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Biomechanics of the human knee joint in compression: reconstruction, mesh generation and finite element analysis

M Z Bendjaballah¹, A Shirazi-Adl², D J Zukor²

¹Division of Applied Mechanics, Department of Mechanical Engineering, École Polytechnique, Montréal, Québec, Canada; ²Chief, Orthopaedic Surgery, Jewish General Hospital, Montréal, Québec, Canada

Summary

Computer assisted tomography with direct digitization and measurements were used to reconstruct the detailed geometry of an entire human knee joint specimen. These data were then merged with a mesh generation algorithm and material properties reported in the literature to develop a three dimensional non-linear finite element model of the knee joint. This model consists of three bony structures (tibia, femur and patella), their articular cartilage layers, medial and lateral menisci, and five principal ligaments (collaterals, cruciates and patellar tendon). The menisci are represented as a non-homogeneous composition of a solid matrix reinforced by radial and circumferential collagen fibres. The articulations of cartilage layers with each other as well as with intervening menisci and the wrapping of the medial collateral ligament with tibia are treated as general large displacement frictionless contact problems. The incremental response of the tibiofemoral joint in full extension is determined under axial forces of up to 1000 N applied on the femur. Analysis are carried out with the tibia fixed while the femur is set free to translate in medial-lateral, anterior-posterior, and proximal-distal directions; the internal-external rotation is either left free or fixed. Cases simulating total meniscectomy are also analyzed. The joint exhibits a non-linear stiffening response in the axial direction with large oriented displacements. At 1000 N, the load transferred through the joint is found to be greater for the lateral compartment than for the medial compartments and at the cartilage-cartilage contact than at the meniscus-cartilage contact. The menisci, fully attached by their horns to the tibia, are radially extruded under the axial compression and create greater contact areas and smaller, more uniform, contact pressures. Removal of menisci markedly increases the primary and coupled laxities of the joint, reduces total contact areas, and increases contact stresses. The predictions are in general agreement with measurements reported in the literature.

Key words: Reconstructive knee joint, meniscectomy, finite element modelling

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Introduction

The human knee joint is distinguished by its complex three dimensional geometry and multibody articulation, that generate complex mechanical responses under physiological loads. The knee joint compliance and stability required for optimal duty function are provided by various articulations, menisci, ligaments and muscle forces. A proper understanding of knee joint bio-

mechanics significantly improves the prevention and treatment of knee joint disorders and injuries. Total knee arthroplasty and prosthetic ligament replacement are two examples that directly benefit from such knowledge.

Knee joint mechanics have consequently been the subject of a large number of studies, the majority of which are experimental and aim at the measurement of the gross multidirectional load-displacement response of the joint under both static and perturbed states¹⁻⁴. Measurements have also been reported on the biomechanical role of the ligaments and menisci⁵⁻¹¹, as well as the mechanism of load transfer and contact areas and pressures at the tibiofemoral and

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Correspondence and requests for Dr A. Shirazi-Adl, Division of Applied Mechanics, Department of Mechanical Engineering, École Polytechnique, PO Box 6071, Stn Ave P, Montréal, Québec, Canada H3C 3A7

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Innovations in Biomedical Engineering Marek Gzik, Zbigniew Paszenda, Ewa Pietka, Ewaryst Tkacz, Krzysztof Milewski, 2020-10-10 This book presents a compact study on recent concepts and advances in biomedical engineering The ongoing advancement of civilization and related technological innovations are increasingly affecting many aspects of our lives These changes are also visible in the development and practical application of new methods for medical diagnosis and treatment which in turn are closely linked to expanding knowledge of the functions of the human body This development is possible primarily due to the increasing cooperation of scientists from various disciplines and related activities are referred to as biomedical engineering The combined efforts of doctors physiotherapists and engineers from various fields of science have helped achieve dynamic advances in medicine that would have been impossible in the past The reader will find here papers on biomaterials biomechanics as well as the use of information technology and engineering modeling methods in medicine The respective papers will promote the development of biomedical engineering as a vital field of science based on cooperation between doctors physiotherapists and engineers The editors would like to thank all the people who contributed to the creation of this book both the authors and those involved in technical aspects

