

Thomas Bortfeld · Rupert Schmidt-Ullrich · Wilfried De Neve · David E. Wazer (Eds.)

Image-Guided IMRT

Thomas Bortfeld · Rupert Schmidt-Ullrich
Wilfried De Neve · David E. Wazer (Eds.)

Image-Guided IMRT

With 124 Figures, 96 in Color and 44 Tables

 Springer

Thomas Bortfeld
Dept. of Radiation Oncology
Massachusetts General Hospital
30 Fruit Street
Boston, MA 02114
USA

Rupert Schmidt-Ullrich
Dept. of Radiation Oncology
Virginia Commonwealth University
401 College Street
Richmond, VA 23298–0058
USA

Wilfried De Neve
Dept. of Radiotherapy
Ghent University Hospital
De Pintelaan 185
9000 Ghent
Belgium

David E. Wazer
Dept. of Radiation Oncology
Tufts University
750 Washington Street
Boston, MA 02111
USA

Library of Congress Control Number 2005925670

ISBN-10 3-540-20511-X Springer Berlin Heidelberg 2006
ISBN-13 978-3-540-20511-1 Springer Berlin Heidelberg 2006

This work is subject to copyright. All rights are reserved, 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 way and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

Springer-Verlag is a part of Springer Science+Business Media
springeronline.com
© Springer-Verlag Berlin Heidelberg 2006
Printed in Germany

The use of general descriptive names, registered names, trademarks, 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.

Product liability: the publishers cannot guarantee the accuracy of any information about dosage and application contained in this book. In every individual case the user must check such information by consulting the relevant literature.

Editor: Dr. Ute Heilmann
Desk Editor: Meike Stoeck
Production and Typesetting: LE-TeX Jelonek, Schmidt & Vöckler GbR, Leipzig
Cover: Frido Steinen-Broo, EStudio Calamar, Spain
Printing and binding: Stürtz, Würzburg

Printed on acid-free paper 21/3150/YL 5 4 3 2 1 0

Preface

Intensity-modulated radiotherapy (IMRT) has widened the horizons of radiation therapy due to its ability to conform radiation dose distributions to complex tumor target volumes while sparing nearby critical structures as much as physically possible. IMRT has also led to paradigm shifts in all elements of the chain of radiotherapy, from treatment prescription over treatment planning (“inverse” planning) to treatment delivery and verification. Although IMRT and inverse planning have the potential to streamline and simplify radiotherapy, at the current stage of the development IMRT is still significantly more involved than conventional radiotherapy.

This book is meant to help the reader understand the concepts and components of IMRT, to give a topical overview of advanced image-guided and biologically guided approaches, and to provide useful hints on how to master IMRT in clinical practice. Reading this text alone is not sufficient to start a clinical IMRT program. The book will rather provide up-to-date theoretical and practical information about IMRT that should be consulted in addition to other sources that are listed as references. We highlight not only the strengths of IMRT but discuss also the weaknesses, limitations, and unique challenges such as the prolonged treatment times and increased leakage radiation. All this, we hope, will be useful for clinicians and physicists who are interested in exploring the potential of IMRT, as well as a reference for those who already apply IMRT in clinical practice.

The book has been written by an international group of authors with an international readership in mind. Some IMRT aspects, such as quality assurance, have different flavors in different countries, because of national regulations and reimbursement issues. We tried to take this into account by covering the American and the European perspectives on quality assurance in two separate chapters. This also emphasizes the importance of the topic. The authors of all chapters are distinguished experts in their field and we are grateful that they devoted some of their precious time to the writing of their chapters.

The material has been organized into three major parts: (I) Foundations, (II) Advanced Image-Guided and Biologically Guided Techniques, and (III) Clinical Ap-

plications. Part I lays the foundation for state-of-the-art IMRT. As for image guidance (part II), it has been said that radiotherapy, and in particular IMRT, has always been image-guided and that the current hype about image guidance is not justified. While there is some truth to this statement, there have been recent developments in image-guided IMRT that deserve separate coverage. The developments with the biggest potential impact are probably the inclusion of functional imaging information into target segmentation and dose prescription, and the advancement of adaptive “4D” radiotherapy techniques, which incorporate temporal changes into the treatment scheme. These developments, which are currently being pursued at only a few centers, will most likely find their way into broader clinical application in the near future.

The Clinical Applications section (III) reviews the use of IMRT for individual anatomic sites and common clinical applications. Each chapter is presented in a similar format: Clinical problem – Potential benefits of IMRT – Unique challenges – Target and organ-at-risk definition – Planning – Delivery issues – Clinical studies and trials – Future directions. We have drawn upon experienced practitioners of IMRT to summarize the current literature as well as provide their personal insights as to how they approach the specifics of treatment planning and delivery including required imaging, anatomic segmentation, normal tissue dose-volume relationships, and target dose. The section is designed to provide detailed and practical information to the clinician and medical physicist as they implement IMRT under a broad set of clinical circumstances.

