



andelson.com

Enrico D. Canale Gordon R. Campbell
Joseph J. Smolich Julie H. Campbell

Cardiac Muscle

With 101 Figures



Springer-Verlag Berlin Heidelberg New York Tokyo

Contents

A. General Introduction	1
B. Morphology of Cardiac Muscle	8
I. Light Microscopy of Cardiac Muscle	8
II. Ultrastructure of Cardiac Muscle	11
1. Sarcolemma	11
2. Caveolae	13
3. T System	15
4. Intercellular Junctions	20
a) Nexus	20
b) Desmosome	26
c) Fascia Adherens	26
5. Sarcoplasmic Reticulum	27
a) Junctional SR	27
b) Network (Free) SR	30
α) Central Region of Sarcomere	30
β) Z Disc Region	30
γ) Mitochondrial Network SR	35
c) Function of SR	35
6. Myofibrillar System	35
a) Contractile Elements	35
b) Sarcomeric Arrangement of Myofilaments	37
c) Myosin ATPase Activity	40
d) Myosin Subunits	40
e) Z Disc (Band)	41
7. Cytoskeleton	43
a) Intermediate Filaments	43
b) Microtubules	44
c) Leptofibrils	45
8. Mitochondria	45
9. Lysosomes	47
10. Atrial Specific Granules	47
11. Other Cell Organelles and Inclusions	47
III. Histochemistry	48
IV. Extracellular Matrix	48
V. Venous Cardiac Muscle	51
C. Morphometry of Cardiac Muscle	52
I. Methodology	52

II. Factors Influencing Morphometric Parameters	54
III. Morphometric Parameters in Adult Myocardium	55
1. Myocyte Density and Ratio of Myocytes and Capillaries	55
2. Dimensions of Myocytes	56
3. Composition of the Myocardium	57
4. Composition of Myocytes	58
a) Myofibrils	58
b) Mitochondria	58
c) Nucleus and Matrix	58
d) Sarcoplasmic Reticulum and T System	58
D. The Conduction System	60
I. The Sinoatrial Node	60
1. Location	60
2. Histology	60
3. Ultrastructure of SA Nodal Cells	61
a) SA Nodal Cell Size	61
b) Myofibrillar System	61
c) T System and Sarcoplasmic Reticulum	62
d) Mitochondria, Other Organelles and Glycogen	62
e) Caveolae	62
f) Intercellular Junctions and Basal Lamina	64
4. Transitional Cells	64
5. Intercalated Clear Cells	66
6. Correlation Between Electrophysiological Pacemakers and the Morphological SA Node	66
7. Shifting Locations of the Leading Pacemaker	68
8. Internodal Myocardium	69
9. The Nodal Artery	71
II. The Atrioventricular Junctional Tissues	71
1. Location	71
2. Definition of the AV Nodal-Bundle Junction	72
3. Non-Junctional Atrial Myocardium Near the AV Junction	72
4. Converging Preferential Pathways	73
5. Transitional Cell Zone	73
6. The Compact Node	73
7. Individual Variation	74
8. Species Differences	75
a) Topography	75
b) Connective Tissue	75
c) Subdivisions of the AV Junction	75
9. Ultrastructure of the AV Nodal Tissues	77
a) Transitional Cells	77
b) AV Nodal Cells	77
10. Correlations Between Ultrastructurally- and Electrophysiologically-defined Zones	78
11. Anomalous AV Conduction Pathways	78

III. The Ventricular Purkinje System	79
1. Introduction	79
a) Distribution	80
b) Conduction Velocity	81
c) Purkinje Network	81
2. Species Differences	81
3. Ultrastructure of Purkinje Fibres	83
a) Purkinje Type I, II and III	83
b) T System	83
c) Purkinje Myofibrillar Arrangement	85
d) Alterations of the Myofibrillar System	85
e) Myosin Subunit Composition	87
f) Myosin ATPase Activity	87
g) Intermediate Filaments	90
h) Leptofibrils	90
i) Intercellular Junctions	92
IV. Histochemistry of Mammalian Conduction Systems	93
a) Glycogen	93
b) Lipids	93
c) Metabolic Enzymes	94
V. Non-Mammalian Conduction Systems	96
1. Anatomy of the Non-Mammalian Vertebrate Heart	96
2. Lower Vertebrates	97
a) Physiology	97
b) Histology	98
c) Ultrastructure	98
3. Birds	99
a) Sinoatrial Node	99
b) Atrioventricular Node	100
c) Ventricular Purkinje System	100
4. Phylogenetic Correlations	102
E. Innervation of the Heart	104
I. Major Nerves Supplying the Heart	104
II. Sensory End Formations	105
1. Myelinated Fibres	105
2. Morphological Types of Sensory End Formations	105
a) End-Nets	106
b) Unencapsulated Endings	106
c) Encapsulated Endings	107
3. Ultrastructure of Sensory End Formations	107
a) Afferent and Efferent Fibres Supplying End Formations	107
b) Cells and Nerve Endings Within the End Formation	107
c) Chemoreceptors	109

