
	Arrhythmia and Conduction Disease	86
	Ventricular Arrhythmias	86
	Premature Ventricular Contractions	87
	Ventricular Tachycardia	87
	Ventricular Fibrillation	87
	Supraventricular Tachycardia	89
	Sinus Tachycardia	89
	Atrial Fibrillation	89
	AV Conduction Delay and Heart Block	90
	Prolonged QTc Interval	91
	Conclusion	92
	References	92
6	ECG Tools: Alternate Lead Placement, Serial ECGs, and ECG Monitoring	97
	<i>Augustus E. Meador, Yasir Akhtar, and Michael Ragosta</i>	
	Introduction	97
	Right-Sided Leads	97
	Posterior ECG	99
	Serial ECG Monitoring	101
	STM-ECG	101
	Serial ECG Monitoring	101
	References	105
7	Electrocardiographic Changes of Ischemia during Stress Testing	107
	<i>Michael J. Lipinski and Victor F. Froelicher</i>	
	Introduction	107
	Exercise Physiology	108
	Normal ECG Changes with Exercise	108
	ECG Changes with Ischemia	109
	Changes in the Q Wave, R Wave, and S Wave	109
	Changes in the ST-Segment	109
	ST Depression	109
	ST Elevation	110

Silent Ischemia	110
Exercise-Induced Arrhythmias	110
Women	114
Diagnostic Scores	114
Termination of Exercise Testing	114
Exercise Testing and Acute Coronary Syndromes	117
Exercise Testing after Myocardial Infarction	117
Recommended Reading	120
Conclusions	120
References	120

Section III The Dysrhythmic ECG 123

1 Bradycardia 125

Andrew E. Darby

Introduction 125

Abnormalities of Sinus Node Function 125

Abnormalities of Atrioventricular Nodal Conduction 126

Indications for Cardiac Pacing 131

Conclusions 131

References 132

2 Atrioventricular (AV) Block 133

Mark Marinescu and Andrew E. Darby

First-Degree AV Block 133

Second-Degree AV Block 133

 Type I Second-Degree AV Block (Mobitz Type I, or Wenckebach) 133

 Type II Second-Degree AV Block (or Mobitz Type II) 134

 2 : 1 AV Block 137

Third-Degree AV Block 137

Indications for Permanent Pacing 137

Conclusions 138

References 138

3 The Dysrhythmic ECG: Intraventricular Block 141

Andrew E. Darby

Introduction 141

Anatomy and Electrophysiology 141

Right Bundle Branch Block 141

Left Bundle Branch Block 143

Nonspecific Intraventricular Conduction Delay 145

Fascicular Block 145

References 146

4 Narrow QRS Complex Tachycardia 149

Augustus E. Mealar and Andrew E. Darby

Introduction 149

Approach to the ECG Diagnosis of NCT 150

The Regular Narrow Complex Tachycardias 151

 Sinus Tachycardia 151

 Atrial Tachycardia 151

 Atrial Flutter 152

Paroxysmal Supraventricular Tachycardia	154
Atrioventricular Nodal Reciprocating Tachycardia (AVNRT)	154
Atrioventricular Reciprocating Tachycardia (AVRT)	155
The Irregular Narrow Complex Tachycardias	158
Atrial Fibrillation	158
Multifocal Atrial Tachycardia	159
References	160
5 Wide QRS Complex Tachycardia	161
<i>Andrew E. Darby</i>	
Ventricular Tachycardia	161
Supraventricular Tachycardia	161
Preexcited Tachycardia	162
Ventricular Paced Rhythm	164
Other Causes of Wide Complex Tachycardia	164
Diagnosis of Wide QRS Complex Tachycardia by Electrocardiogram	166
AV Dissociation	166
Characteristics of QRS Complexes	167
Conclusions	167
References	167
6 Non-Sinus Rhythms with Normal Rates	169
<i>Will Dresen and Andrew E. Darby</i>	
Introduction	169
Ectopic Atrial Rhythm	169
Wandering Atrial Pacemaker	169
Accelerated Junctional Rhythm	169
Accelerated Idioventricular Rhythm (AIVR)	172
Conclusions	172
References	172
7 Rhythms of Cardiac Arrest	173
<i>Erich Kiehl and Andrew E. Darby</i>	
Introduction	173
Ventricular Fibrillation	173
Ventricular Tachycardia	173
Torsade de Pointes	174
Preexcited Atrial Fibrillation	174
Pulseless Electrical Activity	177
Conclusions	179
References	179
8 Premature Atrial and Ventricular Complexes	181
<i>Adrián I. Löffler and Andrew E. Darby</i>	
Premature Atrial Contractions	181
ECG Findings of PACs	181
Treatment	181
Multifocal Atrial Tachycardia (MAT)	181
Pulmonary Vein Tachycardia	182
Premature Ventricular Contractions	184
Symptoms	184
Differential Diagnosis	184
Evaluation	184

