Surgical Robotics
Surgical Robotics

Systems Applications and Visions

Springer
The dictum *Primum non nocere* (First, do no harm) and the dictum “Primum Succurrere” (First, hasten to help) as the prime directives of ethics in medicine may dictate two orthogonal approaches of practicing medicine, both of which are aimed to provide the best health care to the patient. The conservative approach relies on decades of evidence-based practice and clinical experience with a specific medical or surgical approach. However, every now and then, a scientific, technological, or clinical breakthrough occurs (alone or in combination) which leads to a paradigm shift along with disruptive new approach to health care. To some extent, this progressive approach is regulated by rigorous clinical trials as dictated by the Federal and Drug Administration (FDA) aimed at demonstration of safety and effectiveness. Although the progressive treatment approach results in a relatively high risk, there is a concomitant high reward in terms of healing and regaining a high quality of life.

Surgical robotics is a recent and very significant breakthrough in surgery. The introduction of a surgical robot into the operating room (OR) combines a technological breakthrough with a clinical breakthrough in developing new surgical techniques and approaches to improve the quality and outcome of surgery. As significant as these breakthroughs are, it is not surprising that they occurred because they are based on more than a decade of innovation in field of robotics in both academia and industry. The promise of surgical robotics is to deliver high levels of dexterity and vision to anatomical structures that cannot be approached by the surgeon’s fingers and viewed directly by the surgeon’s eyes. Making this technology available to surgeons has led to new surgical techniques that could not be accomplished previously. It is likely that clinical knowledge accumulated using these new systems or even by simply realizing their capabilities will lead to the development of new surgical robotic systems in the future. The surgical robot and various imaging modalities may be viewed as mediators between the surgeon’s hands and eyes and the surgical site, respectively; however, these two elements are part of a larger information system that will continue to evolve and affect every aspect of surgery and healthcare in general. Archived medical history, preoperative
scans, preplanning, quantitative recording of the surgical execution, follow-up and outcome assessment are all part of feed forward and feedback mechanisms that will improve the quality of healthcare.

As product of a rapidly evolving research field, this assembly of monographs aimed to capture a wide spectrum of topics spanning from ambitious visions for the future down to today’s clinical practice. The book is divided into four sections:

1. **The vision and overviews section** reviews the field from the civilian and military perspectives. It includes chapters discussing the Trauma Pod concept – a vision of an OR without humans. The importance of the trauma pod project was that it demonstrated the capability of automating all the services in the OR – services that are currently provided today by a scrub nurse and a circulation nurse that have been demonstrated to be translates to services by a robotic cell – robotic arms and information systems. Whether this concept of automation will be extended into clinical practice and thereby emphasizing even more the role of a surgeon as a decision maker while the operation is executed by the surgical robot automatically is yet to be seen.

2. **The systems section** is divided into two subsections including chapters describing key efforts in systems development and integration of macro- (first section) and micro- (second section) surgical robots in both academia and industry. Developing a macro-surgical robotic system is challenging in part due to the difficulties in translating qualitative clinical requirements into quantitative engineering specifications. Moreover, a successful system development as a whole is often a result of multidisciplinary and interdisciplinary efforts including all the subdisciplines of engineering and surgery – efforts that should not be taken lightly. In addition to challenges of macro-systems development, developing surgical robotics on a micro-system level introduces a significant reduction in scale. Forces, torques, pressures, and stresses do not scale down linearly with the geometrical dimensions. These interesting scaling properties challenge many engineering and surgical concepts. Inspired by the film “Fantastic Voyage,” the promise of a micro-robotic system is the capability to travel in the human body and provide local treatment. This concept is still in its infancy, and the academic research currently conducted in this field is focused on fundamental aspects of the system such as propulsion, navigation, energy source, manipulation, and control.

3. **The engineering developments section** covers technologies, algorithms, and experimental data to enhance and improve the current capabilities of surgical robotics. Topics of chapters in this section include tactile and force feedback, motion tracking, needle steering, soft tissue biomechanics of internal organs, and objective assessment of surgical skill. All of these will be incorporated into different layers of the surgical robotic systems in the future and will eventually put a superior robotic system in the hands of the surgeon for improving the outcome.