In closing, we must make special mention of our coeditor, Rupert K.A. Schmidt-Ullrich. Dr. Schmidt-Ullrich was one of the early pioneers in the development of IMRT and has fostered within his department at the Virginia Commonwealth University one of the most distinguished research programs in the world. His overriding passion in recent years was to produce a textbook for IMRT that would be broadly recognized for its comprehensiveness, quality, and readability. The effort, as reflected in these pages, is a testament to his vision, insight, and commitment to excellence. Sadly, Rupert will

not see his vision fulfilled as he died from metastatic colon cancer just weeks prior to the completion of this volume. It is nonetheless important to note that as a measure of both the strength of his spirit and his

commitment to this important task, he continued to actively work on completing this book until days before his death. As such, we respectfully dedicate this work to the memory of Rupert K.A. Schmidt-Ullrich.

Boston and Ghent
August 2005

*Thomas Bortfeld
Wilfried De Neve
David E. Wazer*

Contents

Part I Foundations

I.1 Rationale of Intensity Modulated Radiation Therapy: A Clinician's Point of View	3
Wilfried De Neve	
I.2 The Potential and Limitations of IMRT: A Physicist's Point of View	11
Radhe Mohan, Thomas Bortfeld	
I.3 Imaging for IMRT	19
Peter Remeijer, Marcel van Herk	
I.4 Physical Optimization	31
Uwe Oelfke, Simeon Nill, Jan J. Wilkens	
I.5 Practical IMRT Planning	47
Wilfried De Neve, Yan Wu, Gary Ezzell	
I.6 Dose Calculations for IMRT	61
Jeffrey V. Siebers	
I.7 IMRT Delivery Techniques	73
Steve Webb	
I.8 Biological Aspects of IMRT Planning and Delivery	91
Andrzej Niemierko	
I.9 Image Guided Patient Setup	97
Dirk Verellen	
I.10 QA-QC of IMRT: European Perspective	117
Carlos De Wagter	
I.11 QA-QC of IMRT: American Perspective	129
Jean M. Moran, Ping Xia	

Part II Advanced Image-Guided and Biologically Guided Techniques

II.1 Imaging Lymph Nodes Using CT and MRI, Imaging Cancer by PET	145
Thierry P. Duprez, Emmanuel E. Coche, Max Lonneux	
II.2 PET and SPECT in IMRT: Future Prospects	171
Christophe Van de Wiele	
II.3 Magnetic Resonance Imaging for IMRT	177
Lynn J. Verhey, Cynthia Chuang, Andrea Pirzkall	
II.4 Molecular/Functional Image-guided Intensity Modulated Radiation Therapy	187
Lei Xing, Yong Yang, Daniel M. Spielman	
II.5 Biological Optimization	199
Andrzej Niemierko	
II.6 Advanced Imaging and Guidance System for Use in Intensity Modulated RT	217
David A. Jaffray, Kristy K. Brock, Michael B. Sharpe	
II.7 External Beam Adaptive Radiation Therapy (ART) on a Conventional Medical Accelerator	229
John Wong, Di Yan, David Lockman, Don Brabbins, Frank A. Vicini, Alvaro Martinez	
II.8 Adaptive Radiation Therapy (ART) Strategies Using Helical Tomotherapy	235
Gustavo Hugo Olivera, Thomas Rockwell Mackie, Kenneth Ruchala, Weiguo Lu, Jeffrey Kapatoes	
II.9 4D CT Simulation	247
George T.Y. Chen, Eike R.M. Rietzel	