PVC Origin 184
Treatment 185
References 186

9 Nontraditional Rhythm Disorders: Dysrhythmias Related to Metabolic and Toxicologic Conditions 187

Andrew E. Darby

Introduction 187
Hyperkalemia 187
Hypokalemia 187
Hypercalcemia 187
Hypocalcemia 188
Antiarrhythmic Drug Toxicity 188
Tricyclic Antidepressant Toxicity 190
Conclusions 191
References 192

10 Dysrhythmia-Related Syndromes 193

Michele Murphy and Andrew E. Darby

Introduction 193
Dysrhythmia-Related Syndromes – Primary Electrical Abnormalities 193
Wolff-Parkinson-White Syndrome 193
Long QT Syndrome 195
Brugada Syndrome 196
Dysrhythmia-Related Syndromes – Primary Cardiac Structural Conditions 197
Hypertrophic Cardiomyopathy 197
PRKAG-2 Mutation 198
Arrhythmogenic Right Ventricular Cardiomyopathy 198
Conclusions 199
References 200

Section IV The ECG in Cardinal Presentations and Scenarios 201

1 The Patient with Cardiac Arrest 203

Michael Cirone, Mitchell Lorenz, and Karis Tekwani

Introduction 203
Ventricular Fibrillation 203
Pulseless Ventricular Tachycardia 203
Asystole 205
Pulseless Electrical Activity 205
Conclusion 206
References 206

2 The Patient with Chest Pain 207

Paul Basel, Lane Thaut, and Nathan Olson

Introduction 207
Acute Coronary Syndrome 207
Pericarditis 213
References 215

3 The Patient with Dyspnea 219

Adriana Segura Olson, Anders Messersmith, and Matthew Robinson

Introduction 219

Pulmonary Embolism	219
Right Ventricular Hypertrophy	219
Right Ventricular Strain	220
Right Atrial Enlargement	220
Right Bundle Branch Block (RBBB)	220
Cor Pulmonale	220
Cardiomyopathy	220
Congestive Heart Failure	223
Pneumothorax	223
ASTHMA/COPD	224
P-Wave Changes	224
QRS Changes	224
Arrhythmias	225
Anaphylaxis/Kounis Syndrome	225
Metabolic	226
Hyperkalemia	226
Hypermagnesemia	227
Hypocalcemia	227
Summary	227
References	227
4 The Patient with Palpitations/Syncope	229
<i>Natasha Wheaton, Emma Nash, and Jeffrey Brown</i>	
Supraventricular Tachycardia	229
Atrial Fibrillation	229
Multifocal Atrial Tachycardia	230
Conduction Blocks	232
The Big 5: Identifying Predisposing Risk for Malignant Arrhythmia on Resting ECG	233
Brugada Syndrome	233
Hypertrophic Cardiomyopathy	234
Wolf-Parkinson-White Syndrome	234
Long QT Syndrome	236
Arrhythmogenic Right Ventricular Dysplasia	237
References	237
5 The Patient with Preoperative Evaluation	239
<i>Sarah Chuzi, Jane Wilcox, and Lisa B. Van Wagner</i>	
Introduction	239
Indications	239
Common ECG Abnormalities	239
Left Ventricular Hypertrophy	239
Conduction Abnormalities	240
Atrioventricular (AV) Conduction Delays	240
Ventricular Conduction Abnormalities – Bundle Branch Blocks	242
Nonspecific ST-T Changes	244
Pathologic Q Waves	244
QT/QTc Prolongation	245
Conclusion	245
References	246
6 The Patient in Shock	249
<i>Meagan R. Hunt and Nicholas D. Hartman</i>	
Introduction	249

