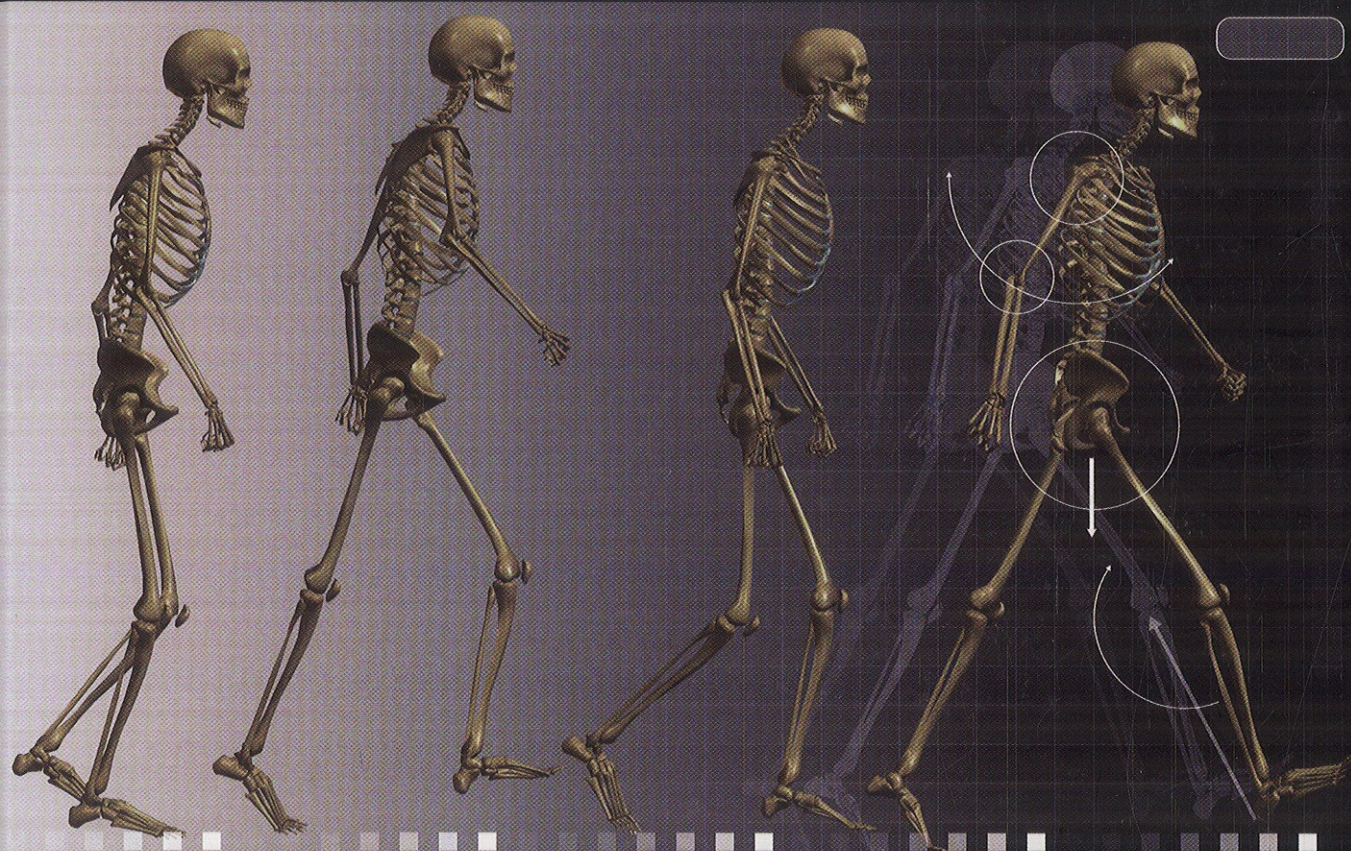


AN ONLINE INTERACTIVE TEACHING AND LEARNING COURSE

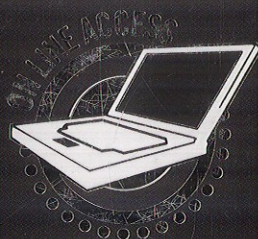
BIOMECHANICS

IN CLINIC AND RESEARCH



Forewords by **KEITH ROME** and **SCOTT SELBIE**

JIM RICHARDS



- A complete course comprising fully integrated print and online components
- Over **100** high-quality animations bring to life abstract concepts

