

Computational Anatomical Animal Models

Methodological developments and research applications

IPEM-IOP Series in Physics and Engineering in Medicine and Biology

Editorial Advisory Board Members

Frank Verhaegen

Maastricht Clinic, the Netherlands

Alicia El Haj

Keele University, UK

Carmel Caruana

University of Malta, Malta

John Hossack

University of Virginia, USA

Penelope Allisy-Roberts

formerly of BIPM, Sèvres, France

Tingting Zhu

University of Oxford, UK

Rory Cooper

University of Pittsburgh, USA

Dennis Schaart

TU Delft, the Netherlands

About the Series

Series in Physics and Engineering in Medicine and Biology will allow IPEM to enhance its mission to ‘advance physics and engineering applied to medicine and biology for the public good.’

Focusing on key areas including, but not limited to:

- clinical engineering
- diagnostic radiology
- informatics and computing
- magnetic resonance imaging
- nuclear medicine
- physiological measurement
- radiation protection
- radiotherapy
- rehabilitation engineering
- ultrasound and non-ionising radiation

A number of IPEM-IOP titles are published as part of the EUTEMPE Network Series for Medical Physics Experts.

Computational Anatomical Animal Models

Methodological developments and research applications

Habib Zaidi

Geneva University Hospital, Switzerland

IOP Publishing, Bristol, UK

© IOP Publishing Ltd 2018

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publisher, or as expressly permitted by law or under terms agreed with the appropriate rights organization. Multiple copying is permitted in accordance with the terms of licences issued by the Copyright Licensing Agency, the Copyright Clearance Centre and other reproduction rights organizations.

Permission to make use of IOP Publishing content other than as set out above may be sought at permissions@iop.org.

Habib Zaidi has asserted his right to be identified as the author of this work in accordance with sections 77 and 78 of the Copyright, Designs and Patents Act 1988.

ISBN 978-0-7503-1344-5 (ebook)

ISBN 978-0-7503-1345-2 (print)

ISBN 978-0-7503-1346-9 (mobi)

DOI 10.1088/2053-2563/aae1b4

Version: 20181201

IOP Expanding Physics

ISSN 2053-2563 (online)

ISSN 2054-7315 (print)

British Library Cataloguing-in-Publication Data: A catalogue record for this book is available from the British Library.

Published by IOP Publishing, wholly owned by The Institute of Physics, London

IOP Publishing, Temple Circus, Temple Way, Bristol, BS1 6HG, UK

US Office: IOP Publishing, Inc., 190 North Independence Mall West, Suite 601, Philadelphia, PA 19106, USA

Contents

Editor biography	x
List of contributors	xi
Part I Computational models	
1 Historical development and overview of computational animal models	1-1
1.1 Introduction	1-1
1.2 Construction of computational models	1-2
1.3 Overview of existing computational animal models	1-9
1.3.1 Mouse models	1-9
1.3.2 Rat models	1-12
1.3.3 Models of other animals	1-13
1.4 Popular simulation tools for computational models	1-14
1.5 Summary	1-15
References	1-17
2 Design and construction of computational animal models	2-1
2.1 Introduction	2-1
2.2 Mathematical phantoms	2-2
2.3 Voxel-based phantoms	2-3
2.4 BREP phantoms	2-6
2.5 Summary and future perspectives	2-7
References	2-9
3 Overview of computational mouse models	3-1
3.1 Introduction	3-1
3.2 Construction of computational mouse models	3-2
3.3 History of computational mouse models	3-7
3.4 Simulation tools used with the computational mouse models	3-9
3.5 Applications of computational mouse models	3-11
3.5.1 Ionizing radiation dosimetry	3-11
3.5.2 Nonionizing radiation dosimetry	3-13
3.5.3 Medical imaging physics	3-13
3.6 Summary	3-14
References	3-16

4	Overview of computational rat models	4-1
4.1	Introduction	4-1
4.2	Overview of existing rat models	4-2
4.3	Development and application of HUST computational rat models	4-5
4.4	Summary	4-10
	References	4-12
5	Overview of computational frog models	5-1
5.1	Introduction	5-1
5.2	History and construction of computational frog models	5-3
5.3	Monte Carlo simulations with computational frog models	5-3
	5.3.1 Absorbed fractions and <i>S</i> values for the voxel-based model	5-5
	5.3.2 Dose coefficients (DCs) for the voxel-based model	5-6
	5.3.3 Comparisons between stylized and voxel-based models	5-7
5.4	Summary	5-8
	References	5-9
6	Overview of computational canine models	6-1
6.1	Introduction	6-1
6.2	General steps for developing canine models	6-1
	6.2.1 Acquisition of tomographic images	6-2
	6.2.2 Segmentation of organs and tissues	6-2
	6.2.3 Development of 3D whole body models	6-3
6.3	Current status of canine models	6-3
	6.3.1 The University of Florida canine models	6-3
	6.3.2 The NIRAS canine models	6-4
	6.3.3 The Vanderbilt University canine models	6-5
6.4	Summary and future perspectives	6-7
	References	6-9
7	Overview of computational rabbit models	7-1
7.1	Introduction	7-1
7.2	Construction of rabbit models	7-2
	7.2.1 Acquisition of CT images	7-2
	7.2.2 Tissue classification from CT images	7-2

