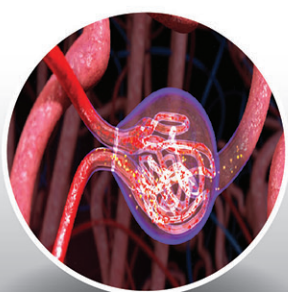
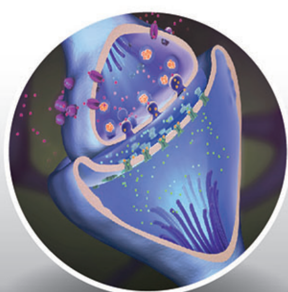
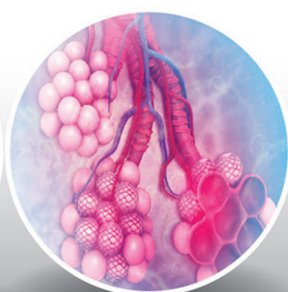
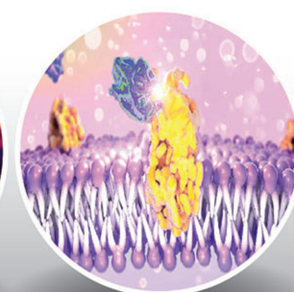
Online Videos & Critical Thinking/Reasoning Qs

TEXTBOOK OF PHYSIOLOGY

Concepts With Clinical Insights



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Co-author

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Key Takeaways

- Simplified Line Diagrams
- Numerous Flowcharts and Tables
- Case Scenarios
- Questions/Fact Boxes
- 1000+ MCQs
- Review Questions
- Crossword Puzzles

JAYPEE

CONTENTS

Section 1: General Physiology

1. Mammalian Cell **3**
- Cell 3
- Nucleus 3
- Mitochondria 3
- Cell Membrane/Plasma Membrane/Unit Membrane 6
- Cell Adhesion Molecules (CAMs) 7

2. Homeostasis **10**
- Regulation of Homeostatic Mechanisms 10
- Feedback Mechanisms 10
- Feed Forward Mechanism 12
- Importance of Homeostatic Control Mechanisms 13
- Gain in Homeostatic Control 13

3. How Do Cells Communicate? **16**
- Intercellular Connections 16
- Mechanism of Action of Chemical Messengers 17

4. Apoptosis: Physiology and Mechanisms **23**
- Mechanism of Apoptosis 23
- Situations in which Apoptosis Occur 24
- Differences between Apoptosis and Necrosis 24
- Effects of Dysregulated Apoptosis (Too Little/Too Much) 25

5. Transport Across Cell Membranes **26**
- Proteins Involved in Transport Across Cell Membrane 26
- Classification of Mechanism of Transport Across Cell Membrane 26
- Passive Transport 26
- Active Transport 29

6. Body Fluids and Compartments **33**
- Body Fluids 33
- Composition of ECF and ICF 34
- Measurement of Body Fluid Volumes 34
- Regulation of Body Fluid Volume and Tonicity 37
- Fluid Replacement Therapy 37

7. Acid-base Balance **40**
- Physiological Significance of pH of Body Fluids 40
- Regulation of pH of the Body Fluids 41
- Role of Lungs and Kidneys in pH Regulation 41
- Clinical Assessment of Acid-Base Balance 44

8. Membrane Potentials of Excitable Tissues **48**
- Resting Membrane Potential 48
- Action Potential in Excitable Tissues 50

9. Applications of Cellular Physiology in Health and Research **55**
- Methods used to Demonstrate the Functions of the Cells and its Products 55
- Methods used to Demonstrate the Cellular Communications 57

Section 2: Hematology

10. Introduction to Blood **65**
- Functions of Blood 65
- Composition of the Blood 65
- Physiological Significance of Each Component of the Blood 66
- Physical Characteristics of Blood 67

11. Plasma Proteins **69**
- Origin of the Plasma Proteins 69
- The Normal Levels of Plasma Proteins 69
- Types of Plasma Proteins 69
- Functions of Plasma Proteins 69
- Variations in the Levels of Plasma Proteins 70
- Plasmapheresis 71

12. Hemoglobin **73**
- Synthesis of Hemoglobin 73
- Structure of Hemoglobin 73
- Types of Hemoglobin 74
- Forms of Hemoglobin 75
- Normal Values, Variation and Functions of Hemoglobin 75
- Functions 75
- Fate/Breakdown of Hemoglobin 76
- Applied Aspects/Clinical Correlates 76

13. Erythrocytes: Formation and Function **79**
- Erythrocytes 79
- Functions of Erythrocytes 80
- Erythropoiesis 80

14. Physiology of Anemia **85**
- Anemia 85
- Iron Deficiency Anemia 86
- Macrocytic Anemia 88
- Hemolytic Anemia 91

15. Physiology of Jaundice **96**
- Classification of Jaundice 97
- Diagnosis of Jaundice 98
- Physiological Jaundice 98

16. Leukocytes and their Formation **101**
- General Structure of a Leukocyte 101
- Leukopoiesis (Formation of Leukocytes) 101
- Counts 103
- Monocyte Macrophage System/Reticuloendothelial System (RES) 106

17. Basics of Immunity **109**
- Functions of Immunity 109
- Classification of Immunity 109
- Cell Mediated Immunity 110
- Humoral Immunity 112
- Immunoglobulin (Ig) 113
- Types of Humoral/Immune Responses 114
- Complement System 115
- Some Other Applications of Immunity 116

18. Platelets: Structure, Formation and Functions **120**
- Formation of Platelets/Thrombopoiesis 120
- Functional Structure of Platelets 120
- Functions of Platelets 121
- Clinical Significance 122
- Antiplatelet Drugs 124

19. Hemostasis **127**
- Definition of Hemostasis 127
- Mechanism of Hemostasis 127
- Temporary Hemostasis (Platelet Plug Formation) 128
- Clot Retraction 131
- Disorders of Hemostasis 133
- Hemophilia 134
- Von Willebrand Disease 135
- Approach to Bleeding Disorders Diagnosis 135

20. Blood Groups **138**
- ABO System of Blood Grouping 138
- Rh Blood Grouping System 139
- Blood Groups Testing 141

21. Blood Banking and Blood Transfusion **145**
- Blood Collection 145
- Blood Typing and Crossmatching 145
- Screening for Diseases 146
- Proper Storage Procedures 146
- Importance of Blood Transfusions 147
- Risks and Complications of Blood Transfusions 147
- Ethical and Legal Considerations 148

Section 3: Nerve and Muscle Physiology

22. Neurons and Neuroglia **155**
- Structure of a Neuron 155
- Classification of Neurons 156
- Neuroglia 156

23. Nerve Growth Factor and Cytokines **159**
- Nerve Growth Factor 159
- Brain-derived Neurotrophic Factor 159
- Neurotropin-3, Neurotropin-4/5 160
- Other Factors Affecting Neuronal Growth 160

24. Nerve Fibers and their Properties **161**
- Structure of an Axon 161
- Classification of Nerve Fibers 162
- Axonal Transport 162
- Properties of Nerve Fibers 163

25. Degeneration and Regeneration of Peripheral Nerves **167**
- Grading of Nerve Injury 167
- Changes in the Nerve After the Injury 167
- Changes in the Cell Body of Neuron 167
- Changes in Proximal and Distal Stumps 167
- Factors Influencing Regeneration of Nerve 169
- Diagnosis of Nerve Injury 170

26. Neuromuscular Junction **172**
- Physiological Anatomy of the Neuromuscular Junction 172
- Transmission of Impulse Across Neuromuscular Junction 174
- Drugs Acting on Neuromuscular Junction 176
- Disorders of Neuromuscular Junction 176

27. Muscle: Structure, Properties and Physiology of Muscle Contraction **182**

Structure of the Muscle 182
- Skeletal Muscle 182
- Muscle Proteins 182
- Myofilaments in Smooth Muscles 186

Sarcotubular System of the Muscle 187
- Skeletal Muscle 187
- Cardiac Muscle 187
- Smooth Muscle 188

Excitability (Electrical Properties of the Muscles) 188
- Action Potential of Skeletal Muscle 189
- Action Potential of the Cardiac Muscle 189
- Electrical Properties of Smooth Muscle 190

Contractility 190
- Physiology of Muscle Contraction in Skeletal Muscle 190
- Contraction in Cardiac Muscle 193
- Contraction in Smooth Muscle 194

Relationship of Electrical and Contractile/Mechanical Response of Muscles 195
- Skeletal Muscle 195
- Cardiac Muscle 195
- Smooth Muscle 196

Contractile Properties of Different Types of Muscles 196
- Properties of Skeletal and Cardiac Muscles 196

Types of Muscle Contractions 200
- Recording of Isotonic and Isometric Contractions 201
- Series Elastic Component 201

Energy Sources of Muscle Contraction 202
- Adenosine Triphosphate 202
- Creatine Phosphate 202
- Oxidative Phosphorylation 202

Disorders of Muscles/Muscular Dystrophy 203

Section 4: Gastrointestinal System

28. Organization of Gastrointestinal System 211
- Physiological Anatomy of GI System 211
- Smooth Muscles of GIT 212
- Migrating Motor Complexes (MMC) 213
- General Principles of Gastrointestinal Secretions 213
- General Principles of Gastrointestinal Motility 215
- Regulation of GI Functions (Secretions and Motility) 215
- Gastrointestinal Reflexes 217
- Physiology of Splanchnic Circulation 218
- Functions of Splanchnic Circulation 218
- Immune Apparatus of Gut 220
- Intestinal Flora/Gut Microbiota 221
- Gut-Brain Axis 221