CHURCHILL
LIVINGSTONE
ELSEVIER

Contents

Contributors ix

Introduction x

Acknowledgements xii

Glossary of terms xiii

Forewords xv

Chapter 1: Maths and mechanics

Jim Richards

1.1 Maths 1

1.1.1 Trigonometry 1

1.1.2 Vectors 4

1.2 Mechanics 7

1.2.1 Units – system international 7

1.2.2 Indices 8

1.2.3 Forces 8

1.2.4 Newton's laws of motion 8

1.2.5 Mass and weight 9

1.2.6 Static equilibrium 10

1.2.7 Free body analysis 10

1.2.8 Moments and forces 12

1.2.9 Pressure 13

1.2.10 Friction 14

Summary: Maths and mechanics 16

Chapter 2: Forces, moments and muscles

Jim Richards

2.1 Centre of mass 17

2.1.1 The centre of mass by calculation 17

2.1.2 Finding the centre of mass by experiment 18

2.1.3 Centre of mass and stability of the body in different positions 18

2.2 Anthropometry 18

2.2.1 Background to anthropometry 18

2.2.2 Common anthropometric parameters 19

2.2.3 Anthropometric calculations 19

2.3 Methods of finding moments, muscle and joint forces 20

2.3.1 How to find forces and moments acting on the musculoskeletal system 20

2.3.2 How to find muscle force 21

2.3.3 How to find the joint force 21

2.4 Joint moments – muscle forces and joint forces in the lower limb 22

2.4.1 Joint moments during a squat exercise 22

2.4.2 Joint moments in the lower limb during walking 23

2.4.3 Muscle forces in lower limb 25

2.4.4 Joint forces in lower limb 25

2.4.5 The effect of the weight of the segments on moment calculations 27

2.5 Calculation of moments, muscle and joint forces in the upper limb 27

2.5.1 Moments, muscle and joint forces while holding a pint of beer 27

2.5.2 Finding the force in the muscle 28

2.5.3 Finding the joint force 28

2.5.4 Moments and forces about the elbow joint while holding a 20 kg weight 28

2.6 Muscle strength 31

2.6.1 Changing the effective moment caused by the weight of the limb 31

2.6.2 The position and size of the applied load 32

2.6.3 Muscle insertion points 32

2.6.4 The effect of the angle of muscle pull 32

2.6.5 Type of muscle contraction 32

2.6.6 The effect of the speed of contraction 33

2.6.7 The Oxford scale and muscle strength 33

Summary: Forces, moments and muscles 34

Chapter 3: Ground reaction forces, impulse and momentum

35

Jim Richards

3.1 Ground reaction forces during standing 35

3.2 Ground reaction forces during walking 36

3.2.1 The vertical force component 36

3.2.2 The anterior–posterior force component 37

3.2.3 The medial–lateral component of the ground reaction force 39

3.3 Centre of pressure and force vectors during normal walking 39

3.3.1 Centre of pressure during walking 39

3.3.2 Resultant ground reaction forces and Pedotti diagrams? 41

3.3.3 Construction of Pedotti diagrams 41

3.3.4 How force vectors relate to muscle activity 41

3.4 Impulse and momentum 43

3.4.1 Impulse 43

3.4.2 Momentum 43

3.4.3 Conservation of momentum	43
3.4.4 Impulse and change in momentum during a sprint start	43
3.4.5 Protection against the force of impacts	44
3.5 Integration and the area beneath data curves	44
3.5.1 Integration	44
3.5.2 Integration of simple shapes	44
3.5.3 Counting the squares	45
3.5.4 Bounds for the area	45
3.5.5 The rectangular rule	45
3.5.6 Trapezium rule	45
3.6 Ground reaction force patterns during running	46
3.6.1 Vertical forces during running	46
3.6.2 Anterior–posterior forces during running	47
3.6.3 Medial–lateral forces during running	48
Summary: Ground reaction forces, impulse and momentum	48