- Cardiogenic Shock 249
 - Cardiomyopathy 249
 - Arrhythmias 250
- Obstructive Shock 252
 - Massive Pulmonary Embolism 252
 - Cardiac Tamponade 252
- Distributive Shock 252
 - Hypothermia 254
 - Thyrototoxicosis 255
 - Myxedema Coma 257
 - Neurogenic Shock 260
 - Systemic Inflammatory Response Syndrome (SIRS) 262
- Hypovolemic Shock 262
- Summary 262
- References 263

- 7 The Patient with Overdose 265**
 - Ashley Pastore and Andrea Carlson*
 - Introduction 265
 - Approach to the ECG in the Poisoned Patient 265
 - Classic Toxicology ECGs 267
 - Cardiac Glycosides 267
 - Drug-Induced SVT 268
 - Brugada Pattern 268
 - Tricyclics Antidepressants 268
 - Calcium Channel Blockers 272
 - Conclusion 273
 - References 274

Section V The ECG in Poison, Electrolyte, Metabolic and Environmental Emergencies 275

- 1 ECG Diagnosis and Management of the Poisoned Patient 277**
 - William F. Rushton and Christopher P. Holstege*
 - Introduction 277
 - Cardiac Action Potential 277
 - Tachycardia in the Poisoned Patient 277
 - Bradycardia 278
 - QRS Prolongation 279
 - QT Prolongation 282
 - Conclusion 283
 - References 284
- 2 The Use of the ECG in the Poisoned Patient: The “Rule-out Ingestion” Strategy 287**
 - Heather A. Borek and Lewis S. Hardison*
 - Introduction 287
 - Background 287
 - Rate 287
 - Rhythm 289
 - Morphology of the Cardiac Action Potential and the ECG 290
 - QRS Interval Prolongation 290
 - QTc Interval Prolongation 292
 - Timing 293

The Undifferentiated Patient	294
Conclusion	294
References	295
3 The ECG and Electrolyte Abnormalities	297
<i>Justin Rizer, Joshua D. King, and Nathan P. Charlton</i>	
Introduction	297
Calcium	297
Hypocalcemia	297
Background	297
ECG Findings	297
Treatment	298
Hypercalcemia	298
Background	298
ECG Findings	298
Treatment	298
Magnesium	298
Hypomagnesemia	299
Background	299
ECG Findings	299
Treatment	299
Hypermagnesemia	299
Potassium	300
Hyperkalemia	300
Background	300
ECG Findings	300
Treatment	302
Hypokalemia	303
Background	303
ECG Findings	303
Treatment	305
References	305
4 The ECG and Metabolic Abnormalities	307
<i>George F. Glass, Amita Sudhir, and Amit Anil Kumar Pandit</i>	
Introduction Metabolic Disturbances and the ECG	307
ECG Findings During Acute Complications of Diabetes Mellitus	307
Hyperglycemia and DKA	307
Hypoglycemia	309
Disturbances Due to Alterations of pH	309
Metabolic Acidosis	310
Metabolic Alkalosis	310
Respiratory Acidosis	310
Respiratory Alkalosis	311
Other Metabolic Conditions	311
The ECG in Hypothyroidism	311
The ECG in Hyperthyroidism	311
The ECG in Mitochondrial Disease	311
References	311
5 The ECG in Environmental Urgencies and Emergencies	315
<i>Heather T. Lounsbury and Seth O. Althoff</i>	
Introduction	315

- Hypothermia 315
 - Background 315
 - ECG Finding 315
 - Treatment 319
- Lightning Strikes 319
 - Background 319
 - ECG Findings 319
 - Treatment 320
- Underwater Submersion 321
 - Background 321
 - ECG Findings 321
 - Treatment 321
- Heat Stroke 322
 - Background 322
 - ECG Findings 322
 - Treatment 323
- Conclusion 324
- References 324