29. Digestion in Oral Cavity and Esophagus 224
- Oral Cavity/Mouth 224
- Salivary Secretion 225
- Physiology of Mastication (Chewing) 228
- Physiology of Swallowing/Deglutition 228
- Digestion of Food in Oral Cavity 230

30. Physiology of Digestion in Stomach 233
- Functional Anatomy of Stomach 233
- Functions of Stomach 234
- Gastric Secretion 235
- Regulation of Gastric Secretion 237
- Gastric Motility 237
- Regulation of Gastric Emptying 239
- Digestion and Absorption in Stomach 239
- Disorders of Stomach 240
- Gastric Function Tests 241

31. Physiology of Digestion in Small Intestine (Including Pancreas) 245
- Anatomy of Small Intestine and Pancreas 245

Secretions of Pancreas and Small Intestine 246
- Pancreatic Secretion 246
- Secretions of Small Intestine 249
- Motility of Small Intestine 251
- Digestion and Absorption in Small Intestine 251
- Disorders of Pancreas and Small Intestine 252
- Pancreatic Function Tests 252

32. Physiology of Hepatobiliary System 255
- Functional Anatomy of Liver 255
- Functions of Liver 256
- Biliary Secretion 257
- Mechanism of Biliary Secretion 258
- Regulation of Bile Secretion 258
- Bile Salts 259
- Enterohepatic Circulation 260
- Choleretics and Cholagogues 260
- Role of Bile in Digestion of Fats 260
- Disorders of Liver and Gallbladder 260
- Liver Function Tests 262

33. Physiology of Digestion in the Large Intestine 264
- Functional Anatomy of Large Intestine 264
- Functions of Large Intestine 265
- Secretion of Large Intestine 265
- Colonic Motility 266
- Defecation 267
- Digestion and Absorption in Large Intestine 269
- Composition of Feces 269
- Physiological Importance of Dietary Fibers 269
- Clinical Correlation: Large Intestinal Disorders 269

34. Physiology of Digestion and Absorption of Nutrients 274
- Digestion and Absorption 274
- Digestion and Absorption of Carbohydrates 275
- Digestion and Absorption of Proteins 276
- Digestion and Absorption of Fats 277
- Absorption of Water, Minerals and Trace Elements (Sodium, Chloride, Calcium, Bicarbonate) 278
- Disorders of Digestion and Absorption 279

Section 5: Cardiovascular System

35. Functional Anatomy of Heart 287
- External Anatomy 287
- Internal Anatomy 287
- Functions of Cardiovascular System 290

36. Cardiac Cycle 293
- Cardiac Cycle Time 293
- Methods to Study Cardiac Cycle 293
- Mechanical Events in the Cardiac Cycle 294
- Description of Events in Cardiac Cycle 294
- Pressure and Volume Changes in Left and Right Heart 296
- Overview of Cardiac Cycle 297
- Applied Physiology 299

37. Basics of Electrocardiography 302
- Components of Normal ECG 303
- Intervals 306
- Segments 307
- Recording of ECG 307

38. Physiological Basis of Abnormalities of Electrocardiogram 314
- Heart Rate 314
- Rhythm 314
- Disorders of Rhythm 316
- Disorders of Conduction 317
- First Degree Heart Block 317
- Second Degree Heart Block 317
- Complete Heart Block 317
- Sick Sinus Syndrome 318
- Axis Deviation 319
- Chamber Enlargement 319
- Myocardial Infarction 319
- Electrolyte Disturbances in ECG 319

39. Circulation and Hemodynamics 324
- Circulatory System 324
- Hemodynamics 326

40. Cardiovascular Regulatory Mechanisms 333
- Higher Centers in Brain and Brainstem for Cardiovascular Regulation 333
- Classification of Cardiovascular Regulatory Mechanisms 333
- Short-term Regulatory Mechanisms 333
- The Lie Detector Polygraph Test 337
- Intermediate Term Regulation 338
- Long-term Regulation 338

41. Heart Rate and Regulation 342
- Heart Rate 344

42. Cardiac Output 347
- Measurement of Cardiac Output 347
- Factors Affecting Cardiac Output 349
- Variations in Cardiac Output 349
- Regulation of Cardiac Output 350
- Cardiac Function Curves 351

43. Venous Return and its Regulation 354
- Factors Affecting the Venous Return 355

44. Blood Pressure and its Regulation 358
- Determinants of Blood Pressure 358
- Measurement of Blood Pressure 359
- Factors Affecting Blood Pressure 360
- Regulation of Blood Pressure 360
- Applied Aspects 362

45. Coronary Circulation 365
- Coronary Blood Flow 365
- Blood Flow in the Coronaries 366
- Pecularities of Coronary Blood Flow 366
- Factors Affecting Coronary Circulation 367
- Regulation of Coronary Blood Flow 367
- Coronary Artery Disease (CAD) or Ischaemic Heart Disease (IHD) 368

46. Blood Flow in Systemic Circulation: Arterial, Capillary, Venous and Lymphatic Circulation 374
- Components of Systemic Circulation 374
- Arterial Circulation (From Heart to Capillaries) 375
- Microcirculation and Capillary Circulation 375
- Venous Circulation (From Capillaries to Heart) 378
- Lymphatic Circulation 379

47. Physiological Basis of Cardiovascular Diseases 383
- Shock 383
- Cardiac Failure 386

Section 6: Respiratory Physiology

48. Functional Anatomy of Respiratory System 395
- Functional Anatomy of the Respiratory Tract 395
- Nonrespiratory Functions of the Respiratory System 401

49. Mechanics of Pulmonary Ventilation (Chest Movements, Pressure Changes, Alveolar Surface Tension, Compliance, Airway Resistance) 404
- Mechanics of Respiration 404
- Muscles of Respiration 405
- Mechanism of Inspiration 405
- Mechanism of Expiration 407
- Pressure Gradients 407
- Lung Compliance 408
- Surface Tension 411
- Surfactant 411
- Infant Respiratory Distress Syndrome 413
- Adult Respiratory Distress Syndrome 414
- Airway Resistance 414
- Work of Breathiing 415

50. Pulmonary Ventilation (Diffusion of Gases Across Respiratory Membrane) 418
- Diffusion of Gases (O_2 and CO_2) 418
- Diffusion Capacity 420
- Inspired, Alveolar and Expired Air 421
- Ventilation-Perfusion Ratio (V_A/Q) 422
- Physiological Shunt 423
- Dead Space Air 423

51. Pulmonary Function Tests 426
- Spirometry 426
- Static Lung Volumes and Capacities vs Dynamic Lung Volumes and Capacities 427
- Pulmonary Ventilation 430
- Other Methods for Assessment of PFT 431

52. Pulmonary Circulation 434
- Physiological Anatomy of Pulmonary Circulation 434
- Blood Volume and Flow in Pulmonary Circulation 436
- Functions of Pulmonary Circulation 438
- Pulmonary Edema 438
- Pleural Effusion 439

53. Transport of Respiratory Gases (Oxygen and Carbon Dioxide) 442
- Transport of Oxygen 442
- Oxygenation of Hemoglobin 443
- Oxygen Hemoglobin Dissociation Curve 443
- Oxygen Release in Tissues at Rest 446
- Oxygen Consumption 447
- Co-Efficient of Utilization of O_2 447
- Vehicles for the Transport of Oxygen: A Comparison of Plasma, Hemoglobin and Whole Blood 447
- Transport of Carbon Dioxide 447
- Carbon Dioxide Dissociation Curves 448

54. Regulation of Respiration 453
- Nervous Regulation 454
- Chemical Regulation 457
- Nonchemical Regulation 459
- Breath Holding 460

55. Respiration in Special Conditions (In Different Barometric Pressures) 463
- High Altitude Physiology 464
- Space Physiology 468
- Deep-Sea Diving 470

56. Physiological Basis of Respiratory Disorders 475
- Hypoxia 475
- Dyspnea 477
- Asphyxia 478
- Cyanosis 479
- Periodic Breathing 480
- Bronchial Asthma 482
- Chronic Obstructive Pulmonary Disease 483
- Respiratory Failure 484

Section 7: Renal Physiology

57. Functional Anatomy of Kidney 491
- Kidney 491
- Nephron 492
- Functions of Kidneys 494
- Renal Blood Flow 494

58. Juxtaglomerular Apparatus and Renin-angiotensin Aldosterone System 499
- Juxtaglomerular Apparatus 499
- Renin-angiotensin Aldosterone System (RAAS) 501

59. Formation of Urine (Glomerular Filtration, Tubular Reabsorption and Secretion, Concentration of Urine) 505
- Glomerular Filtration 505
- Concentration of Urine 514
- Role of Antidiuretic Hormone 516

60. Renal Function Tests (Including Plasma Clearance) 524
- Blood Tests 524
- Tests to Assess Glomerular Filtration Rate (GFR) 526
- Estimation of Renal Blood Flow 528
- Renal Tubular Function Tests 528
- Radiographic Technique/IVP 529
- Urine Analysis 530

61. Physiological Basis of Diuretics and Renal Disorders 533
- Diuretics 533
- Acute Renal Failure (ARF)/Acute Kidney Injury (AKI) 534
- Chronic Renal Failure (CRF)/Chronic Kidney Disease (CKD) 537
- Dialysis/Artificial Kidney 539
- Renal Transplantation 540

62. Urinary Bladder and its Applied Physiology 543
- Functional Anatomy of Urinary Bladder 543
- Urodynamic Studies (Cystometery and Radiographic Technique) 545
- Neurogenic Bladder 546

Section 8: Endocrine Physiology

63. Endocrine System and Hormones 555
- Hormones 555
- Classification of Hormones 555
- Mechanism of Hormone Action 555
- Principles of Endocrinal Disorders 561