4. **The clinical applications section** includes chapters authored by surgeons who use surgical robotic systems clinically and describe the current clinical
applications of surgical robotics in several subdisciplines of surgery including urology, cardiology, neurosurgery, pediatric surgery gynecology, and general surgery as well as telesurgery. Most of these chapters also provide some thoughts about future applications of surgical robots in surgery. The generic nature of the surgical robotic system allows the surgeon to explore many surgical procedures that were not targeted by the robot’s original developers. Moreover, today’s growing vast array of clinical applications of surgical robotics demonstrates that the clinical community can adopt new surgical approaches once a capable tool such as a robot is made available.

Jacob Rosen
Blake Hannaford
Richard M. Satava
Contents

Part I  Visions and Overviews

1  Future Directions in Robotic Surgery ........................................ 3
   Richard M. Satava

2  Military Robotic Combat Casualty Extraction and Care .............. 13
   Andrew C. Yoo, Gary R. Gilbert, and Timothy J. Broderick

3  Telemedicine for the Battlefield: Present
   and Future Technologies .................................................. 33
   Pablo Garcia

4  Overcoming Barriers to Wider Adoption of Mobile
   Telerobotic Surgery: Engineering, Clinical
   and Business Challenges ................................................ 69
   Charles R. Doarn and Gerald R. Moses

Part II  Systems

5  Accurate Positioning for Intervention on the Beating
   Heart Using a Crawling Robot ........................................... 105
   Nicholas A. Patronik, Takeyoshi Ota, Marco A. Zenati,
   and Cameron N. Riviere

6  Miniature In Vivo Robots for NOTES ......................................... 123
   Shane M. Farritor, Amy C. Lehman, and Dmitry Oleynikov

7  A Compact, Simple, and Robust Teleoperated
   Robotic Surgery System .................................................. 139
   Ji Ma and Peter Berkelman
8 Raven: Developing a Surgical Robot from a Concept to a Transatlantic Teleoperation Experiment ...................... 159
Jacob Rosen, Mitchell Lum, Mika Sinanan, and Blake Hannaford

9 The da Vinci Surgical System .............................................. 199
Simon DiMaio, Mike Hanuschik, and Usha Kreaden

10 RIO: Robotic-Arm Interactive Orthopedic System
MAKOplasty: User Interactive Haptic Orthopedic Robotics .......... 219
Benny Hagag, Rony Abovitz, Hyosig Kang, Brian Schmitz, and Michael Conditt

11 Robotic Surgery: Enabling Technology? ............................. 247
Moshe Shoham

12 Enabling Medical Robotics for the Next Generation of Minimally Invasive Procedures: Minimally Invasive Cardiac Surgery with Single Port Access .............................. 257
Howie Choset, Marco Zenati, Takeyoshi Ota, Amir Degani, David Schwartzman, Brett Zubiate, and Cornell Wright

13 Wireless Intraocular Microrobots: Opportunities and Challenges ................................................................. 271
Olgaç Ergeneman, Christos Bergeles, Michael P. Kummer, Jake J. Abbott, and Bradley J. Nelson

14 Single and Multiple Robotic Capsules for Endoluminal Diagnosis and Surgery .............................................. 313
Arianna Menciassi, Pietro Valdastri, Kanako Harada, and Paolo Dario

15 Visual Guidance of an Active Handheld Microsurgical Tool ........... 355
Brian C. Becker, Sandrine Voros, Robert A. MacLachlan, Gregory D. Hager, and Cameron N. Riviere

16 Swimming Micro Robots for Medical Applications ..................... 369
Gábor Kósa and Gábor Székely

17 Flagellated Bacterial Nanorobots for Medical Interventions in the Human Body .................................................. 397
Sylvain Martel
Part III  Engineering Developments


19  Tactile Feedback in Surgical Robotics........................................ 449  Martin O. Culjat, James W. Bisley, Chih-Hung King, Christopher Wottawa, Richard E. Fan, Erik P. Dutson, and Warren S. Grundfest

20  Robotic Techniques for Minimally Invasive Tumor Localization ...................................................... 469  Michael D. Naish, Rajni V. Patel, Ana Luisa Trejos, Melissa T. Perri, and Richard A. Malthaner