Chapter 4: Motion and joint motion 51

Jim Richards and Dominic Thewlis

4.1 Movement analysis in clinical research	51
4.1.1 The early pioneers	51
4.1.2 Clinical gait analysis	51
4.2 The gait cycle	52
4.2.1 Spatial parameters	52
4.2.2 Temporal parameters	54
4.3 Normal movement patterns during gait	55
4.3.1 Plantarflexion and dorsiflexion of the ankle joint	55
4.3.2 Movement of the ankle, rearfoot, midfoot and forefoot	56
4.3.3 Movement of the tibial segment	59
4.3.4 Motion of the knee joint	59
4.3.5 Motion of the hip joint	62
4.3.6 Motion of the pelvis	63
4.3.7 Angle–angle diagrams	64
4.3.8 Angle versus angular velocity diagrams (phase plane portraits)	65
Summary: Motion and joint motion	65

Chapter 5: Work, energy and power 67

Jim Richards

5.1 Linear work, energy and power	67
5.1.1 Linear work	67
5.1.2 Linear energy	68
5.1.3 Potential energy	68
5.1.4 Kinetic energy	68
5.2 The relationship between force, impulse and power	68
5.2.1 The vertical jump test	68
5.2.2 Maximum force at take off and landing	68
5.2.3 Velocity during the jump	68
5.2.4 Calculation of height jumped from force plate data	69
5.2.5 Calculation of power from force plate data	69
5.3 Angular work, energy and power	70
5.3.1 Angular work	70
5.3.2 Angular power	71

5.4 The relationship between moments, angular velocity and joint power during normal gait	71
5.4.1 Joint moments, velocity and power during normal gait	71
5.4.2 Typical ankle moments during normal gait	71
5.4.3 Typical knee moments during normal gait	71
5.4.4 Typical hip moments during normal gait	71
5.4.5 Joint angular velocity during normal gait	71
5.4.6 Ankle angular velocity	71
5.4.7 Knee angular velocity	72
5.4.8 Hip angular velocity	72
5.4.9 Joint power during normal gait	72
5.4.10 Ankle power	73
5.4.11 Knee power	73
5.4.12 Hip power	73
5.5 Motion and power during running	73
5.5.1 Ankle joint	73
5.5.2 Knee joint	74
5.5.3 Hip joint motion	74
5.6 Joint power during the vertical jump test	74
5.6.1 Preparation and propulsion	74
5.6.2 Flight	75
5.6.3 Landing	75
5.7 How to find energies involved in moving body segments	75
5.7.1 Body segment energies	75
5.7.2 Calculation of translational kinetic energy	75
5.7.3 Calculation of rotational kinetic energy	75
5.7.4 Calculation of potential energy	76
5.7.5 Calculation of total segment energy	76
5.7.6 Calculation of total body energy and power	76
5.7.7 Body segment energy patterns during normal walking	77
Summary: Work, energy and power	78

Chapter 6: Inverse dynamics theory 79

Jim Richards

6.1 Introduction to inverse dynamics	79
6.2 A simple wheel	79
6.2.1 Moment of inertia	79
6.2.2 Inertial torque or moment	80
6.3 Body segments	81
6.3.1 Rotation about the centre of mass	81
6.3.2 Rotation about one end	81
6.3.3 Total inertial torque	82
6.3.4 Inertial forces and inertial moment	82
6.3.5 Weight of body segments	82
6.3.6 Centripetal force	82
6.4 Joint forces	83
6.4.1 Terminology	83
6.4.2 Forces on the foot and ankle	83
6.4.3 Forces on the shank and knee	83
6.4.4 Forces on the thigh and hip	84
6.5 Joint moments	84
6.5.1 Ankle joint moment	84
6.5.2 Knee joint moment	84
6.5.3 Hip joint moment	84
6.6 So why does it have to be so complex? A comparison of the simple and advanced models	84

- 6.6.1 Simplified model 84
- 6.6.2 Advanced model 85
- 6.7 So what effects do the simple and advanced methods have on moments and power calculated during gait? 87
 - 6.7.1 The effect the simple and advanced methods have on moments 87
 - 6.7.2 The effect the simple and advanced methods have on power 87
- Summary: Inverse dynamics theory 88