64. Physiology of Bone and Calcium Regulation 564
- Physiology of Calcium Regulation 564
- Calcium Dysregulation 566
- Hormonal Control of Calcium Level 569

65. Physiology of Hypothalamus 577
- Functional Anatomy 577
- Functions of Hypothalamus 578

66. Physiology of Pituitary Gland 585
- Functional Anatomy 585
- Hormones of Pituitary Gland 585
- Growth Hormone 586
- Disorders of Anterior Pituitary Gland 588
- Hormones of Posterior Pituitary Gland 590
- Diabetes Insipidus (DI) 591
- Oxytocin 593

67. Thyroid Gland 597
- Functional Anatomy of Thyroid Gland 597
- Hormones of Thyroid Gland 597
- Functions 598
- Biosynthesis of Thyroid Hormone 598
- Transport in Blood 599
- Mechanism of Action of Thyroid Hormones 599
- Actions of Thyroid Hormone 599
- Metabolism of Thyroid Hormones 600
- Regulation of Thyroid Hormone Secretion 600
- Disorders of Thyroid Gland 600
- Thyroid Function Tests 604

68. Physiology of Adrenal Gland 607
- Physiological Anatomy of Adrenal Gland 607
- Mineralocorticoids (Aldosterone) 608
- Glucocorticoid (Cortisol, Corticosterone) 609
- Disorders of Adrenocortical Hormones 612
- Adrenal Function Tests 614

69. Glucose Homeostasis: Role of Endocrine Pancreas 617
- Insulin 617
- Diabetes Mellitus 619
- Diabetic Ketoacidosis 622
- Hyperosmolar Nonketotic Coma 622
- Glucagon 623
- Somatostatin 623

70. Physiology of Thymus and Pineal Gland 627

Thymus 627
- Physiological Anatomy 627
- Factors Affecting Thymus 628
- Clinical Significance 628

Pineal Gland 629
- Physiologic Anatomy of Pineal Gland 629
- Physiology of Pineal Gland 629
- Function of Pineal Gland 629
- Mechanism of Secretion of Melatonin 629
- Functions of Melatonin 629
- Clinical Significance 630

71. Metabolic Syndrome (A Self-Directed Learning Module) 632

- Introduction to Metabolic Syndrome 632
- Diagnostic Criteria 632
- Pathophysiology 633
- Lifestyle Modifications and Management 633
- Associated Complications 634
- Psychiatry Component 635

Section 9: Reproductive Physiology

72. Reproductive Physiology and Endocrinology 641

- Hypothalamo-Pituitary-Gonadal Axis 641
- Reproductive Hormones 641
- Mechanism of Action 645
- Transport and Metabolism 646
- Regulation of Secretion of Hormones 646

73. Sex Determination and Sex Differentiation of Embryo 648

- Sex Determination 648
- Sex Differentiation 649
- Disorders of Sexual Development 649
- Chromosomal Anomaly 651

74. Life Cycle of Reproductive Physiology 655

- Puberty (Adolescence) 655
- Tanner's Classification/Sexual Maturity Rating 655
- Disorders of Adolescence 657
- Castration/Gonadectomy (Removal of Gonads) 657
- The End of Reproductive Period (Menopause and Andropause) 658

75. Reproductive Physiology in Males 661

- Functional Anatomy of Male Reproductive System 661
- Microscopic Anatomy of Testis 661
- Functions of Testes 663
- Structure of Sperm 664
- Seminal Vesicle 665
- Prostate Gland 665
- Semen 665
- Disorders Related to Spermatogenesis, Resulting in Male Infertility 666

76. Reproductive Physiology in Females 670

- Functional Anatomy of Female Reproductive System 670
- Oogenesis (Formation of Ovum) 670
- The Female Sexual Cycle (Menstrual Cycle) 671
- Uterine Changes 675

77. Physiology of Pregnancy and Lactation 679

- Physiology of Conception 679
- Pregnancy 681
- Placental Hormones 683
- Parturition 685
- Lactation 688

78. Contraception 692

- Rhythm Method 692
- Lactational Amenorrhea Method 693
- Barrier Methods 693
- Intrauterine Device 693
- Oral Contraceptives Pills 694
- Other Methods 694

Section 10: Neurophysiology and Special Senses

79. Organization of Nervous System 701

Central Nervous System 701

- Brain 701
- Functional Anatomy of Brain and Spinal Cord 701

80. Synapse 711

- Types of Synapse 711
- Structure and Functioning of the Synapse 712
- Properties of Synapse 713

81. Neurotransmitters 718

- Small Molecule Neurotransmitters 718
- Large Molecule Neurotransmitters 720

82. Physiology of Sensory Receptors 723

- How are Sensations Carried and Recognized? 723
- Receptors 723
- Properties of Receptors 725

83. Postural Reflexes and their Regulation 730

- What is a Postural Reflex? 730
- The Postural Muscles 730
- Postural Reflexes Integrated at Different Levels of CNS 731

84. Cerebral Cortex 742

- Functional Anatomy of Cerebral Cortex 742
- Lobes of Cerebrum 742
- Communication between Both the Cerebral Hemispheres 749
- Cerebral Dominance 749

85. Thalamus 752

- Structure and Nuclei of Thalamus 752

86. Role of Cerebellum and Basal Ganglia (Motor Planning, Programming and Execution) 755

- Cerebellum 756
- Basal Ganglia 761
- Summary of Motor Programming and Planning in Motor Execution 766

87. Spinal Cord and the Pathways between Cerebrum and Peripheral Parts of Body 769

- Functional Anatomy 769
- Organization of Spinal Cord 769
- Sensory Tracts: Ascending Tracts of Spinal Cord 771
- Spinocerebellar Tracts 775
- Motor Tracts: The Descending Tracts of Spinal Cord 775
- Some Common Lesions of Spinal Cord 778

Pain and Analgesia System 781

- Pain 781
- Analgesia System 783

88. Reticular Activating System (RAS) 787
- Anatomy and Structure of RAS 787
- Functions of RAS 787

89. Physiology of Limbic System, Speech, Memory, EEG and Sleep 789
- Physiology of Emotions—the Limbic System 789
- Physiology of Speech 791
- Physiology of Learning and Memory 792
- Physiology of Electroencephalography 795
- Physiology of Sleep 799

90. Vestibular System 805
- Vestibular Apparatus 805
- Functions of Vestibular Apparatus 807
- Vestibular Pathways and Connections 809
- Vestibular Nuclei 809
- Vestibular Reflexes 810
- Disorders Associated with Vestibular Apparatus 811

91. Autonomic Nervous System 814
- Organization of Autonomic Nervous System 814
- Parasympathetic Nervous System 815
- Sympathetic Nervous System 815
- Fight or Flight Response 818
- Levels of Control of the Autonomic Nervous System 818
- Working of Autonomic Nervous System 818
- Feedback Mechanism in the Autonomic Nervous System 819

92. Cerebral Blood Flow 823
- Functional Anatomy of Cerebral Blood Flow 823
- Physiology of Cerebral Circulation 824
- Cerebrovascular Accidents (CVA)/Stroke 825
- Metabolism in Brain 825

93. Physiology of Olfaction 827
- Smell or Olfaction 827
- Mechanism of Olfaction 828
- Sniffing 832
- Adaptation of Olfactory Receptors 832
- Disorders Related to Olfaction 832
- Method of Quantitative Estimation of the Sense of Smell Using an Olfactometer 833

94. Physiology of Taste Sensation (Gustatory Sensation) 836
- Functional Anatomy of Tongue 836
- Transduction of Gustatory Stimuli 838
- Factors Affecting Taste Sensation 838
- Mechanism of Gustatory Transduction 839
- Taste Pathways 840
- Applied Aspect 841

95. Physiology of Vision 844
- Anatomy of Eye 844
- Genesis of Electrical Activity in Retina 850
- Photoreceptor Potentials 851
- Responses to Bipolar, Amacrine and Horizontal Cells 854
- Response Pattern of Ganglion Cells 855
- Responses of Neurons in Lateral Geniculate Bodies and Visual Cortex 857
- Visual Pathway 857
- Principles of Optics 860
- Eye Movements 865

96. Physiology of Hearing 870
- Sound Waves 870
- Functional Anatomy of Ear 872
- Electrical Responses in the Hair Cells 877
- Central Auditory Pathway 881
- Physiology of Hearing Defects/Deafness 883

Section 11: Integrated Physiology

97. Temperature Regulation and Adaptation 891
- Normal Human Body Temperature 891
- Heat Producing and Heat Dissipating Mechanisms of the Body 892
- Regulation of Temperature (or Adaptation to Heat and Cold) 893

98. Physiology of Physical Activity (Sedentary Lifestyle and Exercise) 898
- Recognizing Sedentary Behavior 898
- Classification of Exercise 900
- Physiological Effects of Exercise 901
- Response to Exercise 903
- Long-term Adaptation of Exercise 904
- Exercise in Extreme Climate (Heat and Cold) 904

99. Physiology of Infancy 910
- Developmental Milestones 910
- Importance of Understanding Infant Physiology 910
- Physiological Changes in Infants 913

100. Physiology of Aging, Free Radicals and Antioxidants 920
- Theories of Aging 920
- Physiological Changes Associated with Ageing 921
- Role of Free Radicals 921
- Antioxidants: Mechanisms and Importance 922
- Strategies to Mitigate Aging and Oxidative Stress 923

101. Physiology of Yoga and Meditation 925

Yoga and Meditation 925
- Physiology of Stress 925
- Yoga 926
- Process of Meditation 928
- Integrating Yoga and Meditation for Health and Wellness 929

102. Brain Death 931
- Concept and Criteria 931
- Implications 931

Appendix (AETCOM 1 and 2) *935*

Answers to Crossword Puzzles *939*

Index *941*

Basics of Electrocardiography

37
CHAPTER

COMPETENCY ADDRESSED

PY5.5: Describe the physiology of electrocardiogram (ECG), its applications and the cardiac axis.

