

Sanjay Gupta · Ceby Mullakkara Saviour ·  
Bidyut Pal · Souptick Chanda ·  
Kaushik Mukherjee

# Biomechanics of Joints and Implants

Concepts to Applications

# Biomechanics of Joints and Implants

Sanjay Gupta · Ceby Mullakkara Saviour ·  
Bidyut Pal · Souptick Chanda · Kaushik Mukherjee

# Biomechanics of Joints and Implants

Concepts to Applications



Springer

Sanjay Gupta  
Department of Mechanical Engineering  
Indian Institute of Technology Kharagpur  
Kharagpur, West Bengal, India

Bidyut Pal  
Department of Mechanical Engineering  
Indian Institute of Engineering Science  
and Technology Shibpur  
Howrah, West Bengal, India

Kaushik Mukherjee  
Department of Mechanical Engineering  
Indian Institute of Technology Delhi  
New Delhi, Delhi, India

Ceby Mullakkara Saviour  
Department of Mechanical Engineering  
Indian Institute of Technology Kharagpur  
Kharagpur, West Bengal, India

Souptick Chanda  
Department of Biosciences  
and Bioengineering  
Indian Institute of Technology Guwahati  
Guwahati, Assam, India

ISBN 978-981-96-0585-9                    ISBN 978-981-96-0586-6 (eBook)  
<https://doi.org/10.1007/978-981-96-0586-6>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature  
Singapore Pte Ltd. 2025

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.  
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721,  
Singapore

If disposing of this product, please recycle the paper.

# Preface

Biomechanics is a field of science that helps to gain insight into the mechanics of living systems. This interdisciplinary subject helps to understand the relationship between the structure and function of human joints, predict changes in the bone tissue due to alterations in the mechanical and biochemical environment, and propose methods of artificial interventions. The fundamental concepts of biomechanics encompass joint kinematics and kinetics, gait analysis and motion capture, tissue mechanics, implant design and analysis, bone remodelling, and bone fracture healing, as well as state-of-the-art techniques of modelling and simulation of biomechanical systems.

This book is derived from materials and lecture notes developed for the course “Mechanics of the Human Body”, taught at the Indian Institute of Technology Kharagpur. It has been further enriched by the NPTEL online course *Biomechanics of Joints and Orthopaedic Implants*. Although primarily aimed at undergraduate and postgraduate engineering students, the course has also attracted medical practitioners with a keen interest in biomedical engineering. This book aims to be a valuable resource for students in biomedical and biomechanical engineering, highlighting recent advancements in the biomechanics of joints and orthopaedic implants.

The authors wish that the book accomplishes five goals. The first goal is to introduce the anatomy, physiology, and movements of the human body and its mechanical analogy to the students in order to evoke interest in the relationship between the structure and functions of the musculoskeletal system, in particular the main joints of the upper and lower limbs, as well as the spine. The second goal is to gain an insight into the structure, functions, movements, and forces acting on the joints during daily activities. The biomechanical concepts of the specific joints, the hip, knee, shoulder, elbow, and spine using the concept of static equilibrium have been presented.

The third goal is to quantitatively analyse the human gait cycle as a complex biomechanical system. Herein, focus on the details of gait analysis, measurement techniques, gait abnormalities, and motion capture system. Moreover, insights into the applications of mechanics of rigid bodies in the field of biomechanics have been provided. The estimation of musculoskeletal forces (joint forces and moments, muscle forces) using the fundamental concepts of joint dynamics (kinematics and

kinetics) has been presented with relevant solved examples and exercises to impart basic understanding. The quantitative study of the skeletal system is envisaged to provide a comprehensive understanding of the applications of rigid body dynamics.

The fourth goal is to revisit the basic concepts of mechanics of deformable bodies relevant to bone tissue as well as implanted bone structure. The efficacies of joint replacement (hip, knee, shoulder) and spinal surgery have been explored in detail. The concepts of composite beams in the bone-implant structure have been presented to enhance the understanding of stress/strain shielding. Common failure mechanisms of implanted bone structures and biomaterials used in orthopaedic implants have been discussed. Moreover, state-of-the-art modelling techniques of biomechanical systems and experimental validation have been presented. The students/instructors are expected to be benefitted from the extensive discussions on state-of-the-art finite element modelling techniques using CT/MRI scan data.