II.10 4D Treatment Planning	259	III.6 IMRT Lung.	359
Paul J. Keall		Kenneth E. Rosenzweig	
II.11 "4D" IMRT Delivery	269	III.7 Breast IMRT	371
Gig S. Mageras, Ellen Yorke, Steve B. Jiang		Douglas W. Arthur, Monica M. Morris, Frank A. Vicini, Nesrin Dogan	
Part III Clinical			
III.1 IMRT for Paranasal Sinus and Nasal Cavity (Sino-Nasal) Tumors	289	III.8 IMRT for Malignancies of the Upper Abdomen and Retroperitoneum	383
Wim Duthoy, Wilfried De Neve		Jerome C. Landry, Christopher G. Willett, Natia Esiashvili, Mary Koshy	
III.2 IMRT for Carcinomas of the Oropharynx and Oral Cavity.	301	III.9 Prostate IMRT.	391
Rupert Schmidt-Ullrich, David Buck, Nesrin Dogan, Jeffrey Siebers, Monica Morris, Yan Wu		Mark K. Buyyounouski, Eric M. Horwitz, Robert A. Price Jr, Steve J. Feigenberg, Alan Pollack	
III.3 IMRT for Carcinomas of the Nasopharynx	319	III.10 Intensity-modulated Radiation Therapy for Carcinomas of the Uterine Cervix and Endometrium	411
Benjamin D. Rosenbluth, William W. Chou, Nancy Y. Lee		Patricia J. Eifel	
III.4 Intensity Modulated Radiotherapy in Cancer of the Larynx.	335	III.11 Integration of IMRT and Brachytherapy.	423
Maria T. Guerrero Urbano, Catherine H. Clark, Margaret Bidmead, David P. Dearnaley, Kevin J. Harrington, Christopher M. Nutting		Jeffrey F. Williamson	
III.5 Central Nervous System, Skull Base and Paraspinal Tumors.	345	III.12 High Precision and Unconventional Fractionation IMRT.	439
Anita Mahajan, Eric L. Chang		Stanley H. Benedict, John Purviance, Danny Song, David E. Wazer	
		Subject Index	455

List of Contributors

Douglas W. Arthur

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Stanley H. Benedict

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Margaret Bidmead

Head and Neck Unit
Royal Marsden Hospital and
Institute of Cancer Research
London, UK

Thomas Bortfeld

Dept. of Radiation Oncology
Massachusetts General Hospital
Boston, USA

Don Brabbins

Dept. of Radiation Oncology
William Beaumont Hospital
Royal Oak, USA

Kristy K. Brock

Radiation Physics
Princess Margaret Hospital
Toronto, Canada

David Buck

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Mark K. Buyyounouski

Dept. of Radiation Oncology
Fox Chase Cancer Center
Philadelphia, USA

Eric L. Chang

Dept. of Radiation Oncology
MD Anderson Cancer Center
Houston, USA

George T.Y. Chen

Dept. of Radiation Oncology
Massachusetts General Hospital
Boston, USA

William W. Chou

Dept. of Radiation Oncology
Memorial Sloan-Kettering Cancer Center
New York, USA

Cynthia Chuan

Dept. of Radiation Oncology
University of California at San Francisco
San Francisco, USA

Catherine H. Clark

Head and Neck Unit
Royal Marsden Hospital and
Institute of Cancer Research
London, UK

Emmanuel E. Coche

Cliniques Universitaires Saint-Luc
Université Catholique de Louvain
Brussels, Belgium

Wilfried De Neve

Dept. of Radiotherapy
Ghent University Hospital
Ghent, Belgium

Carlos De Wagter

Dept. of Radiotherapy
Ghent University Hospital
Ghent, Belgium

David P. Dearnaley

Head and Neck Unit
Royal Marsden Hospital
and Institute of Cancer Research
London, UK

Nesrin Dogan

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Thierry P. Duprez

Cliniques Universitaires Saint-Luc
Université Catholique de Louvain
Brussels, Belgium

Wim Duthoy

Dept. of Radiotherapy
Ghent University Hospital
Ghent, Belgium

Patricia J. Eifel

Dept. of Radiation Oncology
M.D. Anderson Cancer Center
Houston, USA

Natia Esiashvili

Dept. of Radiation Oncology
Emory University and Clinic
Atlanta, USA

Gary Ezzell

Dept. of Radiation Oncology
Mayo Clinic Scottsdale
Scottsdale, USA

Steve J. Feigenberg

Department of Radiation Oncology
Fox Chase Cancer Center
Philadelphia, USA

Maria T. Guerrero Urbano

Head and Neck Unit
Royal Marsden Hospital and
Institute of Cancer Research
London, UK

Kevin J. Harrington

Head and Neck Unit
Royal Marsden Hospital and
Institute of Cancer Research
London, UK

Eric M. Horwitz

Department of Radiation Oncology
Fox Chase Cancer Center
Philadelphia, USA

David A. Jaffray

Radiation Physics
Princess Margaret Hospital
Toronto, Canada

Steve B. Jiang

Dept. of Radiation Oncology
Massachusetts General Hospital
Boston, USA

Jeffrey Kapatoes

TomoTherapy
Madison, USA

Paul J. Keall

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Mary Koshy

Dept. of Radiation Oncology
Emory University and Clinic
Atlanta, USA

Jerome C. Landry

Dept. of Radiation Oncology
Emory University and Clinic
Atlanta, USA

Nancy Y. Lee

Dept. of Radiation Oncology
Memorial Sloan-Kettering Cancer Center
New York, USA

David Lockman

Dept. of Radiation Oncology
William Beaumont Hospital
Royal Oak, USA

Max Lonneux

Cliniques Universitaires Saint-Luc
Université Catholique de Louvain
Brussels, Belgium

