



## CONTENTS

Nº 2857

<b>Preface</b>	<b>xv</b>
<b>Chapter 1. Biomechanics as an Interdiscipline</b>	<b>1</b>
1.0 Introduction	1
1.1 Measurement, Description, Analysis, and Assessment	1
1.1.1 Measurement, Description, and Monitoring	3
1.1.2 Analysis	4
1.1.3 Assessment and Interpretation	6
1.2 Biomechanics and Its Relationship with Physiology and Anatomy	7
1.3 Scope of the Textbook	8
1.3.1 Kinematics	8
1.3.2 Kinetics	9
1.3.3 Anthropometry	9
1.3.4 Muscle and Joint Biomechanics	9
1.3.5 Electromyography	10
1.3.6 Synthesis of Human Movement	10
<b>Chapter 2. Kinematics</b>	<b>11</b>
2.0 Historical Development and Complexity of Problem	11
2.1 Kinematic Conventions	12
2.1.1 Absolute Spatial Reference System	12
2.1.2 Total Description of a Body Segment in Space	13
2.2 Direct Measurement Techniques	14
2.2.1 Goniometers	14
2.2.2 Accelerometers	16
2.3 Imaging Measurement Techniques	18
2.3.1 Review of Basic Lens Optics	18
2.3.2 $f$ -Stop Setting and Field of Focus	19
2.3.3 Cinematography	20
2.3.4 Television	21
	<b>vii</b>

2.3.5 Multiple Exposures	22
2.3.6 Optoelectric Techniques	23
2.3.7 Advantages and Disadvantages of Optical Systems	23
2.3.8 Summary of Various Kinematic Systems	24
2.4 Data Conversion Techniques	24
2.4.1 Analog-to-Digital Converters	24
2.4.2 Movie Conversion Techniques	25
2.4.3 Television Conversion	26
2.5 Processing of Raw Kinematic Data	27
2.5.1 Nature of Unprocessed Data	27
2.5.2 Harmonic (Fourier) Analysis	27
2.5.3 Sampling Theorem	29
2.5.4 Signal versus Noise	33
2.5.5 Smoothing and Fitting of Data	36
2.5.6 Comparison of Some Smoothing Techniques	43
2.6 Calculation of Angles from Smoothed Data	45
2.6.1 Limb-Segment Angles	45
2.6.2 Joint Angles	46
2.7 Calculation of Velocity and Acceleration	47
2.7.1 Velocity Calculation	47
2.7.2 Acceleration Calculation	47
2.8 Problems Based on Kinematic Data	48
2.9 References	50
<b>Chapter 3. Anthropometry</b>	<b>51</b>
3.0 Scope of Anthropometry in Movement Biomechanics	51
3.0.1 Segment Dimensions	51
3.1 Density, Mass, and Inertial Properties	52
3.1.1 Whole-Body Density	52
3.1.2 Segment Densities	53
3.1.3 Segment Mass and Center of Mass	54
3.1.4 Center of Mass of a Multisegment System	58
3.1.5 Mass Moment of Inertia and Radius of Gyration	59

3.1.6	Parallel-Axis Theorem	60
3.1.7	Use of Anthropometric Tables and Kinematic Data	61
3.2	Direct Experimental Measures	64
3.2.1	Location of the Anatomical Center of Mass of the Body	64
3.2.2	Calculation of the Mass of a Distal Segment	64
3.2.3	Moment of Inertia of a Distal Segment	65
3.2.4	Joint Centers of Rotation	67
3.3	Muscle Anthropometry	68
3.3.1	Cross-Sectional Area of Muscles	68
3.3.2	Change in Muscle Length during Movement	69
3.3.3	Force per Unit Cross-Sectional Area (Stress)	71
3.3.4	Mechanical Advantage of Muscle	71
3.3.5	Multijoint Muscles	71
3.4	Problems Based on Anthropometric Data	72
3.5	References	73
<b>Chapter 4. Kinetics: Forces and Moments of Force</b>		<b>75</b>
4.0	Biomechanical Models	75
4.0.1	Link-Segment Model Development	75
4.0.2	Forces Acting on the Link-Segment Model	77
4.0.3	Joint Reaction Forces and Bone-on-Bone Forces	78
4.1	Basic Link-Segment Equations — The Free-Body Diagram	80
4.2	Force Transducers and Force Plates	84
4.2.1	Multidirectional Force Transducers	85
4.2.2	Force Plates	85
4.2.3	Synchronization of Force Plate and Kinematic Data	89
4.2.4	Combined Force Plate and Kinematic Data	89
4.2.5	Interpretation of Moment-of-Force Curves	90
4.2.6	A Note About the Wrong Way to Analyze Moments of Force	92
4.2.7	Differences Between Center of Gravity and Center of Pressure	93