LEARNING OBJECTIVES

At the end of this chapter, the learner should be able to:

- Describe the basic principles of electrocardiography.
- Describe the spread of cardiac impulse resulting the electrical changes in heart.
- Describe the physiological basis of various components of ECG.
- Describe the normal ECG and its physiological significance.

Myocardium is an excitable tissue which responds to electrical changes and results in myocardial contraction. The cardiac impulse generated by the SA node spreads through the entire heart through the conducting system of the heart (discussed in Chapter 5.2). While spreading from the SA node to Purkinje fibers, a dipole is created in the heart, resulting in the ***flow of current from areas of depolarization (negatively charged areas) to polarized/resting (positively charged) areas creating a current sink*** **(Fig. 37.1)**.

These electrical changes vary with the flow of current from one point to another, hence altering the magnitude and direction of dipole created. These changes result in variations in the instantaneous vector of current in terms of direction and magnitude of current and voltage of myocardium (discussed later). There are two main ways to record these changes, either by directly inserting the recording electrodes at various points of the myocardium ***(monophasic recording)*** or by picking up these electrical changes from the body surface ***(electrocardiography)***. The simple explanation that can be given for this procedure is that our body is mainly composed of water and electrolytes, which act as volume conductor and allows these electrical changes to be transmitted to our body surface which can be picked up by simple electrodes. Hence, electrocardiography is defined as ***surface recording of electrical changes taking place in heart from beat to beat (i.e., recording of the electrical changes during the cardiac cycle)***.

It is similar to cardiac action potential **(Fig. 37.2)**. The differences between ECG with that of cardiac action potential is shown in **Table 37.1**.

The surface recording is done using 2 electrodes, hence they yield a biphasic recording, as shown in **Figure 37.3**.

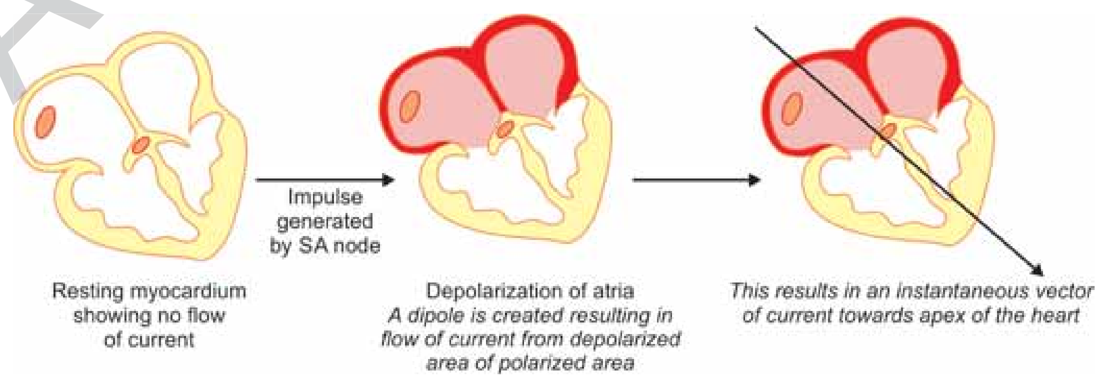
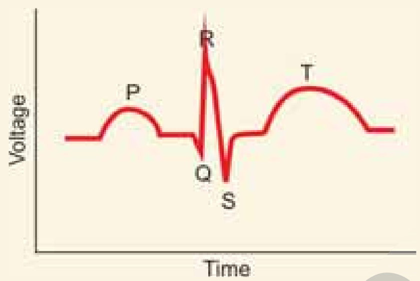
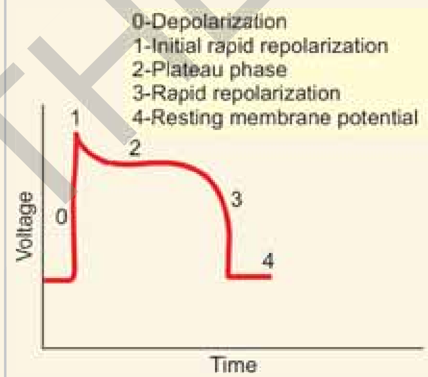
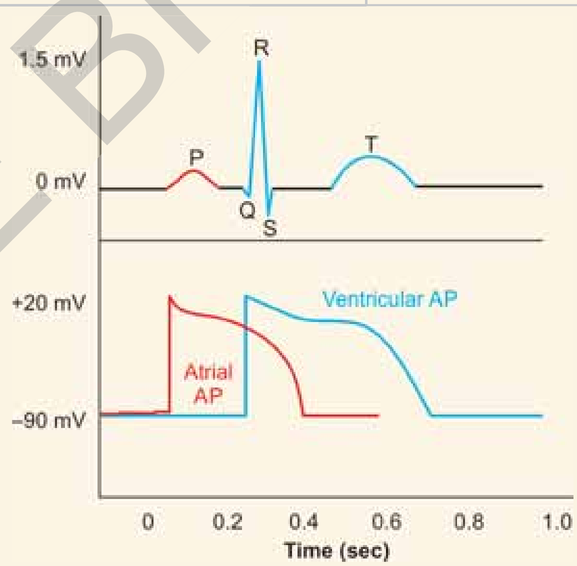


Fig. 37.1: Principle of dipole for flow of current in heart.

Table 37.1: Features of ECG vs cardiac action potential.

Features	ECG	Cardiac action potential
Type of event	Electrical event showing the phases of depolarization and repolarization.	Electrical event showing the phases of depolarization and repolarization.
Electrode placement	On the surface of the body	One electrode on the surface of muscle and another inside the cardiac muscle
Resting membrane potential	Zero, as both the electrodes have no potential difference at rest	–90 mV, as both the electrodes measure resting potential difference across the cell membrane
Type of action potential recorded	Biphasic	Monophasic
Magnitude of maximum potential difference	2–4 mV	100–110 mV
Electrical events captured from	It shows the changes in both the atria and the ventricles	It shows the electrical changes in only one chamber, in which the electrodes are placed
Voltage time graph showing both the recordings		
Correlation between ECG and monophasic AP	 **Fig. 37.2:** Correlation of ECG and myocardial action potentials (AP).	

Normal ECG: The record of the electrical activity of heart in terms of voltage-time graph in a normal disease free heart is called as normal ECG.

COMPONENTS OF NORMAL ECG

- **Waves:** Any deviation above and below the isoelectric line.
- **Intervals:** Intervals between 2 wave including the waves.
- **Segments:** Intervals between 2 waves excluding the waves, i.e., only on isoelectric lines.

Waves

Figures 37.4A and B for physiological basis of waves.

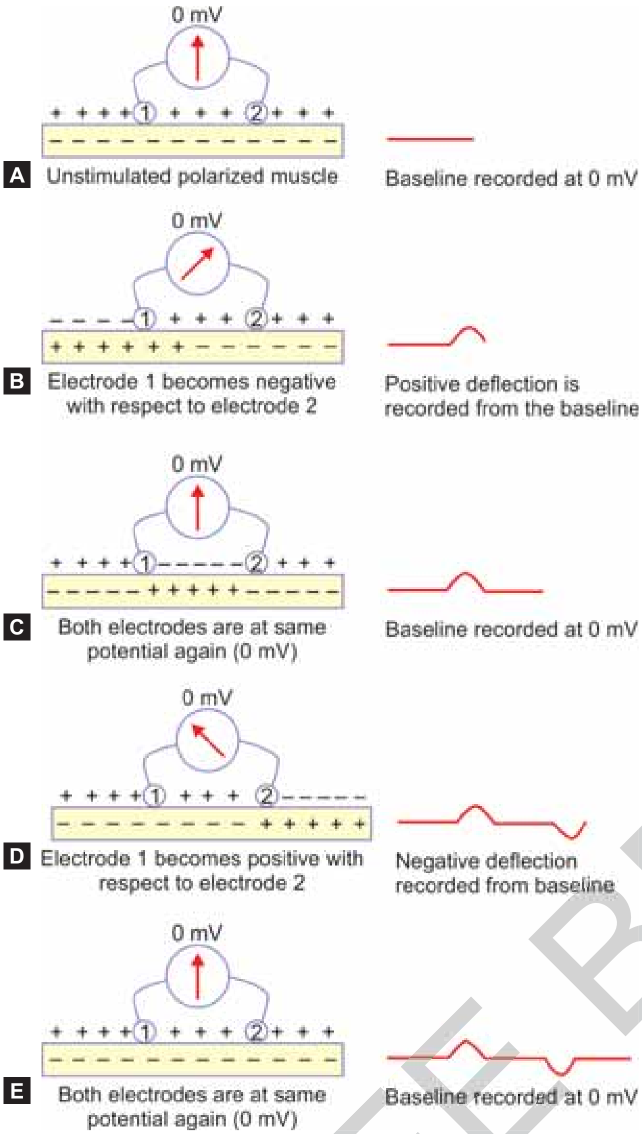


Fig. 37.3: Principle of biphasic recording.

P Wave–Depolarization of Atria

- It is a positive deflection with duration: 0.08–0.1 seconds and magnitude –0.2 mV.
- Depolarization begins in SA node and spreads in all directions.
- It is in the direction of mean cardiac vector, hence positive in all leads.