The fifth goal is to gain insight into the theory and concepts of bone remodelling and fracture healing. The theory, mathematical formulations, and computational framework of bone adaptation have been explored. Different mathematical models of tissue differentiation algorithms, such as mechanoregulatory, bioregulatory, and mechanobioregulatory algorithms have been presented. A brief overview of artificial intelligence and its application in orthopaedic biomechanics research has been discussed.

The contributions of several people have culminated in the development of this manuscript. We sincerely thank Dr. Rahul Gautam Talukdar for his feedback on spine-related content, Dr. Nirmal Kumar Som for his insights into human anatomy, and Mr. Gowtham Reddy for his review on artificial intelligence content. We also thank Mr. Pedada Jagdish for reviewing the manuscript, Mr. Rounak Bhattacharya for his feedback on motion analysis, Mr. Saranjit Sarkar and Ms. Rupa Mukherjee for their contributions to figures and artworks. Lastly, we express our heartfelt gratitude to our families and friends for their unwavering support and encouragement throughout this project.

We welcome corrections and suggestions for improving this textbook, by email to [sangupta@mech.iitkgp.ac.in](mailto:sangupta@mech.iitkgp.ac.in).

Kharagpur, India  
September 2024

Sanjay Gupta  
Ceby Mullakkara Saviour  
Bidyut Pal  
Souptick Chanda  
Kaushik Mukherjee

# Contents

<b>1</b>	<b>Musculoskeletal System: Structure and Function .....</b>	<b>1</b>
1.1	Skeletal System .....	1
1.2	Bone .....	4
1.3	Muscle .....	7
1.4	Ligament .....	7
1.5	Tendon .....	8
1.6	Mechanical Analogy of Anatomical Elements .....	9
1.7	Joints .....	10
1.7.1	Classifications of Joints .....	10
1.8	Structure and Functions of Synovial Joints .....	13
1.8.1	Movements of Synovial Joints .....	14
1.8.2	Mechanical Analogy of Synovial Joints .....	16
1.8.3	Factors Influencing Joint Stability .....	19
1.8.4	Joint Disorders .....	19
1.9	Hip Joint .....	21
1.9.1	Functions of the Hip Joint .....	21
1.9.2	Femoral Neck Shaft Angle and Femoral Neck Anteversion Angle .....	22
1.9.3	Muscles of the Hip Joint .....	23
1.9.4	Factors Affecting Stability of the Hip Joint .....	25
1.9.5	Common Problems of the Hip Joint .....	27
1.10	Knee Joint .....	29
1.10.1	Anatomy of the Knee Joint .....	30
1.10.2	Functions of the Knee Joint .....	31
1.10.3	Patella .....	31
1.10.4	Menisci .....	32
1.10.5	Factors Affecting Stability of the Knee Joint .....	33
1.10.6	Muscles of the Knee Joint .....	33
1.10.7	Ligaments of the Knee Joint .....	34
1.10.8	Knee Deformities .....	36

1.10.9	Common Problems Associated with Knee Joint .....	36
1.11	Ankle Joint .....	37
1.11.1	Anatomy of the Ankle Joint .....	39
1.11.2	Functions of the Ankle Joint .....	40
1.11.3	Muscles of the Ankle Joint .....	40
1.11.4	Factors Affecting Stability of Ankle Joint .....	40
1.11.5	Common Problems Associated with Ankle Joint .....	43
1.12	Shoulder Joint .....	44
1.12.1	Anatomy of the Shoulder Joint .....	44
1.12.2	Movements Associated with Shoulder Joint .....	45
1.12.3	Shoulder Joint Muscles .....	46
1.12.4	Shoulder Joint Ligaments .....	48
1.12.5	Common Problems in the Shoulder Joint .....	48
1.13	Elbow Joint .....	51
1.13.1	Anatomy of the Elbow Joint .....	51
1.13.2	Elbow Joint Movements .....	52
1.13.3	Elbow Joint Muscles .....	52
1.13.4	Elbow Joint Ligaments .....	53
1.13.5	Common Elbow Joint Problems .....	53
1.14	Spine .....	55
1.14.1	Anatomy of the Spine .....	55
1.14.2	Ligaments of the Spine .....	59
1.14.3	Spine Movements .....	59
1.14.4	Disc Degenerative Disease .....	61
	Multiple Choice Questions (MCQ) .....	62
	References .....	65
<b>2</b>	<b>Basic Biomechanics of Human Joints and Spine .....</b>	<b>67</b>
2.1	Biomechanics of the Hip .....	67
2.1.1	Basic Biomechanics of the Hip Joint .....	68
2.1.2	Hip Joint Reaction Forces During Various Activities .....	76
2.2	Biomechanics of the Knee Joint .....	77
2.2.1	Instantaneous Centre of Rotation of the Knee Joint .....	78
2.2.2	Influence of the Patella on Knee Joint Mechanics .....	80
2.2.3	Screw–Home Mechanism of the Knee Joint .....	81
2.2.4	Basic Biomechanics of the Knee Joint: Sample Problems .....	82
2.2.5	Knee Joint Reaction Forces During Various Activities .....	88
2.3	Biomechanics of the Ankle Joint .....	88
2.3.1	Basic Biomechanics of the Ankle Joint: Sample Problems .....	89
2.4	Biomechanics of the Shoulder Joint .....	92