7.3	Model refinement	7-3
7.4	Examples of electromagnetic and thermal dosimetry	7-5
7.5	Summary	7-6
	References	7-7
8	Overview of other computational animal models	8-1
8.1	Introduction	8-1
8.2	Computational models of trout	8-2
8.3	Computational models of crabs	8-2
8.4	Computational models of flatfish	8-3
8.5	Computational models of bees	8-3
8.6	Computational models of deer	8-4
8.7	Computational models of earthworms	8-4
8.8	Computational models of ducks	8-6
8.9	Computational models of goats	8-6
8.10	Computational models of pigs	8-7
8.11	Computational models of non-human primates	8-7
8.12	Summary	8-8
	References	8-8
9	Simulation tools used with preclinical computational models	9-1
9.1	Introduction	9-1
9.2	Tools used for simulation	9-1
	9.2.1 Tools used for ionizing radiation simulation	9-1
	9.2.2 Tools used for nonionizing radiation simulation	9-3
9.3	The Monte Carlo simulation method	9-3
	9.3.1 Monte Carlo simulation of computational phantoms	9-5
	9.3.2 Monte Carlo simulation of medical imaging detectors	9-6
9.4	Monte Carlo packages for preclinical studies	9-6
	9.4.1 EGS	9-7
	9.4.2 Geant4	9-10
	9.4.3 MCNP	9-12
	9.4.4 PENELOPE	9-13
9.5	Comparison of performance of Monte Carlo packages	9-16
	9.5.1 Memory consumption	9-18

9.5.2 CPU time consumption	9-18
9.5.3 Dose and absorbed fraction scoring	9-19
9.5.4 Summary	9-22
References	9-22

Part II Applications in preclinical research

10 Applications of computational animal models in ionizing radiation dosimetry	10-1
10.1 Introduction	10-1
10.2 Fundamentals of radiation dosimetry	10-2
10.2.1 Nuclear medicine dosimetry	10-3
10.2.2 Computed tomography (CT) dosimetry	10-4
10.2.3 Multimodality (SPECT/CT and PET/CT) dosimetry	10-6
10.3 Applications in ionizing radiation dosimetry	10-7
10.3.1 Monte Carlo simulations	10-7
10.3.2 Dosimetry applications in mouse models	10-8
10.3.3 Dosimetry applications in rat models	10-12
10.3.4 Dosimetry applications in small animal models	10-12
10.4 Discussion	10-13
References	10-13
11 Computational animal phantoms for electromagnetic dosimetry	11-1
11.1 Introduction	11-1
11.2 Minimal requirements for EM dosimetry	11-4
11.2.1 Exposure conditions	11-4
11.2.2 Animal phantoms	11-5
11.2.3 Dosimetric data evaluated	11-5
11.2.4 Variation analysis	11-6
11.3 Methods	11-7
11.3.1 Computational animal phantoms	11-7
11.3.2 Segmentation	11-7
11.3.3 Poser	11-13
11.4 Outlook	11-13
11.5 Conclusions	11-14
References	11-15

12 Applications of computational animal models in imaging physics research	12-1
12.1 Introduction	12-1
12.2 Computational animal models in imaging physics	12-2
12.3 Applications of computational animal models in imaging physics research	12-3
12.3.1 Imaging systems design and performance evaluation	12-3
12.3.2 Modeling physical image degradation factors and their correction	12-5
12.3.3 Development and evaluation of image reconstruction algorithms	12-10
12.3.4 Quantification of small-animal PET data	12-10
12.4 Summary and future directions	12-11
References	12-12
13 Applications of computational animal models in radiation therapy research	13-1
13.1 Introduction	13-1
13.2 Design of digital mouse phantoms	13-2
13.3 Monte Carlo simulation platforms	13-4
13.4 Simulation of head of accelerators and energy spectra	13-7
13.4.1 Linear accelerator x-ray beam	13-7
13.4.2 Calibration of the x-ray beam	13-8
13.4.3 Simulation of the x-ray beam	13-8
13.5 Types of absorbed doses calculated in digital mouse models	13-9
13.6 Recommendations by collaborative working groups and agencies	13-10
13.7 Differences between human organs and digital mouse organs in radiation therapy	13-11
13.8 Excerpts of applications in digital mouse radiotherapy/dosimetry	13-11
13.9 Conclusions	13-13
References	13-14
14 Summary and future outlook	14-1
14.1 Summary	14-1
14.2 Future outlook	14-2
14.3 Acknowledgements	14-3
References	14-3