21  Motion Tracking for Beating Heart Surgery......................... 497  Rogério Richa, Antônio P. L. Bó, and Philippe Poignet

22  Towards the Development of a Robotic System for Beating Heart Surgery ........................................... 525  Özkan Bebek and M. Cenk Çavuşoğlu


24  Macro and Micro Soft-Tissue Biomechanics and Tissue Damage: Application in Surgical Robotics ............. 583  Jacob Rosen, Jeff Brown, Smita De, and Blake Hannaford

25  Objective Assessment of Surgical Skills .............................. 619  Jacob Rosen, Mika Sinanan, and Blake Hannaford

Part IV  Clinical Applications/Overviews

26  Telesurgery: Translation Technology to Clinical Practice .......... 653  Mehran Anvari
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>History of Robots in Orthopedics</td>
<td>661</td>
</tr>
<tr>
<td></td>
<td>Michael Conditt</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Robotic-Assisted Urologic Applications</td>
<td>679</td>
</tr>
<tr>
<td></td>
<td>Thomas S. Lendvay and Ryan S. Hsi</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Applications of Surgical Robotics in Cardiac Surgery</td>
<td>701</td>
</tr>
<tr>
<td></td>
<td>E.J. Lehr, E. Rodriguez, and W. Rodolph Chitwood</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Robotics in Neurosurgery</td>
<td>723</td>
</tr>
<tr>
<td>31</td>
<td>Applications of Surgical Robotics in Pediatric General Surgery</td>
<td>743</td>
</tr>
<tr>
<td></td>
<td>John Meehan</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Applications of Surgical Robotics in Gynecologic Surgery</td>
<td>761</td>
</tr>
<tr>
<td></td>
<td>Rabbie K. Hanna and John F. Boggess</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Applications of Surgical Robotics in General Surgery</td>
<td>791</td>
</tr>
<tr>
<td></td>
<td>Ozanan Meireles and Santiago Horgan</td>
<td></td>
</tr>
<tr>
<td>Index</td>
<td></td>
<td>813</td>
</tr>
</tbody>
</table>
Contributors

Jake J. Abbott  
Department of Mechanical Engineering, University of Utah, 50 S. Central Campus Dr., Salt Lake City, UT 84112, USA  
jake.abbott@utah.edu

Rony Abovitz  
MAKO Surgical Corp., 2555 Davie Road, Ft. Lauderdale, FL 33317, USA

Ron Alterovitz  
Department of Computer Science, University of North Carolina, Chapel Hill, NC 27599, USA  
ron@es.unc.edu

Mehran Anvari  
Department of Surgery, McMaster Institute for Surgical Innovation, Invention and Education, Faculty of Health Sciences, McMaster University, Hamilton, ON, Canada;  
St. Joseph’s Healthcare, 50 Charlton Ave, East Room 805, Hamilton, ON L8N 4C6, Canada  
anvari@mcmaster.ca

Özkan Bebek  
Department of Electrical Engineering and Computer Sciences, Case Western Reserve University, Cleveland, OH, USA  
ozkan.bebek@case.edu

Brian C. Becker  
Robotics Institute, Carnegie Mellon University, 5000 Forbes Ave, Pittsburgh, PA 15213, USA

Christos Bergeles  
Institute of Robotics and Intelligent Systems, ETH Zurich, Tannenstr. 3, CLA H 17.1, 8092, Zurich, Switzerland  
cbergeles@ethz.ch
Contributors

**Peter Berkelman**
Department of Mechanical Engineering, University of Hawaii-Manoa, 2540 Dole St, Honolulu, HI 96822, USA
peterb@hawaii.edu

**James W. Bisley**
Center for Advanced Surgical and Interventional Technology (CASIT), University of California Los Angeles, Los Angeles, CA 90095, USA; Department of Neurobiology, UCLA, Los Angeles, CA 90095, USA; Department of Psychology, UCLA, Los Angeles, CA 90095, USA

**António P.L. Bó**
LIRMM, Montpellier France

**John F. Boggess**
The Division of Gynecologic Oncology, Department of Obstetrics and Gynecology, University of North Carolina, Campus Box 7572, Chapel Hill, NC 27599-7572, USA
jboggess@med.unc.edu