Chapter 7: Measurement of force and pressure 89

Jim Richards and Dominic Thewlis

- 7.1 Methods of force measurement 89
- 7.2 Force platform types 89
 - 7.2.1 Frequency content and force platforms 89
 - 7.2.2 Signal drift 90
 - 7.2.3 How force platforms work 90
- 7.3 Force plate scaling 90
- 7.4 Calculating moments using a piezoelectric plate 91
 - 7.4.1 Example of moment calculations using a piezoelectric platform 92
- 7.5 Considerations for force platform fitting and positioning 93
- 7.6 Force platform location and configurations 93
 - 7.6.1 Force platform configuration 1 93
 - 7.6.2 Force platform configuration 2 94
 - 7.6.3 Force platform configuration 3 94
 - 7.6.4 Force platform configuration 4 94
- 7.7 Typical measurements from force platforms 94
 - 7.7.1 The video vector generator 94
 - 7.7.2 General description of graph shapes 95
 - 7.7.3 Vertical force measurements 95
 - 7.7.4 Anterior–posterior force measurements 95
 - 7.7.5 Medio–lateral force measurements 96
 - 7.7.6 Centre of pressure measurements 96
- 7.8 Quantitative assessment of pressure 97
 - 7.8.1 Why is pressure important to the foot? 97
 - 7.8.2 Units of pressure 98
 - 7.8.3 Conversion of commonly used units of pressure into units 98
 - 7.8.4 Average pressure 98
 - 7.8.5 Peak pressures 98
 - 7.8.6 Load beneath areas of the foot 98
 - 7.8.7 Peak pressure–time curves 98
 - 7.8.8 Conversion of commonly used units of pressure time integrals 99
- 7.9 Methods of measuring pressure 99
 - 7.9.1 Pressure-sensitive mats and film 99
 - 7.9.2 Pedobarograph 99
 - 7.9.3 Pressure mats 100
 - 7.9.4 In-shoe pressure systems 100
 - 7.9.5 Force sensors 100
 - 7.9.6 Calibration of pressure sensors 100
- Summary: Measurement of force and pressure 101

Chapter 8: Methods of analysis of movement 103

Jim Richards, Dominic Thewlis and Sarah Jane Hobbs

- 8.1 Early pioneers of movement analysis equipment 103

- 8.2 Instrumented walkmat systems 103
 - 8.2.1 Temporal and spatial parameters in clinical assessment 103
 - 8.2.2 Walkmat systems 104
- 8.3 Electrogoniometers and accelerometers 105
 - 8.3.1 Goniometers and electrogoniometers 105
 - 8.3.2 Development of electrogoniometers 106
 - 8.3.3 Accuracy of electrogoniometers and potentiometers 106
 - 8.3.4 Accelerometers 106
- 8.4 Movement analysis systems 106
 - 8.4.1 Camera positioning 107
 - 8.4.2 Camera speed, sampling frequency and shutter speed 107
 - 8.4.3 Synchronizing the cameras 108
 - 8.4.4 Calibrating image space 108
 - 8.4.5 Data capture 110
 - 8.4.6 Digitizing, transformation and filtering 112
 - 8.4.7 Errors due to digitizing 114
- 8.5 Configurations for camera-based motion capture 115
 - 8.5.1 Configurations of two-dimensional motion analysis systems 115
 - 8.5.2 Three-dimensional motion analysis systems 115
- Summary: Methods of analysis of movement 116

Chapter 9: Anatomical models and marker sets 117

Jim Richards and Dominic Thewlis

- 9.1 The simple marker set 117
- 9.2 Vaughan marker set 117
- 9.3 Helen Hayes marker set 117
- 9.4 The CAST marker set 117
 - 9.4.1 Static ‘anatomical calibration’ markers 119
 - 9.4.2 Dynamic tracking markers 119
 - 9.4.3 So what is the benefit of using CAST compared with other marker sets? 119
 - 9.4.4 So what do we mean by ‘six degrees of freedom’ exactly? 120
 - 9.4.5 So why do we need ‘six degrees of freedom’? 120
- 9.5 Methods of identifying anatomical landmarks 121
 - 9.5.1 The CAST marker set with the Davis dynamic pointer (or pointy stick method) 121
 - 9.5.2 The CAST marker set with functional joint centre identification 121
 - 9.5.3 The effect of using different anatomical landmarks on gait data 121
- 9.6 Foot models 123
 - 9.6.1 The multiple segment foot 123
 - 9.6.2 Models for multiple segment foot 123
- 9.7 Coordinate systems and joint angles 124
 - 9.7.1 Calculation of joint angles in the global coordinate system 125
 - 9.7.2 Errors between global and segment coordinate systems 125
 - 9.7.3 Cardan sequences and their effect on gait data 125
 - 9.7.4 Helical angles 127