2.4.1	Closed Chain Mechanism .....	93
2.4.2	Degrees-of-Freedom of the Shoulder Mechanism .....	94
2.4.3	Glenohumeral Joint Reaction Force During Abduction .....	95
2.4.4	Basic Biomechanics of the Shoulder Joint: Sample Problems .....	95
2.5	Biomechanics of the Elbow Joint .....	98
2.5.1	Carrying Angle .....	98
2.5.2	Basic Biomechanics of the Elbow Joint: Sample Problem .....	99
2.6	Biomechanics of the Spine .....	108
2.6.1	Lumbar Spinal Load for Various Postures .....	108
2.6.2	Basic Biomechanics of the Lumbar Spine: Sample Problems .....	109
	MATLAB Code for Solving 3D Force System Numerical Problem .....	112
	Multiple Choice Questions (MCQ) .....	114
	Practice Problems .....	116
	References .....	120
<b>3</b>	<b>Biomechanics of Gait .....</b>	<b>121</b>
3.1	Gait Cycle .....	121
3.1.1	Phases of Gait Cycle .....	122
3.1.2	Gait Cycle Parameters .....	124
3.1.3	Basic Differences Between Running and Walking Cycles .....	125
3.1.4	Ground Reaction Forces .....	125
3.1.5	Centre of Gravity .....	126
3.1.6	Moment Arm of Ground Reaction Force .....	126
3.1.7	Determinants of Gait Cycle .....	129
3.2	Gait Analysis .....	133
3.2.1	Variation of Ground Reaction Force During Gait Cycle .....	134
3.2.2	Gait Abnormalities .....	137
3.3	Gait Measurement Techniques .....	138
3.3.1	Image Processing Systems .....	139
3.3.2	Floor Sensor Systems .....	140
3.3.3	Wearable Sensors .....	141
3.3.4	Motion Capture Systems: Marker-Based Versus Marker-Less .....	142
	Multiple Choice Questions (MCQ) .....	147
	References .....	149

<b>4</b>	<b>Joint Kinematics and Kinetics</b>	151
4.1	Joint Kinematics	151
4.1.1	Estimation of Joint Angles	151
4.1.2	Lower-Limb Joint Angles During Gait Cycle	152
4.1.3	Linear Variables	156
4.2	Joint Kinetics	156
4.2.1	Anthropometry Data	157
4.3	Biomechanical Models	162
4.4	Inverse Dynamics and Forward Dynamics	164
4.5	Link Segment Analysis: Joint Forces and Moments	165
4.5.1	Assumptions of the Link Segment Model	165
4.5.2	Bone-on-Bone Contact Force	166
4.6	Static Optimisation	173
4.7	Three-Dimensional Motion Analysis	178
4.7.1	Kinetic Analysis	196
4.8	Use of Musculoskeletal Models for Force Estimation	201
4.9	Postural Stability	204
4.10	Swaying During Quiet Stance	206
4.11	Inverted Pendulum Model	207
	MATLAB Code for Solving the Numerical Problem Related	
	to 3D Motion Analysis	210
	Multiple Choice Questions (MCQ)	215
	References	218
<b>5</b>	<b>Bone Tissue Mechanics</b>	219
5.1	Fundamentals of Stress and Strain	219
5.1.1	Stress and Strain	219
5.1.2	Stress–Strain Curve	221
5.1.3	Shear Stress due to Torsion	222
5.1.4	Pure Bending	223
5.1.5	Generalized Hooke’s Law	228
5.1.6	Stress Tensor	229
5.2	Stress Transformation	232
5.3	Bone Structure	239
5.4	Cortical Bone	239
5.4.1	Mechanical Behaviour of Cortical Bone	240
5.5	Cancellous Bone	241
5.5.1	Mechanical Behaviour of Cancellous Bone	242
5.5.2	Density-Modulus Relationship of Cancellous	
	Bone	245
5.5.3	Loading and Deformation of Bone Structure	249
5.5.4	Viscoelastic Property of Bone	250
5.6	Bone Remodelling	252
5.7	Trabecular Architecture	255
5.8	Anisotropic Properties of Bone	256