**Timothy J. Broderick**
US Army Medical Research and Materiel Command Telemedicine, Advanced Technology Research Center MCMR-TT, 504 Scott St Fort Detrick, Frederick, MD 21702, USA
timothy.j.broderick@us.army.mil

**Jeff Brown**
Intuitive Surgical Inc., 1266 Kifer Road, Sunnyvale, CA, USA

**M. Cenk Çavuşoğlu**
Department of Electrical Engineering and Computer Sciences, Case Western Reserve University, 308 Glennan Building, Cleveland, OH, USA
cavusoglu@case.edu

**Gregory S. Chirikjian**
Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD 21218, USA

**W. Rodolph Chitwood**
East Carolina Heart Institute, Department of Cardiovascular Sciences, East Carolina University, Greenville, NC 27834, USA
chitwoodw@ecu.edu

**Howie Choset**
The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA 15213, USA
choset@cs.cmu.edu

**Michael Conditt**
MAKO Surgical Corp., 2555 Davie Road, Fort Lauderdale, FL 33317, USA
mconditt@makosurgical.com
Contributors

Noah J. Cowan
Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD 21218, USA
ncowan@jhu.edu

Martin O. Culjat
Center for Advanced Surgical and Interventional Technology (CASIT), University of California, Los Angeles, Los Angeles, CA 90095, USA; Department of Surgery, UCLA, Los Angeles, CA 90095, USA; Department of Bioengineering, UCLA, Los Angeles, CA 90095, USA
mculjat@mednet.ucla.edu

Paolo Dario
Scuola Superiore Sant’Anna, Pisa, Italy

Smita De
Department of Electrical Engineering, University of Washington, Seattle, WA, USA

Amir Degani
The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA 15213, USA

Simon DiMaio
Intuitive Surgical Inc., 1266 Kifer Road, Sunnyvale, CA, USA
simon.dimaio@intusurg.com

Charles R. Doarn
Departments of Surgery and Biomedical Engineering, University of Cincinnati, 2901 Campus Drive, Cincinnati, OH 45221, USA
charles.doarn@uc.edu

Erik P. Dutson
Center for Advanced Surgical and Interventional Technology (CASIT), UCLA, Los Angeles, CA 90095, USA; Department of Surgery, UCLA, Los Angeles, CA 90095, USA

Olgaç Ergeneman
Institute of Robotics and Intelligent Systems, ETH Zurich, Tannenstr. 3, CLA H 17.1, 8092 Zurich, Switzerland
oergeneman@ethz.ch

Richard E. Fan
Center for Advanced Surgical and Interventional Technology (CASIT), UCLA, Los Angeles, CA 90095, USA; Department of Bioengineering, UCLA, Los Angeles, CA 90095, USA

Shane M. Farritor
Department of Mechanical Engineering, University of Nebraska-Lincoln, N104 SEC, Lincoln, NE 68588-0656, USA
sfarritor@unl.edu
Gabor Fichtinger  
Queen’s University, Kingston, ON, Canada K7L 3N6

D. Friedman  
Department of Electrical Engineering, University of Washington, Seattle, WA, USA

Pablo Garcia  
SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025, USA  
pablo.garcia@sri.com

Gary R. Gilbert  
Georgetown University Imaging Science and Information Systems (ISIS) Center,  
US Army Medical Research and Materiel Command Telemedicine;  
Advanced Technology Research Center MCMR-TT, 504 Scott, St Fort Detrick, Frederick, MD 21702, USA  
gary.gilbert@tatrc.org

D. Glozman  
Department of Computer Engineering, Baskin School of Engineering SOE-3,  
University of California Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA

Ken Goldberg  
University of California, Berkeley, CA 94720, USA

Paul G. Griffiths  
Johns Hopkins University, Baltimore, MD 21218, USA

Warren S. Grundfest  
Center for Advanced Surgical and Interventional Technology (CASIT), UCLA,  
Los Angeles, CA 90095, USA;  
Department of Surgery, UCLA, Los Angeles, CA 90095, USA;  
Department of Bioengineering, UCLA, Los Angeles, CA 90095, USA;  
Department of Electrical Engineering, UCLA, Los Angeles, CA 90095, USA