Inverse Problems In Dynamic Elasticity Imaging Christoph Moosbauer, 2015-03-25 Since the early 1990 s elasticity imaging techniques are developed as a powerful supplement of the medical toolbox in diagnostic analysis and computer aided surgery By solving a so called inverse problem information about the spatial variation of material parameters of soft human tissue are derived from displacement data which can be measured noninvasively using standard imaging devices such as ultrasound or magnetic resonance tomography The terms of quasi static and dynamic elastography refer to the type of load situation by which the tissue in question is excited The extension of the theoretical formulation and implementation of the underlying inverse problem in quasi static elastography to time harmonic approaches poses several additional challenges which are addressed in detail within the course of this study We propose a robust strategy for the reconstruction which takes advantage of the high sensitivity of the accuracy in harmonic elastography to the choice of the starting point While not being reported in the literature up to now the quite competing claims of quasi static and time harmonic elastography motivate a comprehensive comparison of these two techniques Via a spectral decomposition of the curvature information of the underlying inverse problem a clear explanation for an improved robustness of time harmonic elastography in the presence of inaccuracies due to noise and or numerical approximations can be given Several numerical examples confirm these findings as well as the efficiency of the proposed reconstruction strategy In particular it is shown that for moderately low frequencies it is sufficient to use very coarse finite element meshes so that the only additional computational cost stems from the worse conditioning of the system matrix

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CONAT 2024 International Congress of Automotive and Transport Engineering Anghel Chiru, Dinu Covaciu, 2024-11-19 These 3 volume proceedings includes selected and reviewed papers from CONAT 2024 the 13th edition of the International Congress of Automotive and Transport Engineering held in Brasov Romania in November 2024 Authors are experts from research industry and universities coming from around the world The papers are covering the latest developments in automotive vehicles and environment advanced transport systems and road traffic advanced powertrain systems new materials manufacturing technologies and logistics accident research and analysis and innovative solutions for automotive vehicles The congress is organized by SIAR Society of Automotive Engineers from Romania in cooperation with SAE International and Transilvania University of Brasov This third volume presents the papers on Advanced Transport Systems Accident Research and Analysis and some related to History of Automotive Technics and Technology

Computational Intelligence for Movement Sciences Rezaul Begg, Marimuthu Palaniswami, 2006-01-01 This book provides information regarding state of the art research outcomes and cutting edge technology on various aspects of the human movement Provided by publisher

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Dissertation Abstracts International, 1997

Skeletal Anchorage in Orthodontic Treatment of Class II Malocclusion E-Book Moschos A. Papadopoulos, 2014-09-29 The book offers a comprehensive and critical review which presents not only the principles and techniques involved in the use of skeletal anchorage techniques and devices such as orthodontic implants miniscrew implants and mini plates but also the scientific evidence available regarding the use of these contemporary applications and their clinical efficacy Provides an

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University Affairs ,1979 Computer Methods in Biomechanics and Biomedical Engineering 2 J. Middleton,Gyan Pande,M. L. Jones,2020-09-10 Contains papers presented at the Third International Symposium on Computer Methods in Biomechanics and Biomedical Engineering 1997 which provide evidence that computer based models and in particular numerical methods are becoming essential tools for the solution of many problems encountered in the field of biomedical engineering The range of subject areas presented include the modeling of hip and knee joint replacements assessment of fatigue damage in cemented hip prostheses nonlinear analysis of hard and soft tissue methods for the simulation of bone adaptation bone reconstruction using implants and computational techniques to model human impact Computer Methods in Biomechanics and Biomedical Engineering also details the application of numerical techniques applied to orthodontic treatment together with introducing new methods for modeling and assessing the behavior of dental implants adhesives and restorations For more information visit the <http://www.uwcm.ac.uk/biorome> international symposium on Computer Methods in Biomechanics and Biomedical Engineering home page or <http://www.gbhap.com> Computer_Methods_Biomechanics_Biomedical_Engineering the home page for the journal Three-dimensional Analysis of Human Movement Paul Allard,Ian A. F. Stokes,Jean-Pierre Blanchi,1995 Researchers graduate students and practitioners alike will benefit from this state of the art reference It s the first book to explain in a single volume the essential components of three dimensional analysis of human movement Readers will gain a fundamental understanding of methods and technology used to capture reconstruct and process 3 D data concepts and techniques of mechanical and neuromuscular modeling including robotics and the application of 3 D analysis The editors have brought together contributions from international experts to create a technical manual that demonstrates the possibilities and potential pitfalls of 3 D analysis of human movement More than 140 tables diagrams and photos throughout the book illustrate essential content A 3-D spatial reconstruction system for biomechanical motion analysis Stephen Michael Humphrey,1989 **Computational Biomechanics for Medicine** Karol Miller,Adam Wittek,Martyn Nash,Poul M. F. Nielsen,2021-07-17 Computational Biomechanics for Medicine Solid and fluid mechanics for the benefit of patients contributions and papers from the MICCAI Computational Biomechanics for Medicine Workshop help in conjunction with Medical Image Computing and Computer Assisted Intervention conference MICCAI 2020 in Lima Peru