5.8.1	Micro-FE Models .....	258
5.8.2	Fabric Tensor Method .....	259
5.8.3	Strain-Based Algorithm .....	259
	Multiple Choice Questions (MCQ) .....	260
	Practice Problems .....	262
	References .....	263
<b>6</b>	<b>Biomechanics of Orthopaedic Implants Part I: Hip and Knee .....</b>	<b>267</b>
6.1	Joint Replacement .....	267
6.1.1	Classification of Implants: Fixation Techniques .....	268
6.1.2	Implant Failure Mechanisms .....	270
6.2	Structural Analysis of Implant-Bone Structures .....	273
6.2.1	Composite Bar Subjected to Axial Loading .....	274
6.2.2	Composite Beam Subjected to Pure Bending .....	276
6.2.3	Bending of Unsymmetrical Beam .....	280
6.2.4	Bending of Unsymmetrical Composite Beam .....	284
6.3	Biomechanics of Hip Replacement .....	287
6.3.1	Total Hip Replacement .....	287
6.3.2	Common Classification of Stem Designs .....	292
6.3.3	Hip Resurfacing .....	293
6.4	Biomechanics of Knee Replacement .....	296
6.4.1	Effect of Implant Alignment .....	298
6.4.2	Effect of Implant Materials .....	298
6.4.3	Implant Stability: Role of Geometric Features .....	299
	Practice Problems .....	300
	References .....	301
<b>7</b>	<b>Biomechanics of Orthopaedic Implants Part II: Shoulder and Spine .....</b>	<b>305</b>
7.1	Biomechanics of Shoulder Arthroplasty .....	305
7.1.1	Conventional Total Shoulder Arthroplasty .....	306
7.1.2	Implant Stability: Role of Geometric Features .....	308
7.1.3	Reverse Total Shoulder Replacement .....	308
7.2	Biomechanics of Spinal Surgery .....	311
7.2.1	Spinal Fusion .....	312
7.2.2	Non-fusion Surgery .....	314
7.3	Biomaterials .....	315
7.3.1	Primary Requirements .....	316
7.3.2	Types of Biomaterials and Applications .....	317
	Multiple Choice Questions (MCQ) for Chaps. 6 and 7 .....	319
	References .....	323

<b>8</b>	<b>Biomechanical Modelling, Analysis and Design of Orthopaedic Implants</b>	325
8.1	The Need for Finite Element Modelling for Biomechanical Analysis	325
8.2	Development of FE Model	326
8.2.1	Image Processing and Geometrical Reconstruction of Bone	326
8.2.2	FE Modelling of Implanted Bone	329
8.2.3	Assignment of Bone Material Property	331
8.2.4	Musculoskeletal Loading and Boundary Conditions for FE Models	334
8.2.5	Population-Based Model	337
8.3	Verification and Validation of FE Models	338
8.3.1	Validation Using Strain Gauge Method	339
8.3.2	Validation Using Digital Image Correlation Technique	342
8.3.3	Validation Using Digital Volume Correlation Technique	344
8.3.4	Validation Using Linear Displacement Sensor	344
8.4	Steps in the Design of Orthopaedic Implants	346
8.4.1	Design Feasibility	346
8.4.2	Concept and Detailed Design	347
8.4.3	Design Verification	348
8.4.4	Manufacturing	348
8.4.5	Design Validation	349
8.4.6	Design Transfer	349
	Multiple Choice Questions (MCQ)	349
	References	352
<b>9</b>	<b>Adaptive Bone Remodelling</b>	355
9.1	Biology of Bone Remodelling	355
9.1.1	Different Phases of Bone Remodelling	356
9.1.2	Bone Turnover	357
9.1.3	Haversian Bone Remodelling	359
9.1.4	Trabecular Bone Remodelling	359
9.2	Theory of Adaptive Bone Remodelling	361
9.3	Bone Remodelling Models: Mathematical Formulations and Computational Schemes	363
9.3.1	SED-Based Bone Remodelling Model	363
9.3.2	Orthotropic Strain-Based Bone Remodelling Model	366
9.3.3	Mechanobiochemical Bone Remodelling Model	369
	Multiple Choice Questions (MCQ)	376
	References	378