James C. Gwilliam  
Johns Hopkins University, Baltimore, MD 21218, USA

Benny Hagag  
MAKO Surgical Corp., 2555 Davie Road, Ft. Lauderdale, FL 33317, USA  
bhagag@makosurgical.com

Gregory D. Hager  
Computer Science Department, Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218, USA

Rabbie K. Hanna  
The Division of Gynecologic Oncology, Department of Obstetrics and Gynecology, University of North Carolina, Campus Box 7572, Chapel Hill, NC 27599-7572, USA
Blake Hannaford  
Department of Electrical Engineering, University of Washington, Seattle, WA, USA

Mike Hanuschik  
Intuitive Surgical Inc., 1266 Kifer Road, Sunnyvale, CA, USA

Kanako Harada  
Scuola Superiore Sant’Anna, Pisa, Italy

Santiago Horgan  
Department of Surgery, University of California San Diego, San Diego CA 92403  
shorgan@ucsd.edu

Ryan S. Hsi  
Seattle Children’s Hospital, 4800 Sand Point Way Northeast, Seattle, WA, USA

Vinutha Kallem  
University of Pennsylvania, Philadelphia, PA 19104, USA

Hyosig Kang  
MAKO Surgical Corp., 2555 Davie Road, Ft. Lauderdale, FL 33317, USA

Louis J. Kim  
Department of Neurological Surgery, University of Washington, 325, 9th Avenue, Seattle, WA 98104, USA  
ljkim1@u.washington.edu

Chih-Hung King  
Center for Advanced Surgical and Interventional Technology (CASIT), UCLA, Los Angeles, CA 90095, USA;  
Department of Bioengineering, UCLA, Los Angeles, CA 90095, USA

Gábor Kósa  
Computer Vision Laboratory, Department of Information Technology and Electrical Engineering, ETH Zurich, Switzerland  
kosa@vision.ee.ethz.ch

Usha Kreaden  
Intuitive Surgical Inc., 1266 Kifer Road, Sunnyvale, CA, USA

Michael P. Kummer  
Institute of Robotics and Intelligent Systems, ETH Zurich, Tannenstr. 3, CLA H 17.1, 8092, Zurich, Switzerland  
kummerm@ethz.ch

Amy C. Lehman  
Department of Mechanical Engineering, University of Nebraska-Lincoln, N104 SEC, Lincoln, NE 68588-0656, USA  
alehman3@gmail.com
E.J. Lehr  
Department of Cardiovascular Sciences, East Carolina Heart Institute,  
East Carolina University, Greenville, NC 27834, USA  
ericjlehr@gmail.com

Thomas S. Lendvay  
Seattle Children’s Hospital, 4800 Sand Point Way Northeast, Seattle, WA, USA  
thomas.lendvay@seattlechildrens.org

Mitchell Lum  
4801 24th Ave, NE #505, Seattle, WA 98105, USA  
mitchlum@u.washington.edu

Ji Ma  
Department of Mechanical Engineering, University of Hawaii-Manoa,  
2540 Dole St, Honolulu, HI 96822, USA  
jima@hawaii.edu

Robert A. MacLachlan  
Robotics Institute, Carnegie Mellon University, 5000 Forbes Ave,  
Pittsburgh, PA 15213, USA

Richard A. Malthaner  
800 Commissioners Road EastSuite E2-124 London, ON N6A 5W9, Canada  
richard.malthaner@lhsc.on.ca

Sylvain Martel  
NanoRobotics Laboratory, Department of Computer and Software Engineering,  
Institute of Biomedical Engineering École Polytechnique, de Montréal (EPM),  
Station Centre-Ville, Montréal, QC, Canada  
sylvain.martel@polymtl.ca

John Meehan  
Department of Surgery, Seattle Children’s Hospital, University of Washington,  
Seattle, Washington, USA  
john.meehan@seattlechildrens.org

Ozanan Meireles  
Department of Surgery, University of California, San Diago, San Diago, CA 92103  
omeireles@ucsd.edu

Arianna Menciassi  
Scuola Superiore Sant’Anna, Viale Rinaldo Piaggio 34-5602, Pisa, Italy  
arianna.menciassi@sssup.it