Section VI The ECG in Special Inpatient Groups 327

1 The ECG-Monitored Patient 329

Feras Khan

Introduction 329

Clinical Scenarios Requiring Telemetry/Electrocardiographic Monitoring 329

Implantable Cardioverter-Defibrillator (ICD)/Pacemaker Firing 329

Atrioventricular (AV) Block 329

Acute Heart Failure 329

Chest Pain Syndrome 329

Procedures 330

Syncope 330

Acute Coronary Syndrome (STEMI, Non-STEMI, Unstable Angina) 330

Stroke 331

Blood Transfusion 331

Atrial Tachyarrhythmias 331

Electrolyte Abnormalities 331

Drug Overdose or Toxicity 332

Conclusion 332

References 334

2 Electrocardiography in the Operating Room 335

Feras Khan

Introduction 335

Types of Monitoring 335

Risks for Arrhythmias in the OR 335

Postoperative Electrocardiographic Abnormalities 335

Initial Management and ECG Evaluation 335

Types of Arrhythmias 336

Bradycardia 336

Tachyarrhythmias 337

Specific Clinical Conditions	341
Myocardial Ischemia	341
Drug Withdrawal	342
Other Causes of Bradydysrhythmias	342
Postoperative Shivering	342
Electrolyte Disturbances	342
General Anesthetics	342
Conclusion	342
References	343
3 ECG in the ICU Patient: Identification and Treatment of Arrhythmias in the Intensive Care Unit	345
<i>Feras Khan</i>	
Introduction	345
Common Dysrhythmias in the ICU	345
Bradydysrhythmias	345
Tachydysrhythmias	345
Other Common Electrocardiographic Findings	352
The Effect of Vasopressors on Cardiac Conduction	352
Epinephrine, Norepinephrine, and Dopamine	352
Dobutamine	353
Phenylephrine	353
Milrinone	353
Consequences of Anti-Arrhythmic Medications	353
Arrhythmias Induced by Central Line Placement	354
Specific Clinical Conditions	354
Cardiac Arrest	354
Myocardial Infarction	354
Cardiac Surgery	354
Myocarditis	354
Endocarditis	355
Left Ventricular Assist Device Arrhythmias	355
Pulmonary Embolism	355
Pericardial Effusion	355
Hyperthyroidism and Hypothyroidism	355
Hypothermia	355
Subarachnoid Hemorrhage	356
Conclusion	357
References	357
4 The ECG in Patients with Implanted Cardiac Devices	359
<i>Ali Farzad, Benjamin J. Lawner, and Tu Carol Nguyen</i>	
Basics of Pacemakers	359
Electrocardiographic Findings in Normally Functioning Pacemakers	360
Electrocardiographic Findings in Abnormally Functioning Pacemakers	361
Problems with Sensing	362
Problems with Pacing	365
Pacemaker-Associated Dysrhythmias	366
Pseudomalfuction	368
Key Points: Electrocardiographic Clues to Pacemaker Malfuction	368
Electrocardiographic Diagnosis of Acute Myocardial Infarction in the Presence of a Paced Rhythm	368

- Basics of the Implantable Cardioverter Defibrillator 370
 - Ventricular Storm 370
- Electrocardiographic Findings after Defibrillation 370
 - Too Much Noise! 371
- Basics of Left Ventricular Assist Devices 371
- References 375

5 Electrocardiographic Manifestations of Cardiac Transplantation 377

- Semhar Tewelde*
- Introduction 377
- Cardiac Transplantation 377
- Conclusion 380
- Key Points 380
- References 380

Section VII Electrocardiographic Differential Diagnosis 383

1 Abnormalities of the P Wave and PR Interval 385

- Matthew Borloz*
- The Normal P Wave 385
- The Abnormal P Wave 385
 - Atrial Abnormality 385
 - Right Atrial Abnormality 385
 - Left Atrial Abnormality 385
 - Biatrial Abnormality 386
 - Ectopic Atrial Foci 386
 - Biphasic P Waves 386
 - Multifocal Atrial Tachycardia 387
- The Normal PR Interval 387
- The Abnormal PR Interval 387
 - Short PR Interval 387
 - Preexcitation 390
 - Ectopic Atrial Foci 391
 - Junctional Rhythms 391
- Long PR Interval 391
 - First-Degree Atrioventricular Block 391
 - Second-Degree Atrioventricular Block 391
 - Third-Degree Atrioventricular (Complete Heart) Block 395
- Conclusion 395
- References 395

2 Differential Diagnosis of QRS Complex Abnormalities 397

- Matthew Wilson, Michael Ybarra, and Munish Goyal*
- QRS Complex Abnormalities 397
 - The Large QRS Complex 397
 - Left Ventricular Hypertrophy 397
 - Right Ventricular Hypertrophy 398
 - The Small QRS Complex 398
 - The Wide QRS Complex 399
 - Ectopic Beats 399
 - Ventricular Paced Rhythm 399
 - Preexcitation 400