<b>10</b>	<b>Bone Fracture Healing</b>	381
10.1	Types of Bone Fractures	381
10.2	Stages of Bone Fracture Healing	382
10.3	Cellular Mechanisms Involved in Fracture Healing	384
10.4	MSC Differentiation Pathway	387
10.5	Primary and Secondary Bone Healing	388
10.6	Need for Immobilisation of Fracture Site	389
10.7	Factors Affecting Bone Fracture Healing	389
10.8	Common Fracture Fixation Techniques	390
10.9	Secondary Fracture Healing Models	391
10.9.1	Mechanoregulatory Models	392
10.9.2	Bioregulatory Models	399
10.9.3	Mechanobioregulatory Models	400
10.10	Bone Ingrowth Around Porous Coated Implants	400
	Multiple Choice Questions (MCQ)	401
	References	404
	<b>Appendix: Artificial Intelligence in Orthopaedic Biomechanics</b>	407
	<b>Solution to Practice Problems</b>	425

## About the Editors

**Sanjay Gupta** is a Professor in the Department of Mechanical Engineering at the Indian Institute of Technology Kharagpur and is leading the Biomechanics Research Group. He earned his Ph.D. from the Delft University of Technology, The Netherlands. Subsequently, he worked as a senior research fellow at the University of Southampton, UK, and as a research associate at the Imperial College London, UK. He completed his bachelor's degree in mechanical engineering from Bengal Engineering College, University of Calcutta, in 1989 and master's degree in mechanical engineering from Jadavpur University, Calcutta, in 1992. He has 26 years of teaching and research experience. His major areas of research include bone and joint mechanics, pre-clinical analysis of implant design, bone remodelling, and mechanobiology. He has 50 international journal publications in this domain of research. He was awarded the INSA Teachers Award 2022 by the Indian National Science Academy, New Delhi.

**Ceby Mullakkara Saviour** is pursuing his doctoral study in the field of Biomechanics at the Indian Institute of Technology Kharagpur. He completed his bachelor's degree in mechanical engineering at Cochin University of Science and Technology in 2016 and master's degree in mechanical engineering from the Indian Institute of Technology Guwahati in 2019. During his master's degree, he secured the DAAD-IIT sandwich fellowship and conducted his thesis work at Leibniz University Hannover, Germany, from September 2018 to March 2019. His major areas of research include tissue mechanics, orthopaedic implant design, bone remodelling, and mechanobiology.

**Bidyut Pal** is an Assistant Professor in the Department of Mechanical Engineering at the Indian Institute of Engineering Science and Technology (IIEST), Shibpur. He obtained his Ph.D. from Indian Institute of Technology Kharagpur in 2010. Subsequently, he worked as a postdoctoral research associate in the Biomechanics Research Group (Mechanical Engineering Department) at Imperial College London, UK, and as a postdoctoral research fellow in the Medical Engineering Research Group at Anglia Ruskin University, UK. Dr. Pal also served as a senior lecturer and lecturer

in Mechanical Engineering at the University of Portsmouth, UK. He earned his master's degree in biomedical engineering from Jadavpur University, Kolkata, and his bachelor's degree in mechanical engineering from Kalyani Government Engineering College (Kalyani University), West Bengal, India. His broad research area is computational and experimental orthopaedic biomechanics.

**Souptick Chanda** is an Assistant Professor in the Department of Biosciences and Bioengineering at the Indian Institute of Technology Guwahati. He completed his bachelor's degree in mechanical engineering at the Indian Institute of Engineering Science and Technology, Shibpur (Erstwhile Bengal Engineering and Science University, Shibpur) in 2003 and master's degree in the same discipline from Indian Institute of Technology Guwahati in 2006. His doctoral study in biomechanics at the Indian Institute of Technology Kharagpur lasted until August 2015. Subsequently, he joined Nanyang Technological University, Singapore, as a postdoctoral research fellow. Dr. Chanda was awarded the Fulbright-Nehru Academic and Professional Excellence Fellowship in 2019 to carry out research on orthopaedic biomechanics at Harvard Medical School, Boston. His areas of research include biomechanics, implant design and optimisation, surgical simulations, and soft computing.

