

## **KINESIOLOGY**



*Fifth Printing*

# KINESIOLOGY

OF THE HUMAN BODY

*Under Normal and  
Pathological Conditions*

*By*

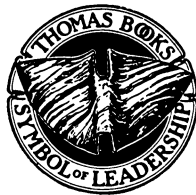
ARTHUR STEINDLER, M.D., (Hon) F.R.C.S.  
Eng. F.A.C.S., F.I.C.S.

*Professor of Orthopedic Surgery, Emeritus*

*State University of Iowa*

*Head of Orthopaedic Department, Mercy Hospital*

*Iowa City, Iowa*



---

CHARLES C THOMAS · PUBLISHER

*Springfield · Illinois · U.S.A.*

*Published and Distributed Throughout the World by*  
CHARLES C THOMAS • PUBLISHER  
BANNERSTONE HOUSE  
301-327 East Lawrence Avenue, Springfield, Illinois, U.S.A.

This book is protected by copyright. No  
part of it may be reproduced in any manner  
without written permission from the publisher.

© 1955, by CHARLES C THOMAS • PUBLISHER  
ISBN 978-0-398-01846-7 (hard) ISBN 978-0-398-01846-6 (paper)  
Library of Congress Catalog Card Number: 55-6121

*First Printing, 1955*  
*Second Printing, 1964*  
*Third Printing, 1970*  
*Fourth Printing, 1973*  
*Fifth Printing, 1977*

*With THOMAS BOOKS careful attention is given to all details of  
manufacturing and design. It is the Publisher's desire to present books  
that are satisfactory as to their physical qualities and artistic possibilities  
and appropriate for their particular use. THOMAS BOOKS will be true  
to those laws of quality that assure a good name and good will.*

*Printed in the United States of America*

00-2

*To my good Wife and Helpmate*  
*Louise Steindler*



## PREFACE

A PREVIOUS publication on the subject of the *Mechanics of Normal and Pathological Locomotion*,<sup>1</sup> has met with what the author believes to be an indifferent reception. There seemed to be two reasons for it. The first problem was that not enough consideration had been accorded to the practical application of rehabilitation and re-education of locomotor deficiencies. With this in mind, the author has endeavored to give the theoretical facts a much wider interpretation in connection with diagnostic and therapeutic questions, fully realizing that the value of the book lies in what help it can offer to clinician and physical educator.

The other criticism was that the analysis of locomotion has ventured too much into the field of general mechanics which made the reading of the book uncomfortable and required much needless concentration. It was argued that practical conclusions could be attained more directly by observation and empiricism without any tedious theoretical preambles. It is with this second argument that the author has to disagree. He is neither willing nor able to reconcile himself to a short cut method based entirely on impressions and to summersault over the hard facts of basic sciences just in order to arrive at quick and usually superficial practical conclusions.

He is convinced that Kinesiology is an indispensable background for the prevention, the treatment, and rehabilitation of locomotor disorders.

On the other hand, it is conceded that mathematical accuracy in the calculation of locomotor events is only too often swallowed up by the stream of physiological and especially of pathological fluctuations; that certain allowances must be made because no two situations, be they normal or abnormal, are so alike that they can be expressed accurately by the same mathematical formula.

After all the analysis of human motion is primarily the job of the biologist, and only secondarily that of the physicist or engineer. The purely mechanical aspect of locomotion, which is the province of kinesiology, is merely a part of the physiology of motion in general.

All motor events are the end result of a long chain of cause and effect, the beginning of which, as in all things, is steeped in mystery. The study of kinetics taps this chain of events at a point just behind the clinical manifestation while the biologist tries to penetrate much farther into the background. In other words, kinetics explains only the physical events which lead immediately to the locomotor performance and it is not concerned with the more remote causes of human motion.

<sup>1</sup> Steindler, A.: Charles C Thomas, Publisher, Springfield, Illinois, 1935.

With these considerations in mind the author has tried to reduce all mathematical calculations to a minimum and has advanced on every occasion the clinical significance and the practical implication of kinetic findings. This, he hopes, should make for more palatable reading.

A. STEINDLER

*Iowa City*



## ACKNOWLEDGMENTS

THE author has received most valuable assistance in the preparation of this book. He is particularly grateful for the help extended to him by his associate, Dr. Webster B. Gelman. He not only furnished the illustrative drawings but he also helped with the arrangement of the book and with reading of the text, for which he made many useful suggestions. For the clerical help in typing the text the author is indebted to Mrs. June Clendenin, Mrs. Marian Heilbrun, and Mrs. Margaret Washburn. The photographic work was in the able hands of the Messrs. Kent. Mrs. Thea Wiegand compiled the table of contents and author and subject indices. The publisher, Mr. Charles C Thomas, has bestowed upon this work his highly appreciated painstaking efforts in the examination of the text, its editing and printing. All of this assistance is hereby thankfully acknowledged by the author.

A. STEINDLER



# CONTENTS

PREFACE .....	vii
ACKNOWLEDGMENTS .....	ix

## PART I

### GENERAL KINETICS

#### LECTURE I. THE AIMS AND PURPOSES OF KINESIOLOGY

I. AIMS AND PURPOSES .....	5
----------------------------	---

#### LECTURE II. ON THE PHYSICAL PROPERTIES OF BONE

I. HISTORICAL .....	9
II. THE MODIFICATION OF THE LAW OF FUNCTIONAL ADAPTATION OF BONE ..	9
III. ON ELASTICITY AND STRESS RESISTANCE OF BONE .....	10
A. The Elasticity of Bone .....	11
B. The Unit Resistance of Bone .....	12
IV. APPLICATION TO THE THEORIES OF BEAM AND COLUMN .....	15
A. The Theory of the Beam Applied to the Skeleton .....	15
B. The Theory of Columns Applied to the Human Skeleton .....	16
C. The Effect of Muscular Tension on Gravitational Stresses in Bone ....	19
V. SUMMARY .....	21