III. Histochemical and Chemical Studies of Efferent Fibres	111
1. Distribution of Parasympathetic Nerves	111
a) Comparison of the Four Chambers	111
b) Densely-Innervated Atrial Muscle Bundles	112
c) Functional Implications of Densely-Innervated Atrial Muscle Bundles	113
2. Distribution of Sympathetic Nerves	114
a) Catecholamine Fluorescence Studies	114
b) Comparisons with Chemical Studies	114
c) Evidence for Different Types of Sympathetic Nerves in the Heart	115
3. Species Differences and Regional Variation of AV Nodal Innervation	115
IV. Ultrastructure of Neuromuscular Relationships in the Heart	116
1. Terminology	116
a) En Passant	116
b) Close Associations	116
c) Intimate Contacts	118
d) Direct and Diffuse Innervation	119
e) Cholinergic and Adrenergic Varicosities	119
2. Innervation of Working Myocardium	119
3. Innervation of the SA Node	121
4. Innervation of the AV Junctional Tissues	123
a) Efferent Fibres	123
b) Sensory Endings	125
c) Species Differences and Regional Variation	125
5. Innervation of the AV Bundle and Purkinje Fibres	128
a) Nerve Fibre Density	128
b) Efferent Fibres	129
c) Sensory Endings	130
d) Species Differences and Regional Variation	131
6. An Alternative Concept for the Role of the Intrinsic Innervation of the Heart	133
V. Innervation of Non-Mammalian Cardiac Muscle	133
1. Fishes	133
a) Parasympathetic Innervation	133
b) Sympathetic Innervation and Circulating Catecholamines	134
c) Chromaffin Tissue	135
d) Morphology of Innervation	136
2. Amphibians and Reptiles	136
a) Functional Anatomy	136
b) Ultrastructure	139
F. Development of Cardiac Muscle	143
I. Developmental Stages	143

II. Embryonic Heart Formation	143
1. Cardiogenic Crescent	143
2. Development of the Epicardium	144
3. Development of the Endocardium	144
III. Formation of the Four-Chambered Heart	145
1. Looping	145
2. Septation	145
IV. Development of the Coronary Circulation	147
V. Ultrastructure of Developing Cardiac Muscle	150
1. Cytodifferentiation	150
2. Ventricular Myocardium	151
a) Myofibrils	151
b) Mitochondria	154
c) Glycogen	155
d) Nucleus and Perinuclear Region	157
e) T System	159
f) Sarcoplasmic Reticulum	160
g) Intercalated Disc	161
h) Other Cytoplasmic Constituents	163
3. Mitosis	163
4. Cell Death	164
5. Atrial Myocardium	164
VI. Morphometric Changes During the Growth of Myocytes	165
1. General Features	165
2. Dimensions	166
3. Volume Composition of the Myocardium	166
4. Volume Composition of Myocytes	166
a) Myofibrils	166
b) Mitochondria	167
c) Mitochondrial/Myofibrillar Ratio	167
d) Matrix	167
e) Nucleus	167
f) Sarcoplasmic Reticulum	168
g) T System	168
5. Correlation of Structure and Function in Developing Myocytes	168
G. Development of the Conduction System	172
I. Conduction in Embryonic Heart	172
1. ECG of Embryonic Heart	172
2. Preferential Conduction in the AV Canal	172
3. Preferential Conduction in the Ventricular Trabeculae	172
II. Development of the Sinoatrial Node	174
1. Development of the Pacemaker	174
2. Cell Coupling in the Absence of Gap Junctions	175

3. Timing of First Appearance and Position of the SA Node . . .	177
4. Cytological Differentiation	177
5. Innervation	180
6. Bilateral Nodal Primordia	180
III. Development of the AV Node	181
1. Formation of the AV Node	181
2. Evidence for Species Differences	182
3. The Specialized Ring Tissue Theory	182
4. Innervation	184
IV. The Development of the Ventricular Purkinje System	185
1. Differentiation	185
2. Formation of the Purkinje Network	185
3. Theories of Purkinje Fibre Development	185
a) Ventriculomyocardium Theory	187
b) Specialized Precursor Tissue Theory	187
c) The Specialized Ring Tissue Theory	188
H. Cardiac Hypertrophy	189
I. General Features	189
II. Morphological Changes	191
III. Morphometric Changes	192
IV. Regional Patterns	193
I. Regeneration	194
J. Cardiac Muscle Cells in Culture	195
I. Introduction	195
II. Methods of Culture	196
1. Methodology	196
a) Monolayer	196
b) Synthetic Strand	196
c) Cluster	197
d) Polystrand	197
2. Culture Medium	197
III. Working Myocardium in Culture	199
1. Morphology	199
2. Intercellular Junctions	202
3. Mitosis	203
4. Metabolism	204
a) ATP as an Energy Source	204
b) Lipid Metabolism	204
c) Carbohydrate Metabolism	205
d) Amino-Acid Metabolism	205
5. Synthesis of Prostaglandins	206
6. Contractility	206
a) Use of Automatic Monitors	206

b) Effect of Anaesthetics	206
c) Effect of Autonomic Agonists and Antagonists	207
d) Effect of Colchicine	207
e) Effect of Dibutyryl Cyclic AMP	207
7. Hypoxia	208
8. Electrical Properties	209
a) Monolayers and Reaggregates	209
b) Changes in Membrane Composition	210
9. Transmembrane Ion Fluxes	210
a) Calcium Homeostasis	210
b) Calcium Regulation of Cyclic AMP and Beating	211
c) Calcium in Myocardial Cell Injury	211
d) Other Ion Fluxes	212
10. Effect of Hormones and Drugs	212
a) Parathyroid Hormone	212
b) Diazepam	213
11. Receptor Modulation	213
a) Adrenergic	213
b) Cholinergic	215
IV. Cellular Interactions	215
1. Nerve – Muscle	215
a) Tropic Interactions	215
b) Functional Junctions	216
2. Muscle – Non Muscle	217
V. Other Cardiac Muscle	218
1. Cardiac Muscle from Blood Vessels	218
2. Conducting System	219
References	222
Author Index	275
Subject Index	311