**Kaushik Mukherjee** is an Assistant Professor in the Department of Mechanical Engineering at the Indian Institute of Technology Delhi. He is leading the orthopaedic biomechanics and implant design research group as well as the Sports Biomechanics research lab. His research lies across orthopaedic biomechanics, implant design, musculoskeletal modelling, and mechanics of human movement. Dr. Mukherjee earned his doctoral and master's degrees from the Indian Institute of Technology Kharagpur, whereas his undergraduate degree was from West Bengal University of Technology (Kalyani Government Engineering College). Dr. Mukherjee pursued his postdoctoral research in the Department of Bioengineering, Imperial College London, UK, where he was also a recipient of the Marie Skłodowska-Curie Research Fellowship.

# Chapter 1

## Musculoskeletal System: Structure and Function

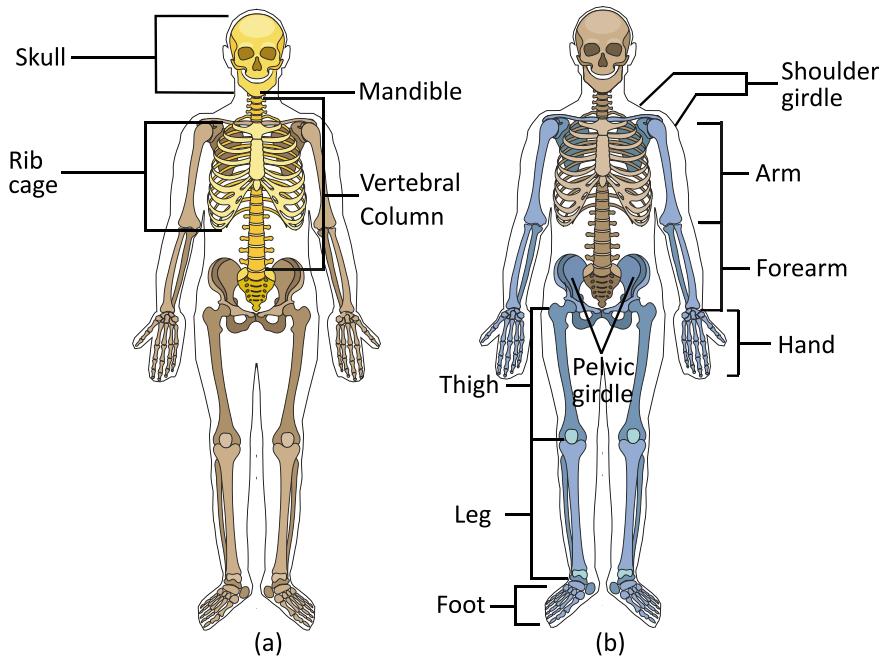


In this chapter, our focus will be directed towards the fundamental aspects of the human musculoskeletal system. A detailed understanding of the musculoskeletal system, particularly the intricate relationship between the structure and its function, is necessary prior to discussions on the biomechanics of the human body. Musculoskeletal elements, e.g. bone, muscle, ligament, and tendon, are discussed in the following articles.

### 1.1 Skeletal System

The skeletal system is a basic framework of bones and connective tissues that provides the human body with essential structure, support, and protection. Additionally, this intricate network of bones and joints allows us to perform a range of movements and activities essential for daily living. The skeletal system is classified into the appendicular skeleton and the axial skeleton, as presented in Fig. 1.1. The group of bones or the skeleton marked in yellow corresponds to the axial skeleton, encompassing the skull, thoracic cage (rib cage), and vertebral column (Fig. 1.1a). The skeletal segment marked in blue colour is knowns as the appendicular skeleton, which includes the upper limbs, lower limbs, shoulder girdle, and pelvic girdle (Fig. 1.1b).