Significance of P wave: A normal P wave signifies that:
- Impulse is originating in SA node
- Spread of impulse is in usual direction (towards the apex)
- There is no defect in conduction
- Atrial musculature is normal

What is the significance of an inverted P wave?
An inverted P wave indicates that SA node fails to generate impulse and the atrial muscle is depolarizing by impulse generated in AV node.

QRS Complex–Depolarization of Ventricles

It is a positive deflection with duration: 0.08–0.12s and magnitude—0.5–2.5 mV.
- Q wave—septal depolarization
- R wave—ventricular depolarization
- S wave—depolarization of basal parts of heart

The first part of the ventricle to become depolarized is ***left endocardial surface of septum***. Followed by endocardial surface of both ventricles. The ventricular mass of left ventricle is more than the right ventricle, ***posterior basal part of left ventricle*** is the last part to get depolarized.

Significance of QRS complex:
Broad QRS complexes are seen in:
- Conduction blocks especially bundle branch block
- Hypercalcemia

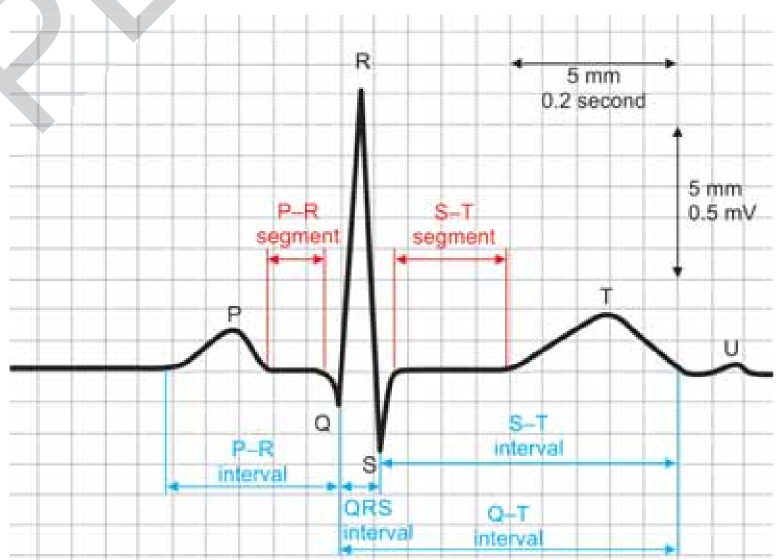


Fig. 37.4A: Physiological basis of waves.

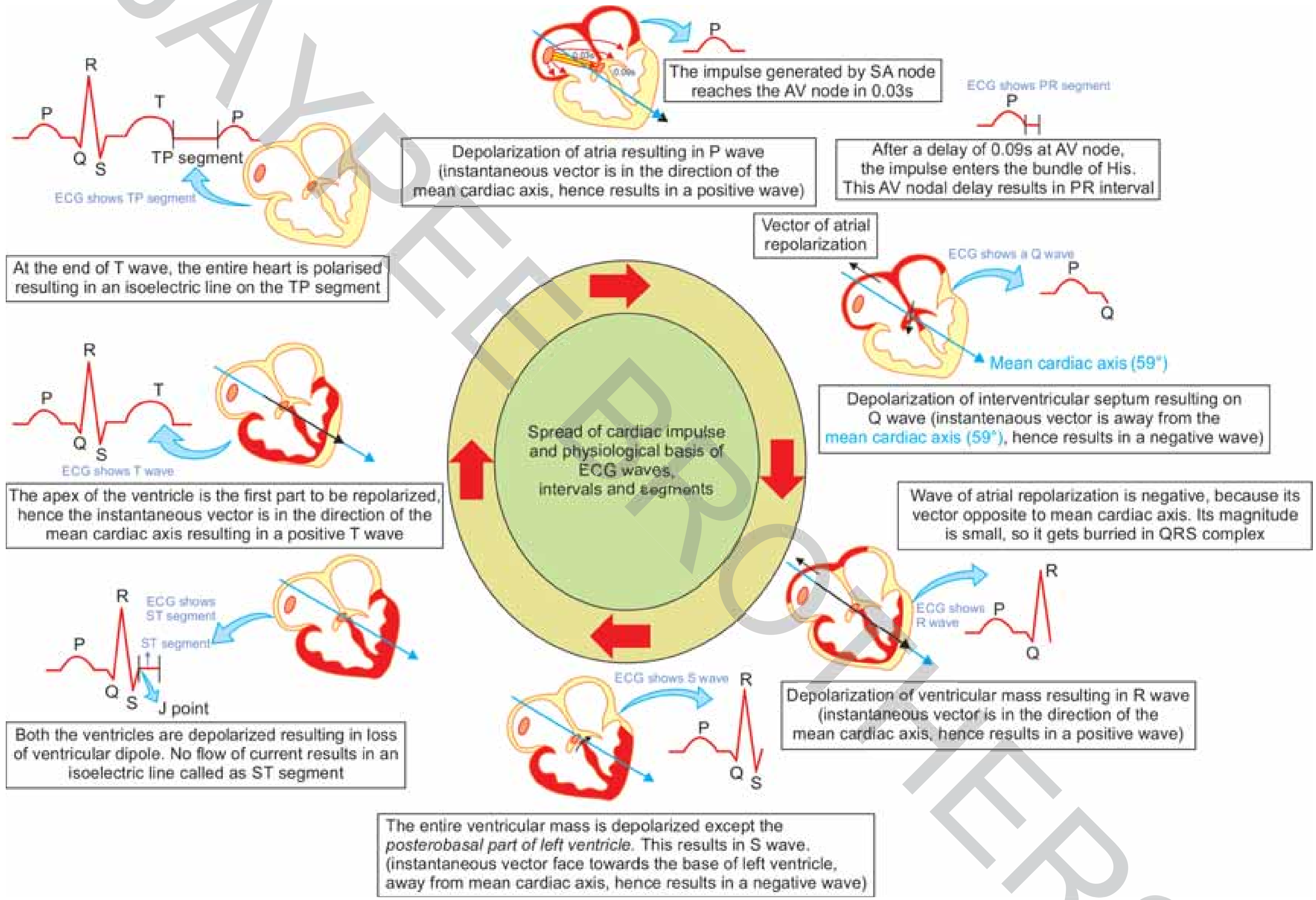


Fig. 37.4B: The physiological basis of generation of waves, intervals and segments of ECG.

T Wave–Repolarization of Ventricles

It is a positive deflection with duration: 0.27 s and magnitude—0.5 mV.

Significance of T wave: T wave inversion indicates serious myocardial damage and is often associated with cardiac hypoxia.

> ***R wave and T wave are positive***
>
> During depolarization and repolarization, the instantaneous vectors are in the direction of mean cardiac axis and hence both the waves of depolarization (QRS complex) and repolarization (T wave) are positive.

U Wave–Slow Repolarization of Papillary Muscles

It is a positive deflection with duration: 0.08 s and magnitude—0.2 mV. It is usually not visible.

Note: Wave of atrial repolarization: It is a negative wave, buried in QRS complex. Hence it is not seen on ECG. But it can be seen in cases of prolonged PR interval.

INTERVALS (FIG. 37.5)

PR Interval

- Indicates atrial depolarization and conduction through AV node.
- It starts from beginning of P wave till the R wave with duration: 0.12–0.20 seconds.
- Longer PR interval indicates impaired conduction through bundle.
- Variable PR interval indicates AV dissociation.

> ***What is the significance of PR interval?***
>
> **Physiological significance:** Denotes conduction delay through AV node. It allows the ventricular filling at the end of atrial systole.
>
> **Clinical significance:** Longer PR interval indicates impaired conduction through bundle.
>
> Variable PR interval indicates AV dissociation.
>
> Heart blocks (discussed in Chapter 38)

RR Interval

It denotes the ***time taken to complete one cardiac cycle***.

It is the distance between two R waves. Its duration is 0.8 seconds.

Physiological significance: It is used to calculate the heart rate by the formula:

HR = 1500/RR interval at paper speed of 25 mm/s.

QRS Duration

It denotes ***ventricular depolarization*** and ***atrial repolarization***.

It is measured as distance between Q wave and S wave. Its duration is 0.08 to 0.10 seconds.

QT Interval

It denotes duration of ***ventricular depolarization*** and ***repolarization***.

It is measured as distance between Q wave and the end of T wave and indicates total ventricular systolic time. Its duration is 0.40–0.43 seconds.

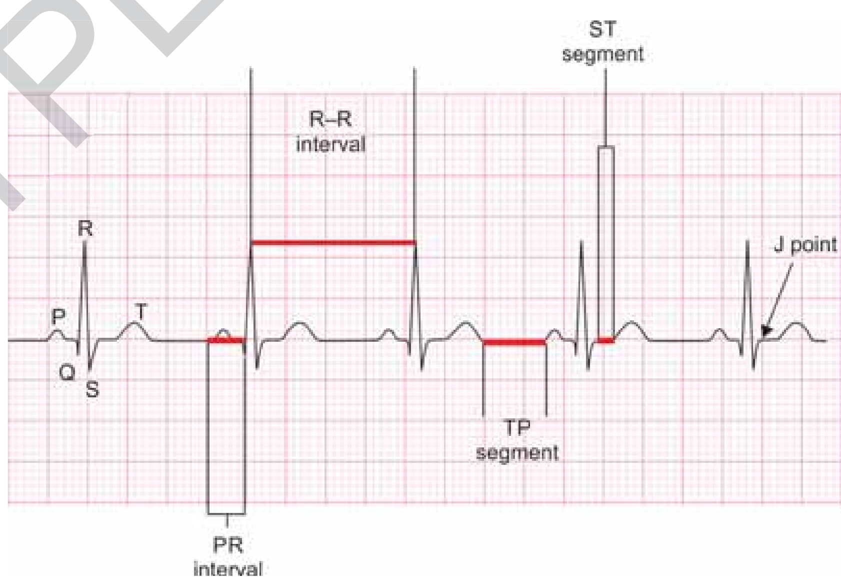


Fig. 37.5: The normal ECG trace showing intervals and segments.

