

Advances in Image-Guided Urologic Surgery

Joseph C. Liao
Li-Ming Su
Editors

 Springer

Advances in Image-Guided Urologic Surgery

Joseph C. Liao • Li-Ming Su
Editors

Advances
in Image-Guided
Urologic Surgery

 Springer

Editors

Joseph C. Liao, MD
Department of Urology
Stanford University School of Medicine
Stanford, CA
USA

Li-Ming Su, MD
Department of Urology
University of Florida College of
Medicine
Gainesville, FL
USA

ISBN 978-1-4939-1449-4 ISBN 978-1-4939-1450-0 (eBook)
DOI 10.1007/978-1-4939-1450-0
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2014950792

© Springer Science+Business Media New York 2015

This work is subject to copyright. All rights are reserved 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. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

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.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

In loving memory of my father Lienjin, who taught me audacity
Joseph C. Liao

Preface

Advances in imaging technologies have been a key source of innovation in modern medicine and surgery. In the preoperative setting, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (US) play indispensable roles in clinical diagnosis and surgical planning. Modern endoscopy and minimally invasive surgery can trace their foundation to the invention of *Lichtleiter* by Bozzini in 1806 and the first laparoscopic procedures a century later. In urological surgery and beyond, patients and their surgeons today strive for precise surgical treatments in the least invasive manner while minimizing collateral damage to surrounding organs.

Advances in Image-Guided Urologic Surgery is a compendium of the emerging field of image-guided surgery and intervention in urology. The book is divided into four sections. The first section focuses on optical imaging technologies including wide-field fluorescence, optical coherence tomography, and endomicroscopy. The second section addresses the current applications of intraoperative ultrasound. The third section focuses on the integration of CT- and MRI-guided surgical interventions, particularly for prostate and kidney cancer. The fourth section introduces other emerging applications including augmented reality, simulators, and molecular imaging.

The intended audience of this book includes urological surgeons and trainees, biomedical engineers, and imaging scientists interested in technology translation. We are grateful for the contribution of a group of international experts who are among the foremost leaders in this emerging field. Ultimately, we share the common goal that by being able to “see” better, we will deliver better surgical outcomes for our patients.

Stanford, CA, USA
Gainesville, FL, USA

Joseph C. Liao, MD
Li-Ming Su, MD

Acknowledgments

We are indebted to our families for their love and support. We thank our mentors and students for their inspiration. We are grateful to the many authors for their time and dedication in the preparation of their chapters. A special acknowledgment goes to Margaret Burns at Springer for her expert assistance in making this book a reality.

Contents

Part I Optical Imaging Technologies

1 Endoscopic Fluorescence Imaging of Bladder Cancer: Photodynamic Diagnosis and Confocal Laser Endomicroscopy	3
Mark Hsu and Joseph C. Liao	
2 Narrow Band Imaging for Urothelial Cancer	11
Harry W. Herr	
3 Optical Coherence Tomography in Bladder Cancer	21
M.T.J. Bus, D.M. de Bruin, Th.M. de Reijke, and J.J.M.C.H. de la Rosette	
4 Optical Coherence Tomography for Prostate Cancer and Beyond	33
Mohit Gupta and Li-Ming Su	
5 Fluorescence Image-Guided Robotic Surgery	41
Guan Wu	
6 Multiphoton Microscopy in Urologic Surgery	59
Sushmita Mukherjee, Manu Jain, and Douglas S. Scherr	
7 Hyperspectral Imaging of Renal Oxygenation (Near-Infrared Tissue Oximetry for Renal Ischemia)	75
Janet Laura Colli and Benjamin R. Lee	
8 Light Reflectance Spectroscopy and Autofluorescence (Kidney and Prostate)	79
Ephrem O. Olweny and Jeffrey A. Cadeddu	

Part II Ultrasound-Guided Interventions

9 Intraoperative Doppler Ultrasound During Robotic Surgery	91
Ahmet Gudeloglu, Jamin V. Brahmbhatt, Annika Mulaney, and Sijo Parekattil	
10 TRUS of the Prostate: State of the Art	103
Osamu Ukimura, Toru Matsugasumi, and Sunao Shoji	