9.7.5 Recommendations	128
Summary: Anatomical models and marker sets	128

Chapter 10: Measurement of muscle function and physiological cost 129

Jim Richards, Dominc Thewlis and James Selfe

10.1 EMG – electromyography	129
10.1.1 So what is the link between electricity and muscle activity?	129
10.1.2 Muscles and fibre types	129
10.1.3 Frequency and amplitude of EMG	130
10.1.4 Methods of recording EMG	130
10.1.5 Processing of EMG signals	135
10.1.6 What information can be gain from EMG	138
10.1.7 Clinical EMG and biofeedback	139
10.2 Muscle strength and power assessment	141
10.2.1 Simple clinical methods	141
10.2.2 Isokinetic and isometric testing machines	141
10.2.3 Measurements taken in isometric testing	141
10.2.4 Typical measurements taken in isokinetic testing	143
10.2.5 Muscle testing using isokinetics	144
10.3 The physiological cost of walking	147
10.3.1 Oxygen consumption and energy expenditure	147
10.3.2 Energy expenditure during walking	148
10.3.3 Energy expenditure with respect to distance walked	149
10.3.4 Heart rate and physiological cost	149
10.3.5 Heart rate and walking speed	149

Summary: Measurement of muscle function and physiological cost 151

Chapter 11: Biomechanics of direct and indirect orthotic management 153

Jim Richards

11.1 Mechanics of direct orthotic management	153
11.2 Modification of joint moments with orthoses	153
11.3 Biomechanics of ankle foot orthoses	153
11.3.1 Rigid ankle foot orthoses	153
11.3.2 The effect of rigid ankle foot orthoses	155
11.3.3 Posterior leaf spring ankle foot orthoses	156
11.3.4 The effect of posterior leaf spring ankle foot orthoses	156
11.3.5 Hinged ankle foot orthoses	158
11.3.6 The effect of hinged ankle foot orthoses	159
11.3.7 Fine tuning ankle foot orthoses	160
11.4 Biomechanics of knee orthoses	161
11.4.1 Knee orthoses to correct moments	161
11.4.2 Consideration of individual segments	162
11.4.3 Consideration of segments together	162
11.4.4 Analysis of the forces acting on valgus bracing	162

11.4.5 Is there a maximum supportable angle using valgus brace?	164
11.4.6 Valgus bracing in medial compartment osteoarthritis	165
11.4.7 Modification of translational forces at the knee with orthoses	168
11.4.8 The ‘mechanics’ of soft bracing of the knee	170
11.5 Biomechanics of knee ankle foot orthoses	171
11.5.1 Use of knee ankle foot orthoses	171
11.5.2 Common force systems for knee ankle foot orthoses	172
11.5.3 Clinical case study of the use of knee ankle foot orthoses	172
11.6 Foot orthoses	173
11.6.1 The assessment of leg-length discrepancy	174
11.6.2 Treatment of leg-length discrepancy	174
11.6.3 Wedging or posting of the rearfoot	176
11.6.4 Control of the line of forces	176
11.6.5 The effect of wedging or posting the rearfoot during normal walking	176
11.6.6 The effect of lateral wedging in medial compartment osteoarthritis	178
Summary: Biomechanics of direct and indirect orthotic management	179

Chapter 12: Common movement tasks in clinical assessment 181

James Selfe, Jim Richards and Dominic Thewlis

12.1 Kinetic chains	181
12.2 Steps and stairs	181
12.2.1 Step and stair ascent	182
12.2.2 Step and stair descent	182
12.2.3 <i>Motion of the lower limbs during stair descent</i>	184
12.3 Sitting to standing	185
12.3.1 Introduction	185
12.3.2 Amount of knee flexion required for sitting	185
12.3.3 Biomechanics of sit to stand	185
12.4 The timed up and go test	186
12.5 Gait initiation	186
12.6 Squats and dips	188
12.6.1 Quadriceps wrap	188
12.6.2 Quadriceps neutral	188
12.6.3 Knee forces during squatting adapted from Escamilla (2001)	188
12.6.4 Squat variations	188
12.6.5 Joint Moments and EMG activity during a single limb dip	188

Summary: Common movement tasks in clinical assessment 190

References 191

Index 199