#### LECTURE III. ON FUNCTIONAL ADAPTATION OF BONE UNDER PATHOLOGICAL CONDITIONS

I. STATIC CONDITIONS .....	23
II. TRAUMATIC CONDITIONS .....	27
III. FUNCTIONAL ADAPTATION IN INFLAMMATORY CONDITIONS .....	29
IV. THE STATIC REORGANIZATION IN NEOPLASM .....	31
V. CONGENITAL DEFORMITIES .....	32
VI. SUMMARY .....	33

#### LECTURE IV. ON THE PHYSICAL PROPERTIES OF CARTILAGE, MUSCLES, FACIA AND TENDONS

A. ON THE PHYSICAL PROPERTIES OF NORMAL CARTILAGE .....	35
I. Stress and Structure .....	35
II. Elasticity, Deformation and Pressure .....	38
B. ON THE PHYSICAL PROPERTIES OF MUSCLES .....	44
I. Introduction .....	44
II. The Elasticity and Contractility of Muscle .....	45
C. THE PHYSICAL PROPERTIES OF LIGAMENTS AND TENDONS .....	54

#### LECTURE V. ON THE MECHANICS OF JOINT AND MUSCLE ACTION

A. THE JOINTS .....	58
I. General Mechanical Principles .....	58
II. The Shape of the Articular Surfaces .....	58
III. The Joint Contact .....	60
IV. The Type of Joint Movement .....	61
V. The Degrees of Freedom of Motion .....	62
VI. A Kinetic Chain .....	63

VII. The Transformation of Rotatory into Translatory Motion in a Kinetic Chain .....	64
B. THE MECHANICS OF MUSCLE ACTION .....	67
I. Stabilizing and Rotatory Components .....	67
II. Leverage and Equilibrium .....	68
III. Morphological Adaptation of the Muscle .....	70
IV. Coordination of Skeletal Muscle Action .....	73
V. The Coordinate Function of the Biarticular Muscles .....	77
VI. Summary .....	82
LECTURE VI. ON THE PATHOMECHANICS OF MUSCLE FUNCTION	
I. FATIGUE AND RECOVERY .....	87
II. THE THEORY OF CONTRACTURES .....	92
III. THE PROPENSITY AND ADAPTATION TO CONTRACTURE .....	94
IV. CONTRACTURE OF THE NON-CONTRACTILE SOFT TISSUES .....	96
V. SUMMARY .....	97
LECTURE VII. ON BODY BALANCE AND BODY EQUILIBRIUM	
I. INTRODUCTION .....	100
II. APPLYING OF THE ABOVE-MENTIONED GENERAL LAWS TO THE HUMAN BODY .....	101
A. Translatory Effect of the Force of Gravity .....	101
B. The Rotatory Effect of Gravity .....	101
C. The Center of Gravity of the Human Body as a Whole .....	101
D. The Location of the Center of Gravity .....	103
III. THE EQUILIBRIUM OF THE HUMAN BODY AS AN ARTICULATED SYSTEM ...	106
IV. SUMMARY .....	108
LECTURE VIII. ON MEASUREMENT AND COMPUTATION OF BODILY MOTION	
I. ORIENTATION PLANES .....	110
II. THE RELATION OF THE PARTIAL CENTERS OF GRAVITY TO THE ORIENTATION PLANES OF THE BODY .....	111
III. THE RELATION OF MUSCLE ACTION TO THE ORIENTATION PLANES .....	114
IV. THE SECONDARY COORDINATION PLANES .....	114
V. ORIENTATION AND MEASUREMENT OF JOINT MOBILITY .....	117
VI. THE RELATION OF JOINT POSITIONS TO THE ACTION OF MUSCLES .....	118
VII. LINEAR EXPRESSION OF ANGULAR VALUES OF ROTATION .....	119
VIII. SUMMARY .....	120

## PART II

## THE TRUNK

## LECTURE IX. THE MECHANICS OF THE SPINAL COLUMN

I. THE FUNCTION OF THE SPINAL COLUMN .....	125
II. CONSTRUCTION AND MORPHOLOGY .....	125
A. The Gross Construction .....	125
B. Spinal Curves .....	126
C. The Articulations .....	130
III. THE NON-CONTRACTILE SOFT STRUCTURES OF THE SPINAL COLUMN ....	133
A. The Intervertebral Disc .....	133
B. The Ligaments .....	134
IV. THE STATICS OF THE NORMAL SPINE .....	138
A. The Architecture of the Spine .....	139
B. The Distribution of Stresses Throughout the Spinal Column .....	140
C. The Intrinsic Equilibrium .....	141
V. SUMMARY .....	142

## LECTURE X. THE DYNAMICS OF THE NORMAL SPINE

I. ANALYSIS OF MOVEMENTS IN THE SPINAL ARTICULATIONS .....	145
A. The Intervertebral Joints .....	145
II. THE DYNAMICS OF THE SPINE .....	149
THE DISTRIBUTION OF MOTION .....	149
A. Mobility Between Bodies .....	149
III. THE MUSCLE MECHANICS OF THE SPINE .....	151
A. The Extensors of the Spine .....	151
B. The Flexors of the Trunk .....	154
C. The Side Benders of the Trunk .....	156
D. The Rotators of the Trunk .....	157
IV. THE EXCURSION FIELDS OF THE SPINE .....	158
A. The Sagittal Plane .....	158
B. The Frontal Plane .....	158
C. The Transverse Plane .....	159
V. SUMMARY .....	160

LECTURE XI. THE PATHOMECHANICS OF THE  
LUMBOSACRAL JUNCTION

INTRODUCTION .....	163
I. ANATOMICAL VARIATIONS .....	163
A. Anatomical Variations Affecting the Mobility of the Spine .....	163
B. Anatomic Variations Which Affect the Stability of the Spine .....	166
C. The General Conditions Affecting Mobility and Stability of the Lumbo- sacral Area .....	170
II. THE PATHOMECHANICS OF LUMBOSACRALGIA .....	171
A. The Structures Under Stress .....	172
B. The Effect of the Lumbosacral Strain on Posture .....	173
C. The Effect of Lumbosacral Strain on Mobility .....	173
III. SUMMARY .....	174