Editor biography

Habib Zaidi



Professor Habib Zaidi, B.Eng, M.Sc, Ph.D, PD, FIEEE

Professor Habib Zaidi is Chief physicist and head of the PET Instrumentation & Neuroimaging Laboratory at Geneva University Hospital and faculty member at the medical school of Geneva University. He is also a Professor of Medical Physics at the University of Groningen (Netherlands), Adjunct Professor of Medical Physics and Molecular Imaging at the University of Southern Denmark, and visiting Professor at IAS/University Cergy-Pontoise (France). He was guest editor for 10 special issues of peer-reviewed journals and serves on the editorial board of leading journals in medical physics and medical imaging. He has been elevated to the grade of IEEE fellow and was elected liaison representative of the *International Organization for Medical Physics (IOMP)* to the World Health Organization (WHO). His academic accomplishments in the area of quantitative PET imaging have been well recognized by his peers and by the medical imaging community at large since he is a recipient of many awards and distinctions among which the prestigious *2003 Young Investigator Medical Imaging Science Award* given by the *Nuclear Medical and Imaging Sciences Technical Committee of the IEEE*, the *2004 Mark Tetalman Memorial Award* given by the *Society of Nuclear Medicine*, the *2007 Young Scientist Prize in Biological Physics* given by the *International Union of Pure and Applied Physics (IUPAP)*, the prestigious (\$100 000) *2010 Kuwait Prize of Applied sciences* (known as the *Middle Eastern Nobel Prize*) given by the *Kuwait Foundation for the Advancement of Sciences (KFAS)*, the *2013 John S Laughlin Young Scientist Award* given by the *American Association of Physicists in Medicine (AAPM)*, the *2013 Vikram Sarabhai Oration Award* given by the *Society of Nuclear Medicine, India (SNMI)*, the *2015 Sir Godfrey Hounsfield Award* given by the *British Institute of Radiology (BIR)* and the *2017 IBA-Europhysics Prize* given by the *European Physical Society (EPS)*. Professor Zaidi has been an invited speaker of over 150 keynote lectures and talks at an international level, has authored over 250 peer-reviewed articles in prominent journals and is the Editor of four textbooks including this volume. Email: habib.zaidi@hcuge.ch; Web: <http://pinlab.hcuge.ch/>.

List of contributors

Tianwu Xie

Geneva University Hospital, Switzerland

Habib Zaidi

Geneva University Hospital, Switzerland

Paul Segars

Duke University, USA

Akram Mohammadi

National Institute of Radiological Sciences (NIRS), National Institutes for Quantum and Radiological Science and Technology, Japan

Mitra Safavi-Naeini

Australian Nuclear Science and Technology Organisation (ANSTO), Australia

Sakae Kinase

Japan Atomic Energy Agency (JAEA)/Ibaraki University, Japan

Qian Liu

Huazhong University of Science and Technology, China

Guozhi Zhang

University Hospitals Leuven, Belgium

José-María Gómez-Ros

Research Centre for Energy, Environment and Technology, Spain

Choonsik Lee

National Institutes of Health, USA

Kanako Wake

National Institute of Information and Communications Technology, Japan

Akimasa Hirata

Nagoya Institute of Technology, Japan

Kenji Taguchi

Kitami Institute of Technology, Japan

Pedro Arce

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Spain

Juan Ignacio Lagares

Medical Applications Unit, CIEMAT, Spain

Josep Sempau

Department of Physics, Universitat Politecnica de Catalunya, Spain

George Kagadis

University of Patras, Greece

Panagiotis Papadimitroulas

BioEmission Technology Solutions R&D Department, Greece

Niels Kuster

IT'IS Foundation and Swiss Federal Institute of Technology Zurich, Switzerland

Rameshwar Prasad

Rush University Medical Center, USA

M'hamed Bentourkia

Université de Sherbrooke, Canada

Mahdjoub Hamdi

University of Mostaganem, Algeria

Faiçal A Slimani

Université de Sherbrooke, Canada