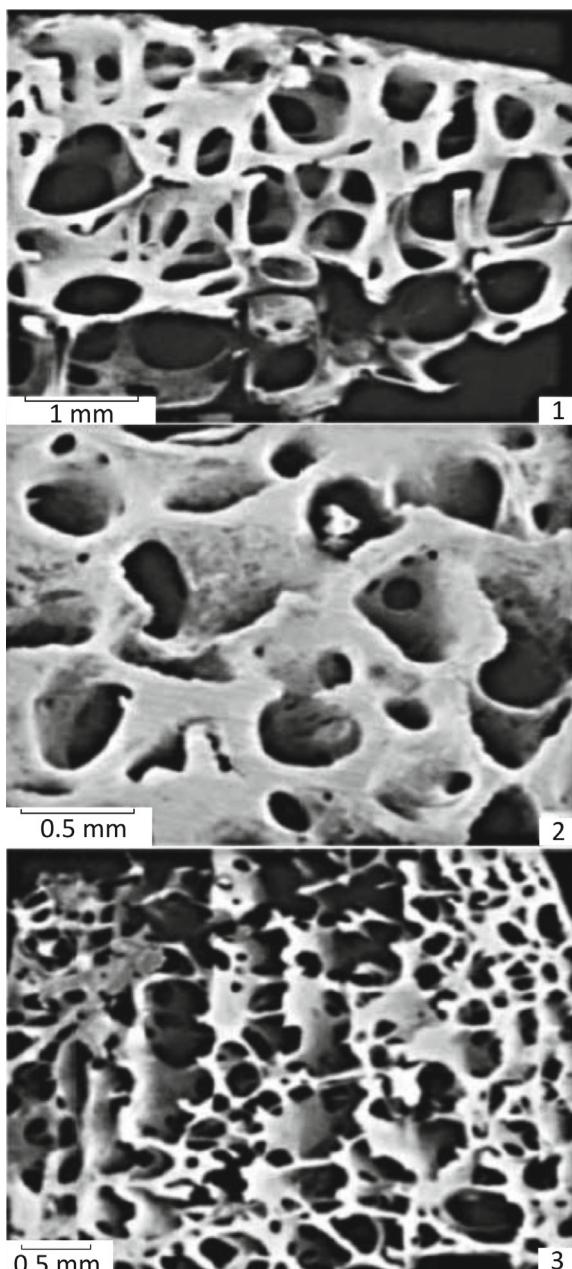
In order to accurately describe the position and orientation of the anatomical structures in space, it is necessary to define anatomical reference planes and anatomical directions. In Fig. 1.2, three mutually perpendicular planes, i.e. the coronal plane, the sagittal plane, and the axial plane, are presented. These planes are referred to as anatomical planes of reference, and they are essential for precisely determining the position of structures in space. The sagittal plane is a vertical plane that passes through the body longitudinally, dividing the body into a left section and a right section. The coronal plane is another vertical plane, perpendicular to the sagittal plane, that divides the body into a front section and a back section. The transverse



**Fig. 1.1** The skeletal system; **a** axial skeleton, **b** appendicular skeleton

plane, also known as the axial plane, is an anatomical plane perpendicular to the above two planes that divides the body into top and bottom sections. Additionally, anatomical directions describe the position of a structure relative to another structure. Specific directions have been designated, including superior, inferior, anterior, posterior, proximal, distal, medial, and lateral, as illustrated in Fig. 1.3. For instance, the anterior and posterior directions are employed to describe structures located toward the front (anterior side) or toward the back (posterior side) of the body. An example is the toe being described as anterior to the heel. Part 'A' is said to be superior to part 'B', if part 'A' lies above part 'B'. Whereas, if part 'A' lies below the reference part 'B', we can say that part 'A' is inferior to part 'B'. For example, the pelvis is inferior to the abdomen. In addition to superior and inferior, anatomical terms such as proximal and distal are commonly used to denote relative positions. As the name suggests, while distal refers to a position far or at a certain distance, proximal indicates proximity. In precise terms, proximal indicates a position closer to the trunk or the point of attachment or origin of a structure, while distal refers to a location further away from it. For example, the foot is distal to the knee joint, whereas the knee is proximal to the foot. The knee joint is located closer to the trunk, while the foot is located farther away from it, making it distal to the knee joint. The femoral head is proximally located in the femur, whereas the femoral condyles are distally located.