## LECTURE XII. THE NORMAL AND PATHOLOGICAL MECHANICS OF THE PELVIS

I. THE NORMAL MECHANICS OF THE PELVIS .....	177
A. Anatomical Consideration .....	177
B. The Orientation Planes of the Pelvis .....	180
C. The Analysis of the Static Condition of the Pelvis as a Whole. The Pelvis at Rest. Standing on Both Legs .....	181
D. The Specific Analysis of Static Stresses of the Pelvic Joints with the Body at Rest .....	186
E. Specific Analysis of Dynamic Stresses of the Pelvic Joints. The Body in Motion .....	187
II. THE PATHOMECHANICS OF THE PELVIS .....	190
A. Developmental Factors .....	190
B. Degenerative Conditions .....	192
C. Static Changes .....	194
D. Traumatic Deformities .....	198
III. SUMMARY .....	201
A. Normal Pelvis .....	201
B. The Pathomechanics of the Pelvis .....	202

## LECTURE XIII. THE MECHANICS OF RESPIRATION, INTRODUCTION AND DEFINITION

I. THE MECHANICS OF THE THORAX AT REST .....	205
A. The Movement Between Ribs and Vertebrae .....	205
B. The Junction Between Ribs and Sternum .....	207
C. The Automatic Equilibrium of the Non-Contractile Structures of the Thorax .....	208
II. THE THORAX IN MOTION .....	210
A. The Movement of the Ribs .....	210
B. The Movement of the Sternum .....	211
III. THE DYNAMICS OF RESPIRATION .....	212
A. The Inspirators .....	212
B. The Expirators .....	215
IV. RESPIRATORY EXCHANGE AND VITAL CAPACITY .....	216
V. RELATION OF RESPIRATION TO THE SPINAL COLUMN .....	217
A. Backward Bending .....	217
B. Forward Bending .....	217
C. Lateral Bending .....	217
D. Longitudinal Rotation .....	217
E. The Normal Upright Position .....	217
VI. THE TYPES OF RESPIRATION, THORACIC AND ABDOMINAL BREATHING ....	218
VII. THE PATHOMECHANICS OF RESPIRATION .....	219
A. The Obstruction of the Air Passages .....	219
B. Congenital Thoracic Defects .....	219
C. Rickets .....	221
D. Static Deformities and Malposture .....	221
E. Degenerative Changes .....	221
F. Tuberculosis of the Spine .....	221
G. Emphysema, Hydro- or Pneumothorax, or Tumors .....	221
H. Senile Kyphosis .....	222
I. Paralysis .....	222
VIII. SUMMARY .....	223

## LECTURE XIV. THE MECHANICS OF POSTURE

I. THE NORMAL POSTURE .....	227
A. Definition .....	227
B. Line of Gravity and Normal Posture .....	228
II. THE PATHOMECHANICS OF MALPOSTURE .....	230
A. Kinetic Consideration .....	230
B. The Propensities to Malposture According to Build .....	231
C. Pathological Factors .....	233
D. The Breathing Mechanism in Malposture and Visceroptosis .....	237
III. SUMMARY .....	238

## LECTURE XV. THE PATHOMECHANICS OF SCOLIOSIS

INTRODUCTION .....	241
I. GENERAL MECHANICAL CONSIDERATION .....	241
A. Relation to the Column Theory. The Effect of the Load .....	241
B. The Effect of Gravitational Reactions .....	243
C. The Effect of Side Bending on Rotation .....	243
D. How the Normal Spine Manages the Problem of Combining Side Bending with Rotation .....	243
II. SPECIAL MECHANICAL CONSIDERATIONS REGARDING THE SCOLIOTIC SPINE .....	244
A. The Mechanogenetic Elements of Scoliosis: Inclinator and Collapse ..	244
B. The Mechanical Effect of Growth Plates and of the Disc .....	245
C. The Relation of Scoliotic Deformity of the Spine to the Thoracic Cage and to the Pelvis .....	248
III. THE PROGRESSION OF THE SCOLIOTIC DEFORMITY UNDER MECHANICAL INFLUENCE .....	250
IV. THERAPEUTIC CONCLUSIONS BASED UPON THE PATHOMECHANICS OF SCOLIOSIS .....	253
V. SUMMARY .....	254

## PART III

## THE EXTREMITIES

## LECTURE XVI. MECHANICS OF THE HIP JOINT

I. ORIENTATION .....	261
A. The Position of the Acetabulum .....	261
B. The Position of the Femoral Head .....	261
C. The Position of the Femur .....	262
D. The Orientation Axes and Reference Planes of the Hip Joint .....	264
E. Contour and Shape of the Hip Joint .....	265
F. Axes and Determination Planes of the Femur .....	267
II. THE STATICS OF THE HIP JOINT .....	267
A. The Architecture of the Femur .....	267
B. Analysis of the Static Forces Operative upon the Femur .....	269
C. The Effect of Muscle Force on the Moulding of the Human Femur (Grunewald) .....	272
D. The Capsular Reinforcement of the Hip Joint .....	272
E. The Ligamentous Reinforcement of the Hip Joint .....	273
III. THE MUSCLE MECHANICS IN STATIC CONDITIONS OF THE HIP JOINT. EQUILIBRIUM .....	274
A. Conditions of Equilibrium in the Frontal Plane .....	275
B. Conditions of Equilibrium in the Sagittal Plane .....	279
C. The Conditions of Equilibrium in the Transverse Plane .....	283

IV. THE STATIC PRESSURE AND THE SHEAR EFFECTS PRODUCED BY MUSCLE ACTION .....	285
A. The Pressure and Shearing Stress Caused by Muscle Action .....	285
V. MUSCLE DYNAMICS .....	287
A. Orientation .....	287
B. Excursion Ranges .....	287
VI. SUMMARY .....	292