Clinical significance of QTc interval: QTc interval denotes QT interval corrected for the heart rate. It is measured as the QT interval divided by square root of RR interval:

$$QTc = \frac{\text{QT interval}}{\sqrt{\text{RR interval}}}$$

A normal QTc interval should be ***0.36–0.44 s in males and 0.36–0.46 s in females***. If this QTc interval is more than 0.47 seconds it acts as the predictor of cardiac disease. But a QTc interval of more than 0.5 s predicts increased risk of life-threatening cardiac disease. It also helps in diagnosis of ***long QT syndrome***.

ST Interval

It is measured from end of QRS complex to end of T wave. Its duration is 0.32 seconds.

TP Interval

It denotes diastolic period of the heart. It is measured from end of T wave and onset of P wave.

Clinical significance of TP interval: Variable TP interval indicates AV dissociation.

SEGMENTS (FIG. 37.5)

PR Segment

- It denotes time taken by AV node to conduct the impulse.
- It is measured as the isoelectric line between end of P wave and beginning of R wave.
- Its duration is 0.04 to 0.08 seconds.

ST Segment

It denotes time gap between depolarization and repolarization of the ventricles.

It is measured as isoelectric line at the end of S wave till the beginning of T wave. Its duration is 0.04–0.08 seconds.

Physiological significance: The ST segment is the important period during the electrical changes in the ventricle, as no current flows through the ventricles at this time. It marks the period of no electrical activity in depolarized ventricle.

Clinical significance: In case of the myocardial injury occurring due to ischemia or infarction, the infarcted muscle does not get depolarized. Hence, this segment shows peculiar changes owing to the dipole so created between the healthy and infarcted myocardium. The current flow in this case is called the ***current of injury***. It appears as ***elevation and sagging*** of this segment indicating myocardial damage or hypoxia respectively.

The point at the beginning of ST segment, when the heart is just completely depolarized and no current flows, is called ***J point***. It is the reference point to see or diagnose the changes in ST segment.

TP Segment

It denotes the polarized or resting state of the heart. In this period, no current flows through the heart and all the chambers are polarized. Its duration is 0.2 s at HR 75/min, which is inversely related to HR.

RECORDING OF ECG

After we have studied the basics of ECG, let us become familiar with certain terms and basics related to recording and analysis of ECG:

- **Electrocardiography:** It is branch of physiology related to recording and analysis of electrical activity of heart
- **Electrocardiogram:** Recording of the electrical changes in heart during the cardiac cycle
- **Electrocardiograph:** Instrument for making permanent record of small potential variations occurring in different parts of body due to electrical activity of heart.

ECG Paper (Fig. 37.6)

It is a ***heat sensitive/thermal paper*** with a graphic pattern, on which the electrocardiograph records the electric fluctuations of heart in terms of voltage and time graph. At the paper speed of 25 mm/s, the small 25 boxes (25 mm) or

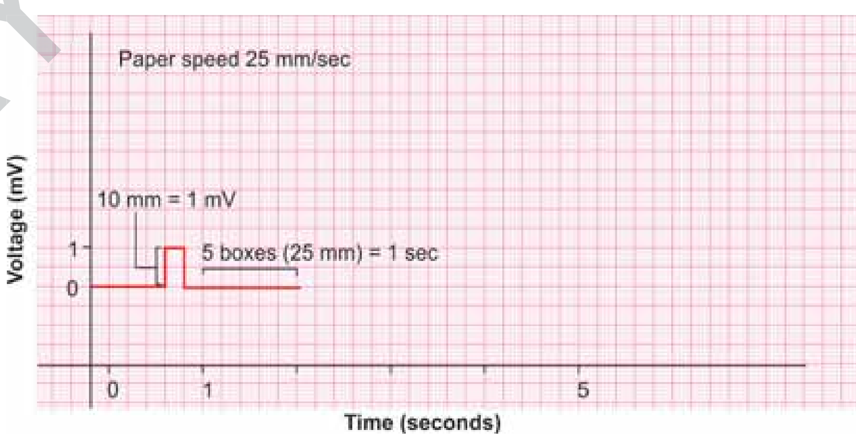


Fig. 37.6: The ECG paper showing calibration.

5 big boxes represent one second on the time scale, whereas 10 mm or two large boxes denote 1 mV of potential change.

ECG Jelly

It is the conducting paste, which contains very fine sand/glass particles, which produce local erythema.

Electrodes and Leads (Fig. 37.7)

The rectangular flat metallic discs (7.5 × 5 cm) are called ***electrodes***, which are placed on the body surface.

In terms of physical lead, it defined as a set of two electrodes connected by a wire. However, the electrical picture of heart recorded between two electrodes on the paper is also called a lead.

Father of ECG: **William Einthoven** (1903), discovered the ECG and proposed the Einthoven's laws, which became the basis of recording ECG. He proposed the ***Einthoven's triangle*** **(Fig. 37.8)** formed by joining 2 acromion processes and the pubic symphysis with heart in the center.

Einthoven's Law: It states that "if the ECGs are recorded simultaneously with the three limb leads, the sum of the potentials recorded in leads I and III will equal the potential in lead II".

Potential of Lead I + Potential of Lead III = Potential of Lead II

This also implies that, if the electrical potential of any two of the bipolar leads are known at any given instance, the third one can be determined mathematically from first two by simply summing the first two, i.e., mathematical sum of all the leads is zero:

$$LI + LII + LIII = 0$$

Mean Cardiac Axis

It is the resultant vector of heart which is produced by the sum of instantaneous vectors during the series of electrical changes.

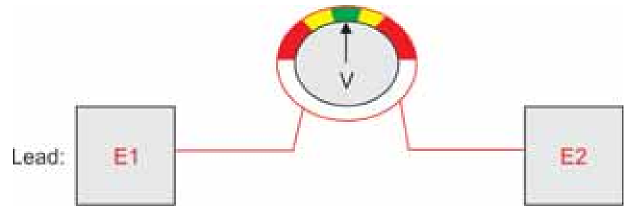


Fig. 37.7: Electrodes and leads.

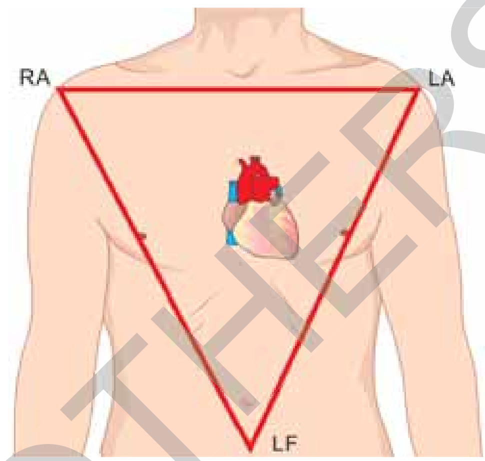


Fig. 37.8: Einthoven's triangle.

Normal Mean QRS vector is 59 degrees.
Limit of normal cardiac axis is ***–30 to +110 degrees***.

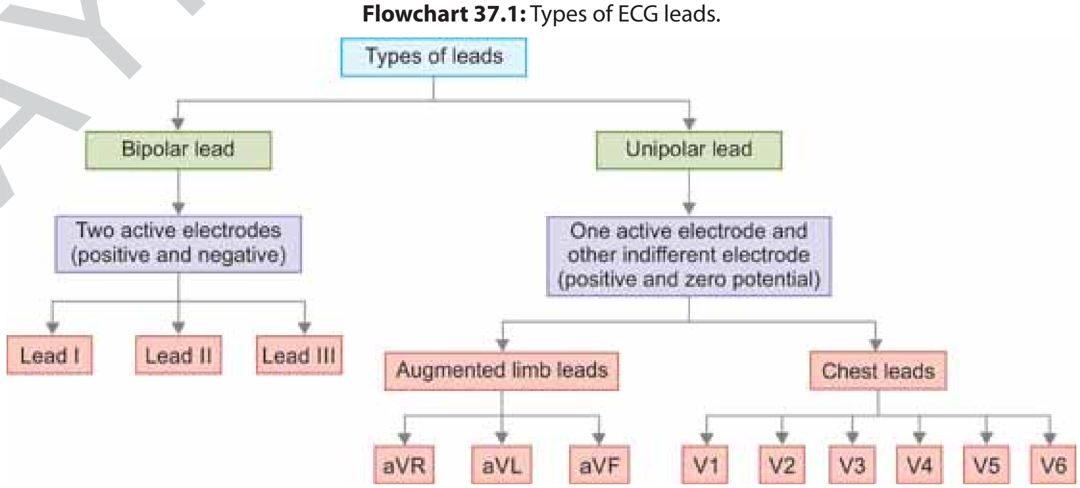
Physiological significance: If the mean cardiac axis lies to the left of -30°, it is called ***left axis deviation***, while to the right of +110° is called ***right axis deviation***.

ECG Leads

Based on the nature of electrodes, the basic 12 ECG leads are classified as **(Flowchart 37.1)**:

1. **Bipolar leads:** It is also called as standard limb leads, having 2 active electrodes (positive and negative electrodes):
   - Lead I → between RA and LA (0°)

Flowchart 37.1: Types of ECG leads.