The content is dedicated to research in the field of methods and applications of computational biomechanics to medical image analysis image guided surgery surgical simulation surgical intervention planning disease prognosis and diagnostics analysis of injury mechanisms implant and prostheses design as well as artificial organ design and medical robotics This book appeals to researchers students and professionals in the field

Computer Methods in Biomechanics and Biomedical Engineering II Wafa Skalli,Sébastien Laporte,Aurélie Benoit,2024-04-23 This book gathers selected extended and revised contributions to the 18th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering held on May 3 5 2023 at Arts Et M tiers Institute Of Technology in Paris France They highlight cutting edge advances in computational modelling in biomedical engineering discusses new developments on imaging and visualization as well as solutions for applying them in the clinical practice All in all this book offers a timely snapshot of the latest research and current challenges at the interface between biomedical engineering computational biomechanics and biological imaging It also aims at fostering future cross disciplinary collaborations

Computer Methods in Biomechanics and Biomedical Engineering Amit Gefen,Daphne Weihs,2018-08-03 This edited volume collects the research results presented at the 14th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering Tel Aviv Israel 2016 The topical focus includes but is not limited to cardiovascular fluid dynamics computer modeling of tissue engineering skin and spine biomechanics as well as biomedical image analysis and processing The target audience primarily comprises research experts in the field of bioengineering but the book may also be beneficial for graduate students alike

Computational Modeling in Biomechanics Suvranu De,Farshid Guilak,Mohammad Mofrad,2010-03-10 Availability of advanced computational technology has fundamentally altered the investigative paradigm in the field of biomechanics Armed with sophisticated computational tools researchers are seeking answers to fundamental questions by exploring complex biomechanical phenomena at the molecular cellular tissue and organ levels The computational armamentarium includes such diverse tools as the ab initio quantum mechanical and molecular dynamics methods at the atomistic scales and the finite element boundary element meshfree as well as immersed boundary and lattice Boltzmann methods at the continuum scales Multiscale methods that link various scales are also being developed While most applications require forward analysis e g finding deformations and stresses as a result of loading others involve determination of constitutive parameters based on tissue imaging and inverse analysis This book provides a glimpse of the diverse and important roles that modern computational technology is playing in various areas of biomechanics including biofluids and mass transfer cardiovascular mechanics musculoskeletal mechanics soft tissue mechanics and biomolecular mechanics

Biomedical Imaging and Computational Modeling in Biomechanics Ugo Andreass,Daniela Iacoviello,2012-10-09 This book collects the state of art and new trends in image analysis and biomechanics It covers a wide field of scientific and cultural topics ranging from remodeling of bone tissue under the mechanical stimulus up to optimizing the performance of sports equipment through the

patient specific modeling in orthopedics microtomography and its application in oral and implant research computational modeling in the field of hip prostheses image based model development and analysis of the human knee joint kinematics of the hip joint micro scale analysis of compositional and mechanical properties of dentin automated techniques for cervical cell image analysis and biomedical imaging and computational modeling in cardiovascular disease The book will be of interest to researchers Ph D students and graduate students with multidisciplinary interests related to image analysis and understanding medical imaging biomechanics simulation and modeling experimental analysis

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