#### LECTURE XVII. THE PATHOMECHANICS OF THE STATIC DISABILITIES OF HIP AND PELVIS

I. THE PHYSIOLOGICAL CURVES OF THE LONG BONES OF THE LOWER EXTREMITY .....	297
A. Physiological Variation .....	297
II. THE PATHOMECHANICS OF COXA VARA .....	300
A. Skeletal .....	300
B. The Ligamentous Restrictions .....	300
III. THE PATHOMECHANICS OF THE VALGA .....	301
A. The Skeletal Factors .....	302
B. The Muscle Mechanical Situation in Coxa Valga .....	303
IV. THE PATHOMECHANICS OF THE DYSPLASIA OF THE HIP JOINT .....	305
V. THE PATHOMECHANICS OF THE FIXED PELVIC OBLIQUITY .....	306
A. The Pelvic Obliquity in Osteoarthritis of the Hip .....	306
B. The Dynamics of Pelvic Obliquities in Coxa Vara and Congenital Dislocations .....	307
VI. SUMMARY .....	308

#### LECTURE XVIII. THE PATHOMECHANICS OF THE PARALYTIC HIP JOINT

INTRODUCTION .....	311
I. THE NORMAL HIP JOINT .....	311
A. The Frontal Plane .....	311
B. The Sagittal Plane .....	313
C. The Horizontal Plane .....	314
II. THE PELVIC MOVEMENT IN PARALYSIS .....	315
A. The Frontal Plane .....	315
B. The Sagittal Plane .....	316
C. The Horizontal Plane .....	316
III. THE PARALYTIC IMBALANCE OF THE HIP JOINT ACCORDING TO THE DIFFERENT MUSCLES .....	318
A. Gluteals and Tensor .....	318
B. The Flexors .....	319
C. The Adductors .....	319
D. In- and Outward Rotation .....	320
E. Combined Contractures .....	320
IV. THE MECHANICS OF RECONSTRUCTIVE PROCEDURES ON THE PARALYZED HIP JOINT .....	321
A. Restoration of Alignment .....	321
B. The Restoration of Motion .....	322
V. SUMMARY .....	323

#### LECTURE XIX. THE MECHANICS OF THE KNEE JOINT

I. MORPHOLOGY .....	326
A. The Bony Constituents .....	326



# CONTENTS

xvii

B. The Capsule and Synovia .....	326
C. The Patella .....	327
D. The Semilunar Cartilages .....	327
E. The Ligaments .....	327
II. THE MECHANICAL ANALYSIS OF THE KNEE JOINT .....	330
A. The Axes of Orientation and Their Relation to the Extremity as a Whole .....	330
B. The Shape and Contour of the Condyles .....	331
C. The Mechanical Status of the Patella .....	334
D. The Tibia .....	335
III. THE STRESS ANALYSIS OF THE BONES .....	336
IV. THE MECHANICS OF THE LIGAMENOUS STRUCTURES OF THE KNEE .....	338
A. The Collaterals .....	338
B. The Cruciates .....	339
V. THE MECHANICS OF THE MENISCI .....	340
VI. THE DYNAMIC ANALYSIS OF THE KNEE JOINT .....	342
A. In the Sagittal Plane: Flexion-Extension .....	343
B. In the Transverse Plane: Length Rotation .....	343
VII. MUSCLE DYNAMICS OF THE KNEE JOINT .....	343
A. The Extensors .....	343
B. The Flexors .....	344
C. The Rotators .....	345
VIII. SUMMARY .....	345

## LECTURE XX. THE PATHOMECHANICS OF STATIC DEFORMITIES OF THE KNEE JOINT

I. THE STATIC DEFORMITIES IN THE FRONTAL PLANE .....	350
A. Physiological Development .....	350
B. Physiological Variations .....	352
II. STATIC DEFORMITIES OF THE KNEE JOINT .....	352
A. The Pathomechanics of Static Genu Valgum .....	352
B. The Pathomechanics of the Static Genu Varum .....	354
C. The Pathomechanics of the Static Genu Recurvatum .....	355
D. The Mechanism of Tibial Torsion .....	357
III. SUMMARY .....	358

## LECTURE XXI. THE PATHOMECHANICS OF THE PARALYTIC KNEE

I. INTRODUCTION .....	361
II. EXTENSOR PARALYSIS .....	362
A. Paralysis of the Vasti .....	362
B. The Paralysis of the Entire Quadriceps .....	362
III. THE PARALYSIS OF THE FLEXORS OF THE KNEE .....	363
A. Loss of Flexion .....	363
B. The Loss of Rotation .....	364
IV. THE RECONSTRUCTIVE OPERATIONS FOR PARALYSIS OF THE KNEE FROM THE PATHOKINETIC VIEWPOINT .....	364
A. The Methods of Reconstruction of the Genu Recurvatum .....	364
B. The Reconstruction of the Paralytic Genu Valgum .....	368
C. The Reconstruction of the Flexion Contracture .....	368
D. The Muscular Imbalance Due to Quadriceps Paralysis. Tendon Transplantation .....	369
V. SUMMARY .....	371

## LECTURE XXII. THE MECHANICS OF FOOT AND ANKLE

I. MORPHOLOGY .....	373
A. Construction of Foot and Ankle .....	373
B. The Axes of the Joints of the Foot .....	376
C. The Internal Architecture of the Foot .....	378
D. The Ligamentous Reinforcements of the Articulations .....	379
II. JOINT MECHANICS .....	383
A. The Ankle Joint .....	383
B. The Subastragalar Joint .....	384
C. The Midtarsal Joint .....	386
D. Combined Movements .....	387
E. The Mechanism of the Tarsometatarsal Joints .....	388
F. The Mechanism of the Metatarsophalangeal Joints .....	388
III. THE MUSCLE DYNAMICS OF THE FOOT .....	389
A. The Ankle Joint .....	389
B. The Subastragalar Joint .....	391
C. The Midtarsal Joint .....	392
D. The Metatarsophalangeal Joint .....	392
IV. THE CONDITIONS OF EQUILIBRIUM OF THE JOINTS OF THE FOOT .....	393
A. The Ankle Joint .....	393
V. SUMMARY .....	395