- Lead II → between RA and LF (60°).
  This lead has the maximum voltage because it is in the direction of mean cardiac axis (59°)
- Lead III → between LA and LF (120°)

2. **Unipolar leads**: These have 1 active/exploring electrode and another indifferent electrode with zero potential, hence called as unipolar leads. They are of two types:
   i. **Augmented limb leads (Figs. 37.9 and 37.10):** These are called as augmented because the signal is augmented by **50%:**
   aVR → The active electrode is at RA and reference/indifferent electrode is average of LA and LF. The ***instantaneous vector of aVR is at 210°***, which is opposite to the mean cardiac axis. Hence, this lead is also called the '***inverted lead***.'
   aVL → The active electrode at LA and reference/indifferent electrode is average of RA and LF. The ***instantaneous vector of aVL is at –30°***

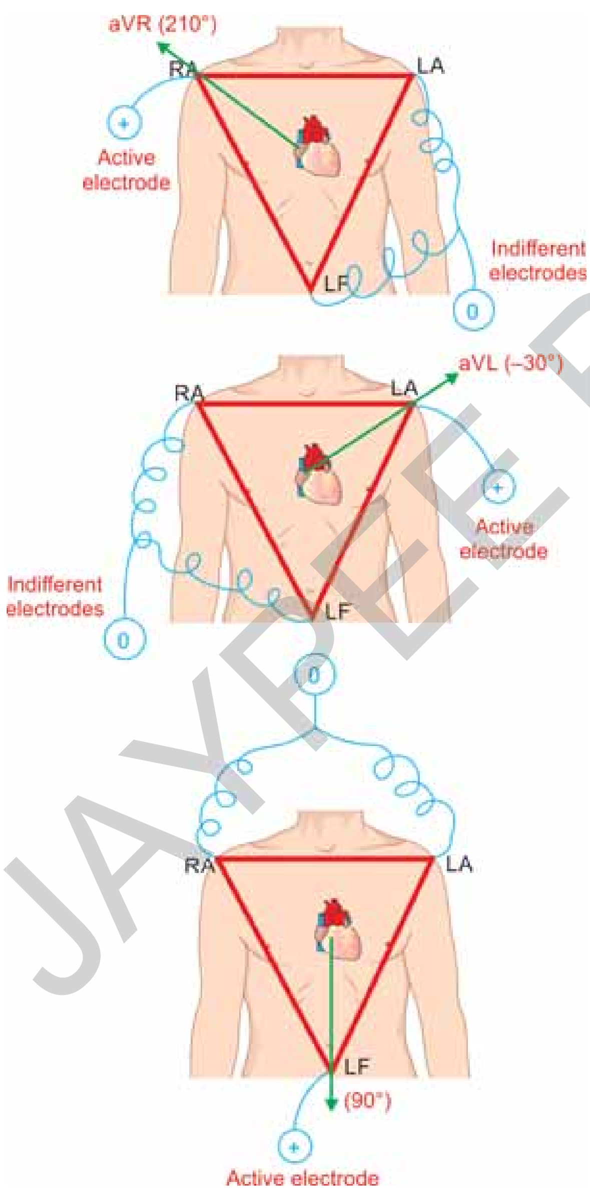


Fig. 37.9: The augmented limb leads.

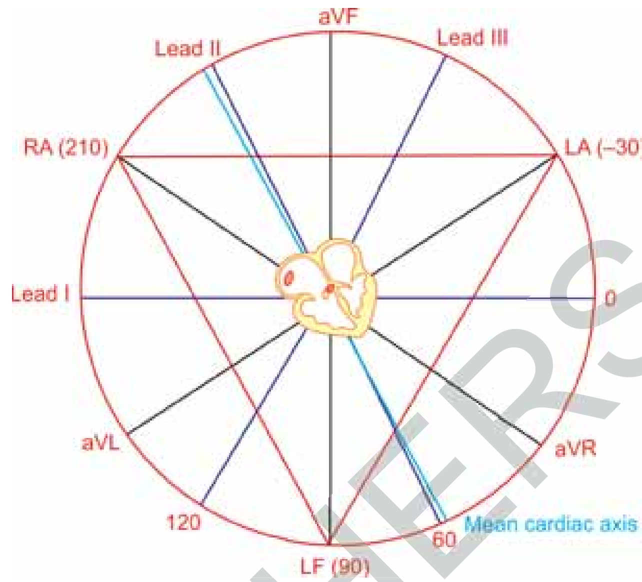


Fig. 37.10: Hexagonal arrangement showing directions of limb leads.

aVF → The active electrode at LF and reference/indifferent electrode is average of LA and RA. The ***instantaneous vector of aVF is at 90°***.

ii. **Chest Leads (Fig. 37.11):**
   - V1—placed in 4th intercostal space 2.5 cm to right of sternum.
   - V2—placed in 4th intercostal space 2.5 cm to left of sternum.
   - V3—placed between V2 and V4.
   - V4—places in 5th intercostal space in midclavicular line.
   - V5—placed in the 5th intercostal space in anterior axillary line.
   - V6—placed in the 5th intercostal space in posterior axillary line.

   Based on the position of these standard chest electrodes with respect to the heart, they are also called:
   - Right sided chest leads (V1 V2)
   - Inferior chest leads (V3 V4)
   - Left sided chest leads (V5 V6)

Normal Wave Patterns in All the Standard ECG Leads (Table 37.2)

Lead I, II and III

- All characteristics are same except for voltage which is maximum in lead II
- P wave: Positive/upward
- Q wave: Absent
- RS wave: Positive R wave
- T wave: Positive

Significance of Lead I, II and III

- For diagnosis of cardiac axis
- For diagnosis of cardiac arrhythmias
- For studying functional abnormality of heart

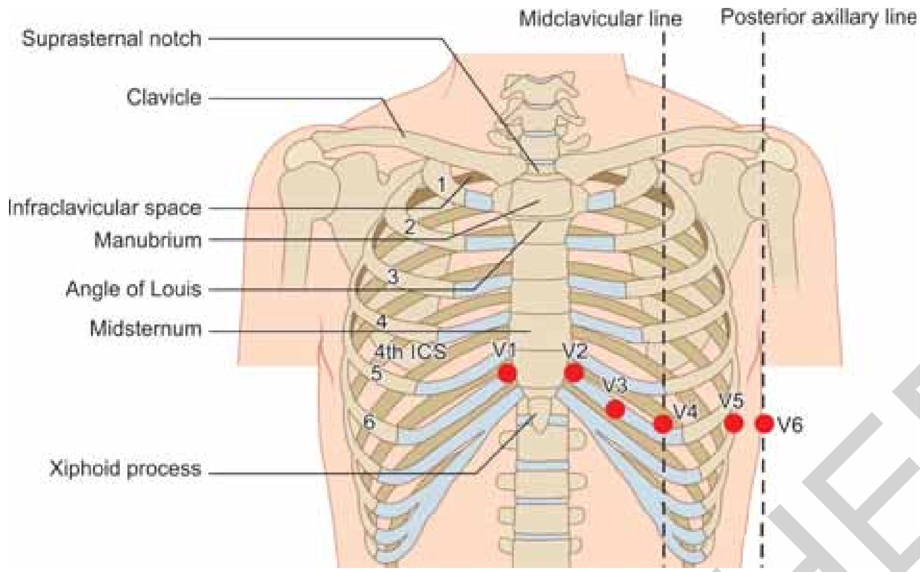


Fig. 37.11: Placement of chest leads.

Table 37.2: Normal wave patterns in all the standard ECG leads.

	I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
P wave	Positive/ upward	Positive/ upward	Positive/ upward	Negative/ Downward	May be upward/ Downward	Positive/ upward	Positive/ upward	Positive/ upward	Positive/ upward	Positive/ upward	Positive/ upward	Positive/ upward
Q wave	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	present	present	present
R wave	Positive	Positive	Positive	Negative	Biphasic	Positive	Positive r<<S	Positive r<S	Positive R=S	Positive R=S	Positive R>s	Positive R>s
S wave	Negative	Negative	Negative	Positive	Biphasic	Negative	Negative r<<S	Negative r<S	Negative R=S	Negative R=S	Negative R>s	Negative R>s
T wave	Upright/ positive	Upright/ positive	Upright/ positive	Inverted	Inverted	Upright/ positive	Upright/ positive	Upright/ positive	Upright/ positive	Upright/ positive	Upright/ positive	Upright/ positive

Augmented Limb Leads

Waves	aVR	aVL	aVF
P wave	Inverted	Biphasic	Upright
Q wave	Absent	Absent	Absent
R wave	Inverted	Positive (Biphasic RS wave)	Positive
T wave	Inverted	Inverted	Positive

Significance of augmented leads

- To find out position of heart
- Confirming ventricular damage or hypertrophy

Chest Leads

- P wave: Positive in all chest leads
- Q wave: Absent in V1, V2 and V3
- RS wave: R increases and S decreases from V1-V6
- T wave: Positive if R>S; negative if R<S ***(it is in the direction of QRS complex)***

Q Wave is Present Only in V4, V5 and V6 (Fig. 37.12)

- V1: rS pattern
- V2: rS pattern
- V3: RS pattern
- V4: qRs pattern
- V5: qRs pattern
- V6: qRs pattern

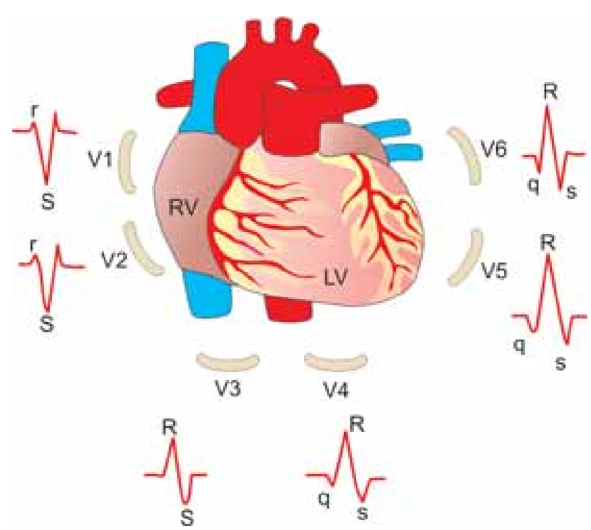


Fig. 37.12: Pattern of QRS complex in chest leads.