**Fig. 5.22** Scanning electron micrographs of cancellous bone structure: **1**. Low density cancellous bone with an asymmetric rod-like structure; specimen taken from femoral head **2**. High density cancellous bone with an asymmetric plate-like structure; specimen taken from femoral head **3**. Plate-like cancellous bone with columnar structure; specimen taken from femoral condyle (Adapted from Gibson L. J. 1985)



Prentice SD, Patla AE, Stacey DA (2001) Artificial neural network model for the generation of muscle activation patterns for human locomotion. *J Electromyogr Kinesiol* 11(1):19–30

Ramkumar PN, Luu BC, Haeberle HS, Karnuta JM, Nwachukwu BU, Williams RJ (2022) Sports medicine and artificial intelligence: A primer. *Am J Sports Med* 50(4):1166–1174

Rapp E, Shin S, Thomsen W, Ferber R, Halilaj E (2021) Estimation of kinematics from inertial measurement units using a combined deep learning and optimization framework. *J Biomech* 116

Rupp MC, Moser LB, Hess S, Angele P, Aurich M, Dyrna F, Nehrer S, Neubauer M, Pawelczyk J, Izadpanah K, Zellner J, Niemeyer P, AGA-Komitee Innovation und Translation, (2024) Orthopaedic surgeons display a positive outlook towards artificial intelligence: A survey among members of the AGA Society for Arthroscopy and Joint Surgery. *J. Exp. Orthop.* 11(3):e12080

Saviour CM, Gupta S (2024) Towards an optimal design of a functionally graded porous uncemented acetabular component using genetic algorithm. *Med Eng Phys* 126:104159

Schulc A, Leite CBG, Csákvári M, Lattermann L, Zgoda MF, Farina EM, Lattermann C, Tósér Z, Merkely G (2024) Identifying anterior cruciate ligament injuries through automated video analysis of in-game motion patterns. *Orthop J Sports Med* 12(3):23259671231221580

Sepulveda F, Wells DM, Vaughan CL (1993) A neural network representation of electromyography and joint dynamics in human gait. *J Biomech* 26(2):101–109. [https://doi.org/10.1016/0021-9290\(93\)90041-c](https://doi.org/10.1016/0021-9290(93)90041-c)

Shefelbine SJ, Augat P, Claes L, Simon U (2005) Trabecular bone fracture healing simulation with finite element analysis and fuzzy logic. *J Biomech* 38(12):2440–2450

Simon U, Augat P, Utz M, Claes L (2003) Simulation of tissue development and vascularization in the callus healing process. *Trans Orthop Res Soc* 28

Vesanto J (1999) SOM-based data visualization methods. *Intell. Data Anal.* 3(2):111–126

Wehner T, Claes L, Niemeyer F, Nolte D, Simon U (2010) Influence of the fixation stability on the healing time: A numerical study of a patient-specific fracture healing process. *Clin Biomech* 25(6):606–612

Winter DA (1987) The biomechanics and motor control of human gait, 2nd edn. University of Waterloo Press

Xue Y, Zhang R, Deng Y, Chen K, Jiang T (2017) A preliminary examination of the diagnostic value of deep learning in hip osteoarthritis. *PLoS ONE* 12(6)

# Solution to Practice Problems

## *Solutions to Practice Problems of Chap. 2*

### **Problem 2.1**

#### **Given data:**

Reaction force,  $R = 80$  kg (subject standing on one foot)

The weight of limb ( $W_L$ ) = 13 kg

#### **Unknown data:**

Hip joint reaction force ( $F_J$ ) acting at an angle  $\theta$  with the horizontal.

Considering the force equilibrium along x- and y-directions (Fig. S2.1),

$$\begin{aligned}\sum F_X &= 0 \\ F_A \cos 70 &= F_J \cos \theta\end{aligned}\tag{S2.1}$$

$$\begin{aligned}\sum F_Y &= 0 \\ F_A \sin 70 + R &= W_L + F_J \sin \theta \\ F_A \sin 70 + 80 &= 13 + F_J \sin \theta \\ F_A \sin 70 + 67 &= F_J \sin \theta\end{aligned}\tag{S2.2}$$

Taking a moment about centre of pressure,

$$\begin{aligned}\sum M &= 0 \\ 0.082 \times F_A \sin 70 + 0.890 \times F_A \cos 70 - 0.008 \times W_L \\ -0.014 \times F_J \sin \theta - 0.9 \times F_J \cos \theta &= 0\end{aligned}\tag{S2.3}$$

Substituting Eqs. (S2.1) and (S2.2) in Eq. (S2.3)