4.3 Bone-on-Bone Forces During Dynamic Conditions	96
4.3.1 Indeterminacy in Muscle Force Estimates	96
4.3.2 Example Problem	97
4.4 Problems Based on Kinetic and Kinematic Data	100
4.5 References	102

**Chapter 5. Mechanical Work, Energy, and Power** **103**

5.0 Introduction	103
5.0.1 Mechanical Energy and Work	103
5.0.2 Law of Conservation of Energy	104
5.0.3 Internal versus External Work	105
5.1 Efficiency	107
5.1.1 Positive Work of Muscles	108
5.1.2 Negative Work of Muscles	109
5.1.3 Muscle Mechanical Power	110
5.1.4 Mechanical Work of Muscles	110
5.1.5 Mechanical Work Done on an External Load	111
5.1.6 Mechanical Energy Transfer Between Segments	114
5.2 Causes of Inefficient Movement	115
5.2.1 Cocontractions	115
5.2.2 Isometric Contractions Against Gravity	116
5.2.3 Generation of Energy at One Joint and Absorption at Another	117
5.2.4 Jerky Movements	118
5.2.5 Summary of Energy Flows	118
5.3 Forms of Energy Storage	119
5.3.1 Energy of a Body Segment and Exchanges of Energy Within the Segment	121
5.3.2 Total Energy of a Multisegment System	124
5.4 Calculation of Internal and External Work	125
5.4.1 Internal Work Calculation	126
5.4.2 External Work Calculation	129
5.5 Power Balances at Joints and Within Segments	129
5.5.1 Energy Transfer via Muscles	131
5.5.2 Power Balance Within Segments	133
5.6 Problems Based on Kinetic and Kinematic Data	135
5.7 References	138

<b>Chapter 6. Synthesis of Human Movement — Forward Solutions</b>	<b>141</b>
6.0 Introduction	141
6.0.1 Assumptions and Constraints of Forward Solution Models	142
6.0.2 Potential of Forward Solution Simulations	142
6.1 Review of Forward Solution Models	143
6.2 Mathematical Formulation	144
6.2.1 Lagrange's Equations of Motion	145
6.2.2 The Generalized Coordinates and Degrees of Freedom	145
6.2.3 The Lagrangian Function $L$	147
6.2.4 Generalized Forces $[Q]$	147
6.2.5 Lagrange's Equations	148
6.2.6 Points and Reference Systems	148
6.2.7 Displacement and Velocity Vectors	150
6.3 System Energy	155
6.3.1 Segment Energy	155
6.3.2 Spring Potential Energy and Dissipative Energy	156
6.4 External Forces and Torques	157
6.5 Designation of Joints	157
6.6 Illustrative Example	157
6.7 Conclusions	162
6.8 References	162
 <b>Chapter 7. Muscle Mechanics</b>	 <b>165</b>
7.0 Introduction	165
7.0.1 The Motor Unit	165
7.0.2 Recruitment of Motor Units	166
7.0.3 Size Principle	167
7.0.4 Types of Motor Units — Fast- and Slow-Twitch Classifications	169
7.0.5 The Muscle Twitch	170
7.0.6 Shape of Graded Contractions	171
7.1 Force–Length Characteristics of Muscles	172
7.1.1 Force–Length Curve of the Contractile Element	172
7.1.2 Influence of Parallel Connective Tissue	173