Significance of chest leads

- Localization of recent or old ventricular damage
- Bundle branch block
- Ventricular hypertrophy

SUMMARY

- In this chapter, we have studied about electrocardiography (ECG), focusing on its basic principles, physiological basis, and clinical significance.
- An Electrocardiogram (ECG) is a graphic representation of the electrical activity of the heart. It comprises several key components:
  a. P Wave: Represents atrial depolarization, the contraction of the atria.
  b. QRS Complex: Depicts ventricular depolarization, the contraction of the ventricles.
  c. T Wave: Reflects ventricular repolarization, the recovery phase of the ventricles.
  d. PR Interval: Indicates the time it takes for the electrical impulse to travel from the atria to the ventricles.
  e. QT Interval: Represents the total time for ventricular depolarization and repolarization.
- A normal Electrocardiogram (ECG) consists of several segments:
  a. PR Segment: The flat line between the end of the P wave and the beginning of the QRS complex, representing the delay at the atrioventricular (AV) node.
  b. ST Segment: The flat, isoelectric line between the end of the QRS complex and the beginning of the T wave, indicating the period when the ventricles are electrically depolarized but not yet repolarized.
  c. TP Segment: The interval between the end of the T wave and the beginning of the next P wave, representing the time when the ventricles are fully repolarized.
- ECG leads are electrodes placed on the body to record the heart's electrical activity. The standard 12-lead ECG includes:
  a. Bipolar Limb Leads (I, II, III): Record electrical activity between two limbs.
  b. Augmented Voltage Leads (aVR, aVL, aVF): Measure electrical activity from a single limb and the augmented (combined) electrical activity of the other two limbs.
  c. Precordial (Chest) Leads (V1-V6): Record electrical activity across the chest, providing a comprehensive view of the heart's horizontal plane.
- Applied aspects of ECG involve utilizing electrocardiography for clinical purposes and patient care. Key applications include:
  a. Diagnosis of Heart Conditions: ECG is crucial for diagnosing various heart conditions such as arrhythmias, myocardial infarction, and conduction abnormalities by analyzing the waveform patterns and intervals.
  b. Monitoring Cardiac Health: ECG monitoring is used in hospitals and ambulatory settings to continuously track and assess a patient's cardiac activity, providing real-time information about rhythm changes and potential issues.
  c. Risk Stratification: ECG findings contribute to assessing the risk of cardiovascular events, aiding healthcare professionals in determining appropriate interventions and treatments.
  d. Exercise Stress Testing: ECG is commonly employed during exercise stress tests to evaluate the heart's response to physical activity, helping diagnose coronary artery disease and assess cardiovascular fitness.
  e. Electrolyte Imbalance Detection: ECG can reveal abnormalities associated with electrolyte imbalances, such as potassium or calcium, which can impact cardiac function.

LET US SEE, WHAT YOU HAVE LEARNT?

Review Questions

Long/Short Answer Questions

Q1. Define electrocardiogram. Describe the physiological basis of the genesis of ECG waves and intervals.
Q2. Draw a well labeled diagram of normal electrocardiogram.
Q3. Describe the physiological basis of PR interval. Describe the clinical significance of PR interval.
Q4. What is relationship of ECG waves with cardiac action potential?
Q5. Name the inverted lead, why it is called inverted?

Explain Why? (Reasoning Questions)

Q1. P wave on an ECG represents atrial depolarization.
Q2. QRS complex on an ECG is larger in amplitude than the P wave.
Q3. PR interval on an ECG is important for assessing atrioventricular (AV) conduction.
Q4. ST segment should be isoelectric (flat) in a normal ECG.

Critical Thinking Case-Based Questions

Q1. A 25-year-old healthy male, came for a routine physical examination. His physician suggested an electrocardiogram (ECG) as part of the examination due to a family history of heart disease. The ECG showed a normal sinus rhythm with no abnormalities. Depending upon given scenario, answer the following question:

a. Describe the physiological basis of a normal electrocardiogram (ECG) tracing.
b. How does the ECG reflect the different phases of the cardiac cycle?
c. What are the physiological significance of ECG leads?

Multiple Choice Questions

Q1. Vagal stimulation of the heart causes:
a. Increased heart rate
b. Increased R-R interval in ECG
c. Increased force of heart contraction
d. Increased cardiac output.

Q2. Einthoven's triangle, what is the value of Lead III when Lead I = 2 mV and Lead II = 1 mV?
a. 1
b. 2
c. 3
d. 4

Q3. In a standard electrocardiogram, an augmented limb lead measures the electrical potential difference between:
a. Two limbs
b. One limb and two other limbs
c. One limb and neutral (zero)
d. Two limbs and two other limbs

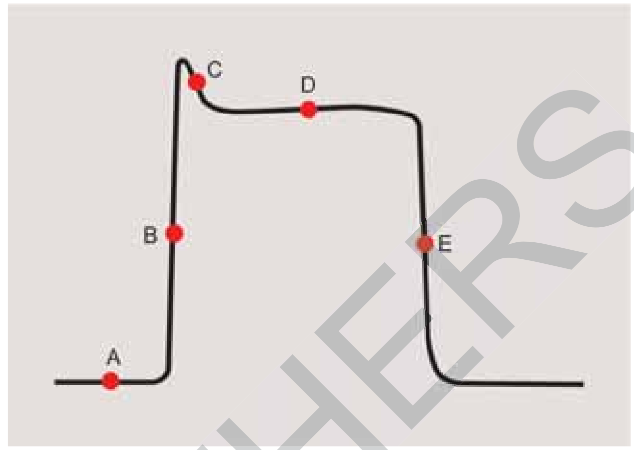
Q4. QRS complex indicates:
a. Atrial repolarization
b. Atrial depolarization
c. Ventricular repolarization
d. Ventricular depolarization

Q5. The ECG of a 40-year-old male was recorded using standard bipolar limb leads. The sum of voltage of the three standard leads was found to be 5 millivolts. This indicates:
a. A normal heart
b. Right ventricular hypertrophy
c. Left ventricular hypertrophy.
d. Increased cardiac muscle mass.

Q6. A male long-term smoker who is 62-year-old, weighs 110 kg. He had the following ECG recorded at his local hospital. Which of the following is the mean electrical axis calculated from standard Leads I, II and III shown in his ECG?

a. –110°
b. –20°
c. +90°
d. +105°

Q7. The phases of the ventricular muscle action potential is given below:

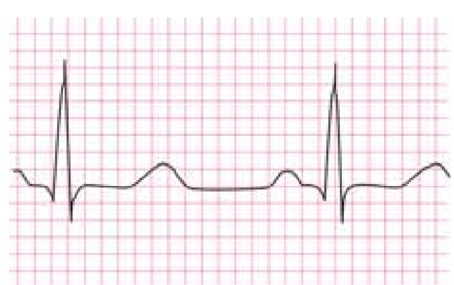


At which point on the above ventricular action potential is membrane potential most dependent on calcium permeability?
a. Point B
b. Point C
c. Point D
d. Point E

Q8. The 58 -year-old male is brought to cardiac emergency unit with chest pain. From his symptoms and lab diagnosis, he is diagnosed with inferior wall myocardial infarction. His ECG shows ST segment elevation and T wave inversion. Which phase of cardiac cycle is affected in this patient?
a. Atrial depolarization and repolarization
b. Ventricular depolarization and repolarization
c. Ventricular repolarization
d. Ventricular depolarization

Q9. What is the mean cardiac axis of a patient if the net magnitude of Lead I is +6mV, Lead II is +10 mV and lead III is +5mV. It shows
a. Right axis deviation
b. Left axis deviation
c. Data is insufficient
d. Normal axis, no deviation

Q10. How is the heart rate, calculated in the given ECG strip, recorded at 25 mm/sec?



a. 25 × 60/RR interval (in mm)
b. 1500/RR interval (in cm)
c. 25/RR interval (in cm)
d. 150/RR interval (in mm)

Q11. ECG (electrocardiogram) was developed first by:
a. Wilhelm His
b. Steward
c. Hubert Mann
d. Willem Einthoven

Q12. A normal ECG report must consist of the following information:
a. Rhythm, cardiac axis
b. Conduction intervals
c. Description of the ST segments, QRS complexes, T-waves
d. All of these

Q13. For the normal heartbeat, depolarization stimulus originates in:
a. His-bundle areas
b. Epicardium
c. Sinoatrial (SA) node
d. Atrioventricular (AV) node

Q14. P wave indicates:
a. Depolarization of right ventricle
b. Depolarization of left ventricle
c. Depolarization of both atria
d. Atria to ventricular conduction time

Q15. Ventricular muscle depolarization is indicated by:
a. PR interval
b. P wave
c. U wave
d. The QRS complex

ANSWERS

1. b **2.** c **3.** c **4.** d **5.** d **6.** d **7.** c **8.** c **9.** d **10.** a **11.** d **12.** d **13.** c **14.** c **15.** d

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Printed in India

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Medical Publishers (P) Ltd.
EMCA House, 23/23-B, Ansari Road,
Daryaganj, New Delhi - 110 002, INDIA
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ISBN 978-93-5696-364-1

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