11	Ultrasound-Guided Prostate Cryotherapy	111
	Kathleen F. McGinley, Bryce W. Polascik, and Thomas J. Polascik	
12	Endoluminal Ultrasonography	131
	Sima Porten, Raghu Vikram, and Surena F. Matin	
Part III Cross-Sectional Image-Guided Interventions		
13	Multiparametric Magnetic Resonance Imaging for Prostate Cancer	141
	Geoffrey A. Sonn, Daniel J.A. Margolis, and Katherine J. To'o	
14	MR-Guided Prostate Interventions	167
	Ashley E. Ross, Dan Stoianovici, and Mohamad E. Allaf	
15	CT-Guided Renal Ablation	175
	Michael J. Glamore, Raymond J. Leveillee, and Thomas Scagnelli	
16	MR-Guided Renal Ablation	185
	Michael Ordon, Laura Findeiss, and Jaime Landman	
Part IV On the Horizon		
17	Augmented Reality for Percutaneous Renal Interventions . . .	203
	Jens Rassweiler, Marie-Claire Rassweiler, Michael Müller, Estevao Lima, Bogdan Petrut, Johannes Huber, Jan Klein, Manuel Ritter, Ali S. Gözen, Phillipe Pereira, Axel Häcker, Hans-Peter Meinzer, Ingmar Wegner, and Dogu Teber	
18	Image Guidance in Robotic-Assisted Renal Surgery	221
	S. Duke Herrell, Robert L. Galloway Jr., and Michael I. Miga	
19	Urologic Surgery Training Using Computer-Assisted Simulators	243
	Jason Cheng-En Sea and Chandru P. Sundaram	
20	Molecular Imaging in Urology	265
	Ying Pan, Mark Hsu, and Joseph C. Liao	
	Index	281

Contributors

Mohamad E. Allaf, MD Departments of Urology, Oncology, and Biomedical Engineering, Johns Hopkins Brady Urological Institute, Baltimore, MD, USA

Jamin V. Brahmhatt, MD Department of Urology, The PUR Clinic, South Lake Hospital in Partnership with Orlando Health, Clermont, FL, USA

M.T.J. Bus, MD, MSc Department of Urology, Academic Medical Center Amsterdam, Amsterdam, The Netherlands

Jeffrey A. Cadeddu, MD Department of Urology, UT Southwestern Medical Center, Dallas, TX, USA

Janet Laura Colli, MD Department of Urology, University of Tennessee, Memphis, TN, USA

D.M. de Bruin, MSc Department of Urology, Academic Medical Center Amsterdam, Amsterdam, The Netherlands

Department of Biomedical Engineering & Physics, Academic Medical Center Amsterdam, Amsterdam, The Netherlands

J.J.M.C.H. de la Rosette, MD, PhD Department of Urology, Academic Medical Center Amsterdam, Amsterdam, The Netherlands

Th.M. de Reijke, MD, PhD Department of Urology, Academic Medical Center Amsterdam, Amsterdam, The Netherlands

Laura Findeiss, MD, FSIR, FAHA Department of Radiology, University of Tennessee Graduate School of Medicine, Nashville, TN, USA

Robert L. Galloway Jr., PhD Department of Urologic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA
Department of Neurosurgery, Vanderbilt University Medical Center, Nashville, TN, USA

Department of Biomedical Engineering, Vanderbilt University Medical Center, Nashville, TN, USA

Michael J. Glamore, MD Herbert Wertheim College of Medicine, Florida International University, University Park, FL, USA

Ali S. Gözen, MD Department of Urology, SLK Kliniken Heilbronn, University of Heidelberg, Heidelberg, Germany

Ahmet Gudeloglu, MD Department of Urology, The PUR Clinic, South Lake Hospital in Partnership with Orlando Health, Clermont, FL, USA

Mohit Gupta, MD Department of Urology, University of Florida College of Medicine, Gainesville, FL, USA

Axel Häcker, MD Department of Urology, Medical School Mannheim, University of Heidelberg, Heidelberg, Germany

Harry W. Herr, MD, FACS Department of Urology, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

S. Duke Herrell, MD, FACS Department of Urologic Surgery, Vanderbilt University, Nashville, TN, USA

Department of Biomedical Engineering, Vanderbilt University, Nashville, TN, USA

Mark Hsu, MD Department of Urology, Stanford University School of Medicine, Stanford, CA, USA

Johannes Huber, MD Department of Urology, Medical School, Technical University of Dresden, Dresden, Germany