## LECTURE XXIII. THE PATHOMECHANICS OF THE STATIC DEFORMITIES OF FOOT AND ANKLE

I. INTRODUCTION .....	399
A. Developmental Factors .....	399
II. THE PATHOMECHANICS OF THE STATIC DEFORMITIES OF THE FOOT .....	401
A. Premises .....	401
B. The Pathological Equilibrium .....	402
III. THE PATHOMECHANICS OF THE SOFT STRUCTURES .....	405
A. The Subastragalar Joint .....	406
B. The Midtarsal Joint .....	407
C. The Anterior Arch .....	408
IV. SECONDARY SKELETAL CHANGES FOLLOWING RELAXATION OF SOFT STRUCTURES .....	409
A. The Ankle Joint .....	409
B. The Subastragalar Joint .....	409
C. The Midtarsal Joint .....	410
V. CLINICAL ANALYSIS .....	411
VI. SUMMARY .....	412

## LECTURE XXIV. THE PATHOMECHANICS OF THE PARALYTIC FOOT AND ANKLE

I. INTRODUCTION .....	415
II. THE CONDITIONS OF EQUILIBRIUM FOR THE JOINTS OF FOOT AND ANKLE .....	416
A. The Ankle Joint. Flexion-Extension Equilibrium .....	416
B. The Subastragalar Joint .....	417
C. The Midtarsal Joint .....	417
D. The Metatarsophalangeal Articulation .....	417
III. WHAT DEFORMITIES DEVELOP FROM SPECIFIC MUSCLE DEFICIENCIES? ..	418
A. The Ankle Joint .....	418
B. The Subastragalar Joint .....	419
C. The Midtarsal Joint .....	419

## CONTENTS

xix

D. The Metatarsophalangeal Articulation .....	420
IV. THE ARTHRODESES AND ARTHROSES OF PARALYTIC JOINTS FOR THE ESTABLISHMENT OF EQUILIBRIUM .....	420
A. Stabilization of the Ankle Joint .....	421
B. The Stabilization of the Subastragalar and Midtarsal Joints. Mechanical Principles .....	424
V. WHAT MECHANICAL CAUSES ARE RESPONSIBLE FOR FAILURE AND RECURRENCE AFTER STABILIZATION? .....	428
VI. SUMMARY .....	429

### LECTURE XXV. THE LOWER EXTREMITY AS A WHOLE

I. INTRODUCTION .....	433
EQUILIBRIUM AND STABILITY .....	433
A. The Sagittal Plane .....	433
B. Relation of Ankle, Knee, and Hip Joint in the Stance .....	435
C. The Transverse Plane .....	436
II. DYNAMICS. MUSCLE INTERRELATIONSHIP. REMOTE EFFECT IN KINETIC CHAIN .....	436
A. Uniaxial Muscles .....	437
B. Biaxial Muscles .....	438
III. INTERPRETATION OF PATTERNS. ACTIVE AND PASSIVE INSUFFICIENCY ....	440
IV. SPECIAL MECHANICAL SITUATIONS OF THE LOWER EXTREMITY AS A KINETIC CHAIN .....	441
A. Standing on the Toes .....	441
B. Gravity as the Flexor of the Hip and Extensor of the Knee .....	443
C. Gravity as an Extensor of the Hips .....	443
V. SUMMARY .....	443

### LECTURE XXVI. MECHANICS OF SHOULDER-ARM COMPLEX

I. INTRODUCTION .....	446
II. MORPHOLOGY .....	447
A. Relation of the Scapula .....	447
B. The Sternoclavicular Articulation .....	447
C. The Acromioclavicular Articulation .....	449
D. Static Stresses of the Clavicle .....	452
E. The Scapulohumeral Joint .....	452
III. THE DYNAMICS OF THE SHOULDER-ARM COMPLEX .....	459
A. The Movements of the Scapula .....	459
B. The Movements in the Sternoclavicular Articulation .....	464
C. The Movements in the Acromioclavicular Joint .....	464
D. The Movements in the Glenohumeral Joint .....	464
E. The Working Capacity of the Shoulder Girdle Muscle .....	466
F. Analysis of the Movements of the Whole Shoulder-Arm Complex ....	467
IV. SUMMARY .....	470

### LECTURE XXVII. THE PATHOMECHANICS OF PARALYSIS OF THE SHOULDER

I. INTRODUCTION .....	475
II. THE PARALYSIS OF THE THORACOSCAPULAR MUSCLES OF THE SHOULDER GIRDLE COMPLEX .....	476
A. Paralysis of the Trapezius .....	476
B. The Paralysis of the Serratus Anterior .....	476

C. The Combined Paralysis of Trapezius and Serratus .....	478
D. The Paralysis of the Rhomboids .....	478
III. THE PARALYSIS OF THE SCAPULOHUMERAL MUSCLES .....	478
A. Paralysis of the Deltoid .....	478
B. Paralysis of the Supraspinatus .....	479
C. The Paralysis of the Infraspinatus and the Teres Minor .....	480
D. The Paralysis of the Subscapularis .....	480
E. The Paralysis of the Coracobrachialis and Short Head of the Biceps, Long Head of the Biceps and the Triceps .....	480
IV. THE PARALYSIS OF THE THORACOHUMERAL MUSCLES .....	480
A. Paralysis of the Pectoralis Major .....	481
B. The Paralysis of the Latissimus Dorsi .....	481
C. The Combined Pectoralis Major and Latissimus Paralysis .....	481
V. THE REVIEW OF RECONSTRUCTIVE OPERATIONS FOR PARALYSIS OF THE SHOULDER GIRDLE SYSTEM FROM THE KINETIC POINT OF VIEW .....	481
A. Operations for Paralysis of the Trapezius .....	481
B. The Operations for the Paralysis of the Anterior Serratus .....	482
C. The Operations for the Paralysis of the Deltoid .....	483
VI. SUMMARY .....	487