8.4.2	EMG During Muscle Shortening and Lengthening	209
8.4.3	EMG Changes During Fatigue	209
8.5	References	210

**APPENDICES**

<b>A.</b>	<b>Kinematic, Kinetic, and Energy Data</b>	<b>213</b>
Figure A.1	Walking Trail — Marker Locations and Mass and Frame Rate Information	213
Table A.1	Raw Coordinate Data	214
Table A.2(a)	Filtered Marker Kinematics — Rib Cage and Greater Trochanter (Hip)	218
Table A.2(b)	Filtered Marker Kinematics — Femoral Lateral Epicondyle (Knee) and Head of Fibula	222
Table A.2(c)	Filtered Marker Kinematics — Lateral Malleolus (Ankle) and Heel	226
Table A.2(d)	Filtered Marker Kinematics — Fifth Metatarsal and Toe	230
Table A.3(a)	Linear and Angular Kinematics — Foot	234
Table A.3(b)	Linear and Angular Kinematics — Leg	238
Table A.3(c)	Linear and Angular Kinematics — Thigh	242
Table A.3(d)	Linear and Angular Kinematics — 1/2 HAT	246
Table A.4	Relative Joint Angular Kinematics — Ankle, Knee, and Hip	250
Table A.5(a)	Reaction Forces and Moments of Force — Ankle and Knee	254
Table A.5(b)	Reaction Forces and Moments of Force — Hip	258
Table A.6	Segment Potential, Kinetic and Total Energies — Foot, Leg, Thigh, and 1/2 HAT	262
Table A.7	Power Generation/Absorption and Transfer — Ankle, Knee, and Hip	266
<b>B.</b>	<b>Units and Definitions Related to Biomechanical and Electromyographical Measurements</b>	<b>269</b>
Table B.1	Base SI Units	269
Table B.2	Derived SI Units	269

**INDEX**

8.4.2	EMG During Muscle Shortening and Lengthening	209
8.4.3	EMG Changes During Fatigue	209
8.5	References	210

**APPENDICES**

<b>A.</b>	<b>Kinematic, Kinetic, and Energy Data</b>	<b>213</b>
Figure A.1	Walking Trail — Marker Locations and Mass and Frame Rate Information	213
Table A.1	Raw Coordinate Data	214
Table A.2(a)	Filtered Marker Kinematics — Rib Cage and Greater Trochanter (Hip)	218
Table A.2(b)	Filtered Marker Kinematics — Femoral Lateral Epicondyle (Knee) and Head of Fibula	222
Table A.2(c)	Filtered Marker Kinematics — Lateral Malleolus (Ankle) and Heel	226
Table A.2(d)	Filtered Marker Kinematics — Fifth Metatarsal and Toe	230
Table A.3(a)	Linear and Angular Kinematics — Foot	234
Table A.3(b)	Linear and Angular Kinematics — Leg	238
Table A.3(c)	Linear and Angular Kinematics — Thigh	242
Table A.3(d)	Linear and Angular Kinematics — 1/2 HAT	246
Table A.4	Relative Joint Angular Kinematics — Ankle, Knee, and Hip	250
Table A.5(a)	Reaction Forces and Moments of Force — Ankle and Knee	254
Table A.5(b)	Reaction Forces and Moments of Force — Hip	258
Table A.6	Segment Potential, Kinetic and Total Energies — Foot, Leg, Thigh, and 1/2 HAT	262
Table A.7	Power Generation/Absorption and Transfer — Ankle, Knee, and Hip	266
<b>B.</b>	<b>Units and Definitions Related to Biomechanical and Electromyographical Measurements</b>	<b>269</b>
Table B.1	Base SI Units	269
Table B.2	Derived SI Units	269