Manu Jain, MD Department of Pathology and Laboratory Medicine, Weill Medical College of Cornell University, New York, NY, USA

Jan Klein, MD Department of Urology, SLK Kliniken Heilbronn, University of Heidelberg, Heidelberg, Germany

Jaime Landman, MD Department of Urology, University of California Irvine, Orange, CA, USA

Benjamin R. Lee, MD Departments of Urology and Oncology, Tulane University School of Medicine, New Orleans, LA, USA

Raymond J. Leveillee, MD, FRCS-G Department of Urology, University of Miami Miller School of Medicine, Miami, FL, USA

Joseph C. Liao, MD Department of Urology, Stanford University School of Medicine, Stanford, CA, USA

VA Palo Alto Health Care System, Palo Alto, CA, USA

Estevao Lima, MD Department of Urology, Medical School Braga, University of Braga, Braga, Portugal

Daniel J.A. Margolis, MD Department of Radiological Sciences, UCLA Geffen School of Medicine, Los Angeles, CA, USA

Surena F. Matin, MD Department of Urology, The University of Texas MD Anderson Cancer Center, Houston, TX, USA

Toru Matsugasumi, MD Department of Urology, Norris Cancer Center, University of Southern California, Los Angeles, CA, USA

Kathleen F. McGinley, DO Division of Urology, Department of Surgery, Duke University Medical Center, Durham, NC, USA

Hans-Peter Meinzer, PhD Division of Medical and Biological Informatics, German Cancer Research Center, Heidelberg, Germany

Michael I. Miga, PhD Departments of Neurological Surgery, Vanderbilt University, Nashville, TN, USA

Departments of Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, USA

Departments of Biomedical Engineering, Vanderbilt University, Nashville, TN, USA

Sushmita Mukherjee, PhD, MS Department of Biochemistry, Weill Medical College of Cornell University, New York, NY, USA

Annika Mulaney Intern, The PUR Clinic, South Lake Hospital in Partnership with Orlando Health, Clermont, FL, USA

Michael Müller, PhD Division of Medical and Biological Informatics, German Cancer Research Center, Heidelberg, Germany

Ephrem O. Olweny, MD Department of Urology, University of Texas Southwestern Medical Center, Dallas, TX, USA

Michael Ordon, MD, MSc, FRCSC Division of Urology, Department of Surgery, University of California, Irvine, CA, USA

Ying Pan, PhD Department of Urology, Stanford University School of Medicine, Stanford, CA, USA

Sijo J. Parekattil, MD Department of Urology, The PUR Clinic, South Lake Hospital in Partnership with Orlando Health, Clermont, FL, USA

Phillipe Pereira, MD Department of Radiology, SLK Kliniken Heilbronn, University of Heidelberg, Heidelberg, Germany

Bogdan Petrut, MD Department of Urology and Oncology, Medical School Cluj, University of Cluj, Cluj-Napoca, Romania

Bryce W. Polascik Division of Urology, Department of Surgery, Duke University Medical Center, Durham, NC, USA

Thomas J. Polascik, MD, FACS Division of Urology, Department of Surgery, Duke University Medical Center, Durham, NC, USA

Sima Porten, MD, MPH Department of Urology, The University of Texas MD Anderson Cancer Center, Houston, TX, USA

Jens Rassweiler, MD Department of Urology, SLK Klinikum Heilbronn, Heilbronn, Germany

Marie-Claire Rassweiler, MD Department of Urology,
Medical School Mannheim, University of Heidelberg, Heidelberg, Germany

Manuel Ritter, MD Department of Urology, Medical School Mannheim,
University of Heidelberg, Heidelberg, Germany

Ashley E. Ross, MD, PhD Departments of Urology, Oncology, Pathology,
Johns Hopkins Brady Urological Institute, Baltimore, MD, USA

Thomas Scagnelli, MD, FSIR Department of Interventional Radiology,
Baptist Cardiac and Vascular Institute, Doctor's Hospital, Miami, FL, USA

Douglas S. Scherr, MD Department of Urology, Weill Medical College
of Cornell University, New York, NY, USA

Jason Cheng-En Sea, MD Department of Urology,
Indiana University, Indianapolis, IN, USA

Sunao Shoji, MD, PhD Department of Urology,
Tokai University Hachioji Hospital, Hachioji, Japan

Geoffrey A. Sonn, MD Department of Urology,
Stanford University School of Medicine, Stanford, CA, USA