#### LECTURE XXVIII. THE MECHANICS OF THE ELBOW JOINT

I. THE ANATOMICAL CONSTRUCTION OF THE ELBOW .....	490
A. Joint Construction .....	490
B. The Axes and Plane Relations .....	492
C. The Angular Values and Contact Areas of the Joint Constituents ....	495
D. The Capsular Ligaments and Ligamentous Checks .....	496
E. Tension Resistance .....	498
II. THE TYPES OF MOTION .....	499
A. The Ulnohumeral Articulation .....	499
B. The Radiohumeral Articulation .....	499
C. The Radioulnar Articulation .....	500
III. THE JOINT DYNAMICS .....	502
A. Flexion-Extension .....	502
B. Pro- and Supination .....	502
IV. SUMMARY .....	504

#### LECTURE XXIX. THE PATHOMECHANICS OF THE PARALYTIC ELBOW

INTRODUCTION .....	508
I. THE PARALYSIS OF THE EXTENSORS OF THE ELBOW JOINT: TRICEPS AND ANCONEUS .....	508
II. THE PARALYSIS OF THE FLEXORS .....	509
A. Substitution by the Triceps .....	510
B. Substitution by the Long Range Transference: Pectoralis Major ....	510
C. Substitution by Long Range Transference: Sternocleidomastoid ....	510
D. The Methods of Transposition of the Forearm Muscles .....	511
III. SUMMARY .....	514

#### LECTURE XXX. MECHANICS OF HAND AND FINGERS

INTRODUCTION .....	516
I. MORPHOLOGY .....	516

# CONTENTS

xxi

A. The Radiocarpal Articulation .....	516
B. The Intracarpal Articulation .....	520
C. The Combined Movements of Both Carpal Joints .....	521
D. The Carpometacarpal Articulation .....	522
E. The Metacarpophalangeal Articulations .....	523
F. The Interphalangeal Joints .....	525
II. THE DYNAMICS OF THE WRIST AND FINGERS .....	526
A. Review of Hand and Finger Muscles .....	526
B. The Action of the Muscles of the Wrist .....	528
C. The Functional Pattern of Wrist Motion .....	529
D. The Muscle Action of the Fingers .....	530
E. The Action of the Muscles of the Thumb .....	533
III. THE COMPUTATION OF WORK OF THE MUSCLES OF THE WRIST AND FINGERS .....	534
A. The Working Capacity of the Muscles of the Wrist .....	534
B. The Relaxation Angle of the Wrist Muscles .....	534
C. The Hand as an Instrument of Grip .....	535
IV. SUMMARY .....	536

## LECTURE XXXI. THE PATHOMECHANICS OF PARALYSIS OF HAND AND FINGERS

I. REVIEW OF NORMAL MECHANICS OF WRIST AND FINGER FUNCTION ....	541
A. The Wrist .....	541
II. THE PATHOKINETICS OF PARALYTIC DISABILITIES .....	543
A. The Wrist .....	543
B. The Fingers .....	543
III. THE RECONSTRUCTION OPERATIONS IN PARALYSIS OF THE WRIST AND FINGERS .....	547
A. The Paralysis of the Extensors of the Wrist and Fingers .....	547
B. Thenar Palsy. Mechanics of Reconstruction .....	548
C. Paralysis of Interossei. Mechanics of Substitution .....	551
IV. SUMMARY .....	553

## LECTURE XXXII. THE ARM AS A WHOLE

I. ORIENTATION .....	556
II. COMBINED MOVEMENTS .....	557
A. Shoulder and Elbow .....	557
B. Elbow and Wrist .....	558
C. Shoulder, Elbow and Wrist .....	558
III. THE ANALYSIS OF SOME OF THE ARM MOVEMENTS UNDER OPEN KINETIC CHAIN CONDITIONS. NO EXTERNAL RESISTANCE .....	559
A. Ball Throwing .....	559
B. Discus Throwing .....	561
C. Shot Putting .....	562
D. The Role of the Arms in Maintaining Body Equilibrium .....	562
IV. MOVEMENT OF THE UPPER EXTREMITY IN A CLOSED KINETIC CHAIN ....	563
A. Weight Lifting .....	564
B. Chinning on the Horizontal Bar .....	565
C. Boxing .....	565
V. SUMMARY .....	566

## LECTURE XXXIII. SPRAINS OF THE JOINTS OF THE UPPER EXTREMITY

I. SPRAINS OF THE SHOULDER JOINT .....	569
--	-----

A. Capsular and Ligamentous Strain of the Glenohumeral Joint .....	569
B. Ligamentous Strain of the Coraco- and Acromioclavicular Joints ....	570
C. The Avulsions .....	570
D. The Pathomechanics of Muscle Ruptures .....	570
II. SPRAINS OF THE ELBOW JOINT .....	571
A. The Collateral Ligaments .....	572
B. The Anterior Ligaments .....	573
C. The Tennis Elbow .....	573
III. SPRAIN OF THE WRIST .....	573
IV. SPRAINS OF THE THUMB .....	575
V. SPRAIN OF THE METACARPOPHALANGEAL JOINTS OF THE THUMB AND FINGERS .....	575
VI. SUMMARY .....	576