Weiguo Lu

TomoTherapy
Madison, USA

Gig S. Mageras

Dept. of Medical Physics
Memorial Sloan-Kettering Cancer Center
New York, USA

Anita Mahajan

Dept. of Radiation Oncology
MD Anderson Cancer Center
Houston, USA

Alvaro Martinez

Dept. of Radiation Oncology
William Beaumont Hospital
Royal Oak, USA

Radhe Mohan

MD Anderson Cancer Center
University of Texas
Houston, USA

Jean M. Moran

Dept. of Radiation Oncology
University of Michigan Medical Center
Ann Arbor, USA

Monica Morris

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Andrzej Niemierko

Dept. of Radiation Oncology
Massachusetts General Hospital
Boston, USA

Simeon Nill

Dept. of Medical Physics
DKFZ Heidelberg
Heidelberg, Germany

Christopher M. Nutting

Head and Neck Unit
Royal Marsden Hospital and
Institute of Cancer Research
London, UK

Uwe Oelfke

Dept. of Medical Physics
DKFZ Heidelberg
Heidelberg, Germany

Gustavo Hugo Olivera

TomoTherapy
Madison, USA

Andrea Pirzkal

Dept. of Radiation Oncology
University of California at San Francisco
San Francisco, USA

Alan Pollack

Department of Radiation Oncology
Fox Chase Cancer Center
Philadelphia, USA

Robert A. Price Jr.

Department of Radiation Oncology
Fox Chase Cancer Center
Philadelphia, USA

John Purviance

Dept. of Radiation Oncology
Tufts University
Boston, USA

Peter Remeijer

The Netherlands Cancer Institute
Antoni van Leeuwenhoek Ziekenhuis
Amsterdam, The Netherlands

Eike R.M. Rietzel

Dept. of Radiation Oncology
Massachusetts General Hospital
Boston, USA

Thomas Rockwell Mackie

Medical Radiation Research Center
Madison, USA

Benjamin D. Rosenbluth

Dept. of Radiation Oncology
Memorial Sloan-Kettering Cancer Center
New York, USA

Kenneth E. Rosenzweig

Dept. of Radiation Oncology
Memorial Sloan-Kettering Cancer Center
New York, USA

Kenneth Ruchala

TomoTherapy
Madison, USA

Rupert Schmidt-Ullrich

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Michael B. Sharpe

Radiation Physics
Princess Margaret Hospital
Toronto, Canada

Jeffrey V. Siebers

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Danny Song

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Daniel M. Spielman

Dept. of Radiology, Stanford University
School of Medicine
Stanford, USA

Christophe Van de Wiele

Dept. of Nuclear Medicine
University Hospital Ghent
Ghent, Belgium

Marcel van Herk

The Netherlands Cancer Institute
Antoni van Leeuwenhoek Ziekenhuis
Amsterdam, The Netherlands

Dirk Verellen

Dept. of Radiotherapy
AZ-VUB
Brussels, Belgium

Lynn J. Verhey

Dept. of Radiation Oncology
University of California at San Francisco
San Francisco, USA

Frank A. Vicini

Dept. of Radiation Oncology
William Beaumont Hospital
Royal Oak, USA

David E. Wazer

Dept. of Radiation Oncology
Tufts University
Boston, USA

Steve Webb

Joint Dept. of Physics
Institute of Cancer Research
And Royal Marsden NHS Trust
Sutton, UK

Jan J. Wilkens

Dept. of Medical Physics
DKFZ Heidelberg
Heidelberg, Germany

Christopher G. Willett

Dept. of Radiation Oncology
Duke University
Durham, USA

Jeffrey F. Williamson

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

John Wong

Dept. of Radiation Oncology
Johns Hopkins University
Baltimore, USA

Yan Wu

Dept. of Radiation Oncology
Virginia Commonwealth University
Richmond, USA

Ping Xia

Dept. of Radiation Oncology
University of California at San Francisco
San Francisco, USA

Lei Xing

Dept. of Radiation Oncology
Stanford University
School of Medicine
Stanford, USA

Di Yan

Dept. of Radiation Oncology
William Beaumont Hospital
Royal Oak, USA

Yong Yang

Dept. of Radiation Oncology
Stanford University
School of Medicine
Stanford, USA

Ellen Yorke

Dept. of Medical Physics
Memorial Sloan-Kettering Cancer Center
New York, USA