Dan Stoianovici, PhD Departments of Urology, Mechanical Engineering,
and Neurosurgery, Johns Hopkins Brady Urological Institute,
Baltimore, MD, USA

Li-Ming Su, MD Division of Robotic and Minimally Invasive Urologic
Surgery, Department of Urology, University of Florida
College of Medicine, Gainesville, FL, USA

Chandru P. Sundaram, MD Department of Urology,
Indiana University, Indianapolis, IN, USA

Dogu Teber, MD Department of Urology, Medical School Heidelberg,
University of Heidelberg, Heidelberg, Germany

Katherine J. To'o, MD Department of Radiology,
VA Palo Alto Health Care System, Palo Alto, CA, USA
Department of Radiology, Stanford University School of Medicine,
Stanford, CA, USA

Osamu Ukimura, MD, PhD Department of Urology, Norris Cancer
Center, Keck School of Medicine, University of Southern California,
Los Angeles, CA, USA

Raghu Vikram, MD Department of Diagnostic Radiology,
The University of Texas MD Anderson Cancer Center, Houston, TX, USA

Guan Wu, MD, PhD Departments of Urology, Pathology, and Oncology,
University of Rochester Medical Center, Rochester, NY, USA

Ingmar Wegner, PhD Division of Medical and Biological Informatics,
German Cancer Research Center, Heidelberg, Germany

Part I

Optical Imaging Technologies

Endoscopic Fluorescence Imaging of Bladder Cancer: Photodynamic Diagnosis and Confocal Laser Endomicroscopy

1

Mark Hsu and Joseph C. Liao

Bladder cancer is the second most common genitourinary cancer and the fifth most common cancer overall in the United States. In 2014, there are projected 72,570 new cases and 15,210 cancer-related deaths [1]. Modern white-light cystoscopy (WLC), the standard approach to evaluate the lower urinary tract and manage non-muscle-invasive bladder cancer (NMIBC), has been the result of sequential landmark innovations over the last two centuries [2]. Despite significant advances, WLC and WL-guided transurethral resection (TUR) have numerous limitations that can affect accurate detection and staging of bladder cancer, including differentiation of nonpapillary urothelial carcinoma from inflammatory lesions and delineation of tumor borders [3]. While histology is the standard for definitive cancer diagnosis, it is not available intraoperatively in real time to guide surgical intervention. The inherent subjective nature and operator dependence of WLC can lead to incomplete resection, thereby increasing the risk of tumor persistence, recurrence, and progression [4]. Thus, there has

been great interest in developing optical imaging technologies that can enhance the diagnostic accuracy of WLC, improve completeness of TUR, and thereby improve surgical and cancer outcomes.

Fluorescence imaging that utilizes exogenous contrast agents is emerging as a useful adjunct for intraoperative guidance across different surgical disciplines, including urology [5]. With ease of access, the bladder is a well-suited target organ amenable to intraoperative fluorescence imaging. Imaging strategies typically combine a fluorescence illumination source in combination with exogenous contrast agents. Currently, three fluorescent contrast agents are approved for clinical use: protoporphyrin IX precursor hexaminolevulinate (HAL), fluorescein, and indocyanine green (ICG). This chapter focuses on the approved endoscopic fluorescence imaging technologies for bladder cancer: photodynamic diagnosis (PDD) and confocal laser endomicroscopy (CLE). Considerations including optical specifications, ease of OR integration, available clinical evidence, and suggested future directions will be highlighted.

M. Hsu, MD
Department of Urology, Stanford University
School of Medicine, Stanford, CA, USA
e-mail: markhsu@stanford.edu

J.C. Liao, MD (✉)
Department of Urology, Stanford University
School of Medicine, Stanford, CA, USA

VA Palo Alto Health Care System,
Palo Alto, CA, USA
e-mail: jliao@stanford.edu

Photodynamic Diagnosis

PDD provides wide-field fluorescence imaging of the bladder mucosa with a field of view comparable to WLC (i.e., ~cm). Also known as fluorescence cystoscopy or blue-light cystoscopy,