#### LECTURE XXXIV. THE PATHOMECHANICS OF SPRAINS OF THE LOWER EXTREMITY

I. SPRAINS OF THE HIP JOINT .....	579
A. Capsular and Ligamentous Sprains .....	579
B. Muscle Sprains .....	580
II. PATHOMECHANICS OF THE SPRAINS OF THE KNEE JOINT .....	581
A. Sprain of the Collaterals .....	581
B. The Meniscus Sprain .....	582
C. Sprains of the Cruciates .....	583
D. Sprains of Tendons and Their Aponeuroses .....	584
III. THE PATHOMECHANICS OF SPRAINS OF FOOT AND ANKLE .....	585
A. Sprains of the Lower Tibiofibular Articulation .....	586
B. The Sprains of the Ankle Joint .....	586
C. The Sprains of the Subastragalar Joint .....	588
D. Sprains of Chopart's Joint .....	589
E. The Sprain of the Scaphocuboid Junction .....	590
F. The Sprain of the Scaphocuneiform Junction .....	590
G. The Sprains of Lisfranc's Tarsometatarsal Joint .....	591
IV. SUMMARY .....	591

#### LECTURE XXXV. THE PATHOMECHANICS OF THE MORE COMMON FRACTURES OF THE UPPER EXTREMITY

I. INTRODUCTION .....	595
A. External Force and Intrinsic Resistance .....	595
B. The Mechanical Essentials of Alignment .....	595
II. COMMON FRACTURES OF THE SHOULDER JOINT .....	597
A. Fracture of the Humeral Neck .....	597
B. Fracture of the Shaft .....	597
C. Dislocation and Fracture Dislocation of the Shoulder .....	599
III. COMMON FRACTURES AT THE ELBOW .....	600
A. The Supracondylar Fracture (Ros Codorniu) .....	600
B. The Diacondylar Fracture .....	603
C. Split Fractures of the Humeral Epiphysis .....	603
D. Monteggia's Fracture .....	604
IV. COMMON FRACTURES AT THE WRIST .....	606
A. Pathomechanics of Colles' Fracture .....	606
B. Epiphyseal Separation .....	606

## CONTENTS

xxiii

C. Fracture of the Scaphoid .....	606
V. SUMMARY .....	607

### LECTURE XXXVI. THE PATHOMECHANICS OF THE MORE COMMON FRACTURES OF THE LOWER EXTREMITY

I. THE HIP JOINT .....	610
A. The Fracture of the Neck of the Femur .....	610
B. The Intertrochanteric Fracture .....	614
C. Mechanics of Restoration of Pelvic Support Lost in Ununited Fractures .....	615
II. THE KNEE JOINT .....	617
A. The Supracondylar Fracture .....	617
B. The Pathomechanics of Fractures of the Tibial Plateau .....	618
III. FOOT AND ANKLE .....	618
A. Malleolar Fracture .....	618
B. The Pathomechanics of the Fracture of the Os Calcis .....	621
IV. SUMMARY .....	623

## PART IV

### THE GAIT

#### LECTURE XXXVII. ON THE MECHANICS OF THE GAIT

I. HISTORICAL .....	631
II. THE DEVELOPMENT OF THE HUMAN GAIT FROM THE QUADRUPEDAL TO THE ALTERNATING BIPEDAL TYPE .....	632
A. The Quadrupedal Gait .....	633
B. The Bipedalism .....	633
C. The Alternating Bipedalism .....	634
III. THE MORPHOLOGICAL DESCRIPTION OF THE GAIT .....	635
A. The Walk .....	635
B. The Run .....	639
IV. THE GRAPHIC PRESENTATION OF THE GAIT .....	641
A. The Path Curves .....	641
B. The Path Curves of the Common Center of Gravity .....	644
C. The Velocities and Accelerations of the Common Center of Gravity ..	646
D. The Interpretation of Path, Velocity and Acceleration of the Common Center of Gravity .....	647
V. THE CALCULATION OF WORK PERFORMED IN WALKING .....	653
VI. SPECIAL MUSCLE DYNAMICS OF THE GAIT .....	656
A. The Hip Muscles .....	657
B. The Knee Muscles .....	657
C. The Ankle Muscles .....	658
VII. SUMMARY .....	659

#### LECTURE XXXVIII. THE PATHOMECHANICS OF THE GAIT

INTRODUCTION .....	665
I. THE BORDERLINE GAIT .....	665
A. Physiological Exaggeration of the Periods of Gait .....	665
B. Borderline Gaits with Dynamic Deficiencies .....	666
II. THE PATHOLOGICAL GAIT .....	667
A. Inequality of the Lower Limbs. The Short-Leg Gait .....	667
B. The Contracture Limp .....	669

C. The Gait in Static Disabilities of the Hip Joint .....	674
D. The Antalgic Gait .....	675
E. The Pathomechanics of the Gait in Muscular Deficiencies .....	678
III. THE PROSTHETIC GAIT (Slocum) .....	683
A. Amputation Through the Distal Tarsus .....	683
B. The Amputation of the Foot .....	684
C. Below-the-Knee Amputation (Slocum) .....	685
D. Above-Knee Amputation .....	685
IV. SUMMARY .....	687
INDEX	
Author Index .....	693
Subject Index .....	697



## **KINESIOLOGY**



**Part I**

**GENERAL KINETICS**



## Lecture I

### THE AIMS AND PURPOSES OF KINESIOLOGY

**K**INESIOLOGY is that part of physiology of motion which describes and analyzes locomotor events so far as they reflect the action of mechanical forces. In other words, it presents bodily motion as a special case in mechanics.

The question is, can it be so represented; can human motion, with its boundless variability and being the product of a multitude of only partially known factors, be forced into the narrow frame of precise and austere mathematical and physical laws?

This is the very point which ultimately decides whether or not there is enough practical value in the undertaking to warrant this line of investigation. It must be admitted that locomotion involves certain unknown and incalculable factors which preclude a strictly mathematical presentation.

Nevertheless, the operation of known physical laws can be clearly recognized and evaluated in properly observed locomotor events. The Newtonian laws are accepted as being fundamental for terrestrial mechanics. We intend to interpret the operation of these laws in terms of human motion. We do not attempt to formulate general mechanical laws from our observation as Newton formulated his law of gravitation from observing the falling apple. In other words, our reasoning is *deductive* from the accepted mechanical laws to their interpretation in terms of our observations; it is not *inductive* from the observation to the formulation of the laws.