Hyperkalemia	400
Sodium Channel Blockade	400
Intraventricular Blocks	402
References	405

3 Differential Diagnosis of ST Segment Changes 407

Korin Hudson and Norine McGrath

Introduction	407
Describing ST-Segment Changes	407
Acute Coronary Syndrome and Related ST Segment Deviation	408
Nonischemic Causes of ST-Segment Changes	412
Bundle Branch Block (BBB)	412
Left BBB	412
Right BBB	413
Ventricular-Paced Rhythms (VPRs)	413
Ventricular Hypertrophy	414
Benign Early Repolarization	414
Acute Myocarditis/Pericarditis	415
Ventricular Aneurysm	416
Digitalis	416
Hypothermia	417
Hyperkalemia	417
Brugada Syndrome	417
Tachycardia-Related STD	418
CNS Injury	418
Other Causes	418
References	419

4 ECG Differential Diagnosis of T Wave and QT Interval Abnormalities 421

Sanjay Shewakramani and Kari Gorder

The T Wave	421
Prominent T Waves	421
Hyperkalemia	421
Myocardial Infarction	421
Benign Early Repolarization	422
T-Wave Inversions	422
Deep and Giant T-Wave Inversions	424
Biphasic T Waves	425
Wellens Syndrome	425
T-Wave Flattening	426
The QT Interval	427
QT Prolongation	428
Congenital Long QT Syndrome	429
Short QT Interval	429
Congenital Short QT Syndrome	429
References	429

5 Bradycardia 433

B. Elizabeth Delasobera and Tress Goodwin

Bradycardia Basics	433
Definition of Bradycardia	433
Differential Diagnosis of Bradycardia	433

Bradycardia Rhythms	433
Sinus Bradycardia	433
Junctional Bradycardia	433
Idioventricular	433
Sinoventricular Rhythm with Hyperkalemia	434
Hypokalemia	434
Hypothermia	434
Rhythms That Can Be Slow	434
Slow Atrial Fibrillation	435
Slow Atrial Flutter	437
AV Blocks	437
First-Degree AV Block	438
Second-Degree AV Block: Mobitz Type 1 (Wenckebach)	438
Second-Degree AV Block: Mobitz Type 2	438
Third-Degree or Complete Heart Block	439
Conclusion	439

6 Rhythms Presenting with Normal Rate	441
<i>Robert Katzer and Janet Smereck</i>	
Definitions and Clinical Considerations	441
Regular Rhythms	441
Normal Sinus Rhythm	441
First-Degree AV Block	441
Accelerated Junctional Rhythm	442
Irregular Rhythms	442
Sinus Arrhythmia	442
Atrio-Ventricular Blocks	443
Premature Atrial Contractions (PAC)	443
Atrial Fibrillation with Normal Rate	444
Atrial Flutter	444
Wandering Atrial Pacemaker or Multifocal Atrial Rhythm	445
Ventricular Extrasystoles	445
Paced Rhythms	446
References	447

7 Narrow Complex Tachycardia	449
<i>David J. Carlberg and Rahul Bhat</i>	
Introduction	449
Mechanisms for NCTs	449
Reentry	449
Enhanced and Abnormal Automaticity	450
Triggered Activity	450
Approach to NCT	450
Determining Regularity	451
Determining Sinus Rhythm	451
Evaluating P-Wave Presence and Morphology	451
Onset and Variability	452
Sinus Node Tachycardias	453
Sinus Tachycardia	453
Inappropriate Sinus Tachycardia	453
Sinus Node Reentrant Tachycardia	453
Atrial Tachycardias	453

Atrial Tachycardia	453
Multifocal Atrial Tachycardia	453
Atrial Flutter	454
Atrial Fibrillation	455
Reentrant Tachycardia Involving the AV Node	457
AV Nodal Reentry Tachycardia	457
AV Reentry Tachycardia	457
Junctional Tachycardia	459
Conclusions	459
References	460
8 Wide Complex Tachycardia	461
<i>Scott Young and Rachel Villacorta Lyew</i>	
Introduction to Wide Complex Tachycardia	461
Monomorphic WCT	461
Ventricular Tachycardia	461
Supraventricular WCT	463
Other Etiologies	465
Differentiating VT from Supraventricular WCT	467
Polymorphic WCTs	468
Prolonged QT Interval	469
Normal QT Interval	469
Conclusion	469
References	470
Index	473