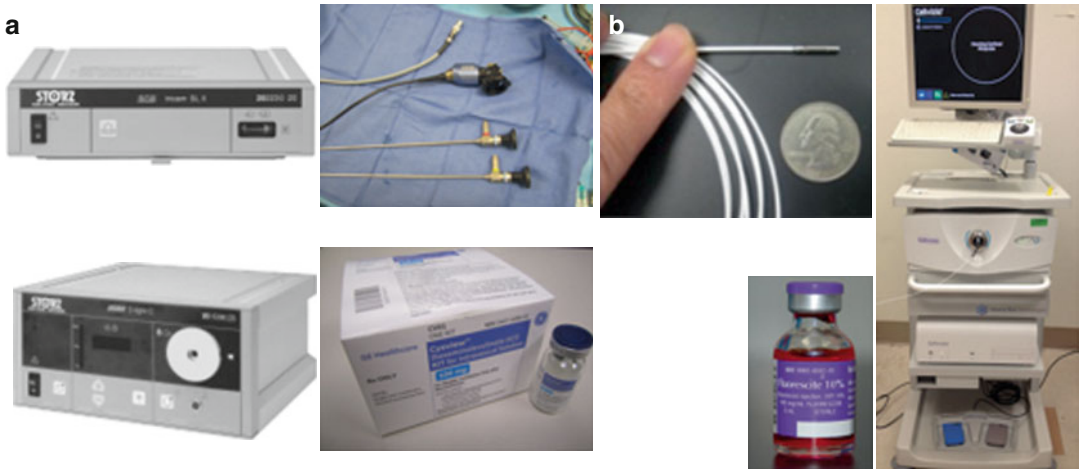
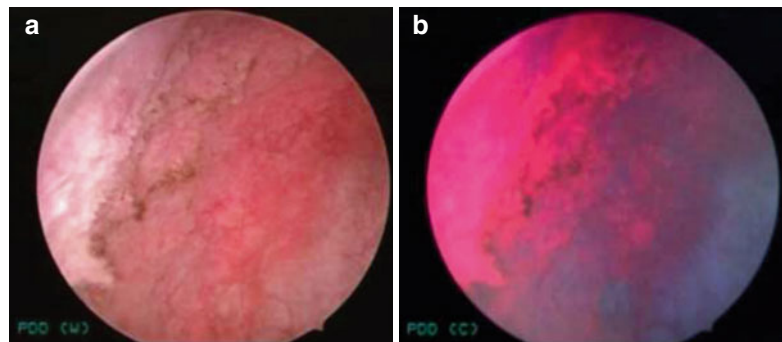


Fig. 1.1 Endoscopic fluorescence imaging systems for bladder cancer. **(a)** Photodynamic diagnosis (PDD) composed of a blue-light source, specialized camera head and lens, and hexaminolevulinate as the contrast agent.

(b) Confocal laser endomicroscopy (CLE) composed of a 2.6-mm fiberoptic imaging probe, fluorescein as the contrast agent, and the laser scanning unit

Fig. 1.2 PDD of bladder cancer. **(a)** White-light image of a large flat lesion at the right bladder wall showing indistinct borders and **(b)** the corresponding PDD image. The region was confirmed to be carcinoma in situ (CIS) (From Hsu et al. [27], with permission)



PDD uses photosensitive protoporphyrin IX precursor as the contrast agent, a blue-light source that illuminates at 375–440 nm, and a specialized lens and camera (Fig. 1.1a). The protoporphyrin, introduced intravesically, accumulates preferentially in neoplastic tissues and emits red fluorescence under blue light (Fig. 1.2). In the bladder, two protoporphyrin analogues, 5-aminolevulinic acid (5-ALA) and hexaminolevulinate (HAL), have been investigated. HAL is the more potent lipophilic ester analogue of 5-ALA and is approved for clinical use in Europe and the United States for patients with suspicion for or known bladder cancer. Due to increased potential for increased false positives, it is currently approved for single administration after 90 days

following intravesical bacillus Calmette-Guerin (BCG).

Integration in the OR environment is overall straightforward. HAL is solubilized and instilled intravesically by either the surgical team or nursing staff via a catheter 1–3 h prior to cystoscopy and TUR. Fluorescence imaging is switched on and off dynamically through the press of a button on the camera head. Fluorescence imaging is used for generalized survey of the urothelium as well as in conjunction with standard TUR, with improved contrast-enhanced visualization of both papillary and flat (i.e., carcinoma in situ, CIS) lesions.

In diagnostic cystoscopy, PDD is reported to have a sensitivity and specificity ranging from 87