If we are in error the quarrel is with the observation and its interpretation and not with the law itself. The danger then lies not in failing to recognize that a mechanical law is operating but rather in overlooking the existence of other laws, not mechanical in nature, which have their share in human locomotion.

A good example is the interpretation of the functional adaptation of bone as formulated by Julius Wolff in 1876. When it was recognized by Culman that the internal structure of the upper end of the femur presents a perfectly calculated construction of a loaded crane, it was believed that the physical laws had absolute and complete control over the form and texture of the human bone and that the lamellar arrangements or trajectories, as they are called, fall strictly in line with tension and pressure stresses. This is no doubt true to a large extent. The only mistake was that the operation of other laws biological in nature had been overlooked because their influence on the structure of the bone was less evident. As a matter of fact, the architectural response of bone to the mechanical forces of stress and strain merely approaches but never completely conforms with the accurate engineering calculation. The reason is that there are other biological laws in operation which, under certain conditions, may become more conspicuous than the mechanical laws themselves. For instance, the organization of bone after fracture may proceed under the laws of transformation on stress and strain resistance. But it would be more

difficult to demonstrate the same law of functional adaptation in cases of severe osteomalacia or in severe rickets.

This is merely one of the many situations in which biological factors may take precedence over mechanical ones.

The apparent discrepancy which exists between the biomechanical laws of Hueter-Volkmann and those of Wolff and Roux is another illustration. The former stipulates that pressure produces bone atrophy, the latter that it leads to bone formation. The fact is that under pressure both bone production and bone atrophy may occur as the degree and duration of stress varies and as the resistance to pressure fluctuates under the biological influence of growth and maturity. When Scaglietti in 1930 examined the effect of pressure on the growing femur, he found that the epiphyseal cartilage responded with arrest of bone growth despite a marked proliferation of cartilage cells. Such an arrest must be interpreted as the result of excessive and continuous pressure at the time when the growing bone shows marked biological activity and when it is therefore much more vulnerable than resting bone. Such instances reveal how fallacious it would be to explain morphological phenomena of the locomotor system purely in terms of mechanical laws.

With all these complicating influences at work, how can it still be maintained that locomotion is a special case of mechanics? Is it possible to analyze and calculate human motion on similar lines as we calculate the movement of an inert mechanical device?

Our contention is that this is indeed possible under certain reservations; and the question now arises whether the concessions which must be made to mathematical accuracy are so far reaching as to make the value of calculations illusory or whether they are still within acceptable limits of accuracy.

Here are some of the principal concessions to be made.

1. In human locomotion we are dealing with bodies and parts of irregular morphological shapes composed of tissue of varying density and specific gravity for which data regarding weight, volume, center of gravity and inertia must be established. To do that one must approximate the human body or its part to standard geometrical forms of homogeneous structure. The arm is considered as a cylinder, as is the trunk, the whole extremity as a truncated cone, the head as a sphere and so forth. The inertia of the body or its parts which resists rotatory motion is then calculated on this basis.

2. Although we know that the different systems of the bones, muscles, and so forth, are not of uniform density, we accept an average density without great loss of accuracy.

3. We know that the rotatory moment produced by muscle contraction depends upon the angle of application of the muscle to the bone and that this angle changes with the position of the joint; we further know that with increasing contraction the tension which the muscle can develop rapidly diminishes; consequently, for both situations we must accept mean values provided it can be done without too great damage to accuracy.

4. Some motor events are so complicated and the result of so many individual factors that to compute mechanical events, factors of lesser importance must be eliminated. This is particularly the case in computing the mechanics of the gait. It is a license which admittedly detracts from the desirable accuracy of our computation. On the other hand it is useful and practical for purposes of drawing comparisons between normal and pathological situations.

The argument is advanced that all these concessions add up to a degree of inaccuracy which makes any mechanical analysis of locomotor events a futile effort. Against this stands the fact that the effect of mechanical forces on the human locomotion is so strong and dominant that even the aggregate inaccuracies do not vitiate the practical value of mathematical computations.

In comparing the relative efficiency of normal and pathological motor performances, another source of information comes from the science of physiochemistry. It consists in the determination by gasometric methods of the expenditure of energy and its relation to the output of visible motion, thereby establishing the efficiency quotient of the specific motor act. Any movement which requires a greater amount of energy for production of the same mechanical effect can be said to be performed with less efficiency and with less skill. The normal efficiency for certain movements such as walking, bicycling and so forth have been determined. For instance, normal walking has an efficiency index of 35%, which is a high rate for a combustion engine such as the human body represents. We also had occasion to compare efficiency indexes in certain pathological conditions, for example, paralysis, dislocation of the hip, etc., where the efficiency index was found considerably lowered. High efficiency can be established against clumsiness; economical against uneconomical technique of manual work; physical alertness can be compared with lassitude and sluggishness. Important as such observations are in industry, they are equally helpful to the physical trainer and still more essential to the surgeon engaged in the rehabilitation of locomotor function.

It is hardly necessary to adduce further evidence to show that the study of the mechanics of the human body is a practical even though a formidable undertaking. Its approach involves a number of fundamental principles.

The first of these is unbiased observation and truthful recording. In the last decades the methods of observation and records have made great advances: from simple photography to cinematography; from palpation and faradization to electromyography; from the kymograph to the oscillograph. We are now able to observe and measure motion as it occurs in the joints under normal and pathological conditions and to determine its effect on different parts of the body with much greater accuracy than before.

The second principle is that of analyzing the forces which produce motion. This makes it unavoidable to invade to some extent the field of general mechanics. Kinesiology differs from systematic anatomy in that it analyzes motion as it occurs under actual living conditions when carried out against some extrinsic force such as gravity or any other external resistance. We call