Sarthak Misra  
University of Twente, 7500 AE Enschede, The Netherlands

K. Moe  
Department of Neurological Surgery, University of Washington,  
325, 9th Avenue, Seattle, WA 98104, USA
Gerald R. Moses  
University of Maryland, Baltimore, MD, USA  
gmoses@smail.umaryland.edu

Michael D. Naish  
Department of Mechanical & Materials Engineering,  
Department of Electrical & Computer Engineering, The University of Western Ontario, London, Ontario, Canada N6A 5B9;  
Lawson Health Research Institute (LHRI), Canadian Surgical Technologies & Advanced Robotics (CSTAR), 339 Windermere Road London, Ontario, Canada N6A 5A5  
mnaish@uwo.ca; michael.naish@lawsonresearch.com

Bradley J. Nelson  
Institute of Robotics and Intelligent Systems, ETH Zurich, Tannenstr. 3, CLA H 17.1, 8092, Zurich, Switzerland  
bnelson@ethz.ch

Allison M. Okamura  
Department of Mechanical Engineering, Johns Hopkins University,  
Baltimore, MD 21218, USA  
aokamura@jhu.edu

Dmitry Oleynikov  
Department of Surgery, University of Nebraska Medical Center,  
983280 Nebraska Medical Center, Omaha, NE 68198-3280, USA  
doleynik@unmc.edu

Takeyoshi Ota  
Division of Cardiothoracic Surgery, University of Pittsburgh,  
Pittsburgh, PA 15213, USA

Wooram Park  
Johns Hopkins University, Baltimore, MD 21218, USA

Rajni V. Patel  
Department of Mechanical & Materials Engineering,  
Department of Electrical & Computer Engineering, The University of Western Ontario, London, Ontario, Canada N6A 5B9;  
Lawson Health Research Institute (LHRI), Canadian Surgical Technologies & Advanced Robotics (CSTAR), 339 Windermere Road London, Ontario, Canada N6A 5A5

Nicholas A. Patronik  
Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, USA
Melissa T. Perri  
Department of Mechanical & Materials Engineering,  
Department of Electrical & Computer Engineering, The University of Western Ontario, London, Ontario, Canada N6A 5B9;  
Lawson Health Research Institute (LHRI), Canadian Surgical Technologies & Advanced Robotics (CSTAR), 339 Windermere Road London, Ontario, Canada N6A 5A5

Philippe Poignet  
LIRMM, Montpellier, France  
philippe.poignet@lirmm.fr

D. Ramanathan  
Department of Neurological Surgery, University of Washington,  
325, 9th Avenue, Seattle, WA 98104, USA

Kyle B. Reed  
University of South Florida, Tampa, FL 33620, USA

Rogerio Richa  
LIRMM 161 Rue Add, 34392 Montpellier Cedex 5, France  
philippe.poignet@lirmm.fr

Cameron N. Riviere  
Robotics Institute, Carnegie Mellon University, 5000 Forbes Ave, Pittsburgh, PA 15213, USA  
camr@ri.cmu.edu

E. Rodriguez  
Department of Cardiovascular Sciences, East Carolina Heart Institute, East Carolina University, Greenville, NC 27834, USA  
rodrigueze@ecu.edu

Jacob Rosen  
Department of Computer Engineering, Jack Baskin School of Engineering, University of California Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA  
rosen@ucsc.edu

Richard M. Satava  
Department of Surgery, University of Washington Medical Center, Box 356410, 1959 Pacific Street NE, Seattle, Washington 98195, USA;  
US Army Medical Research and Material Command, Fort Detrick, Frederick, MD, USA  
rsatava@u.washington.edu

Brian Schmitz  
MAKO Surgical Corp., 2555 Davie Road, Ft. Lauderdale, FL 33317, USA

David Schwartzman  
Cardiovascular Institute, University of Pittsburgh, Pittsburgh, PA 15213, USA
L.N. Sekhar
Department of Neurological Surgery, University of Washington, 325, 9th Avenue, Seattle, WA 98104, USA
lsekhar@u.washington.edu

Moshe Shoham
Robotics Laboratory, Department of Mechanical Engineering, Technion – Israel Institute of Technology, Haifa, Israel; Mazor Surgical Technologies, Cesarea, Israel
shoham@technion.ac.il

Mika Sinanan
Department of Surgery, University of Washington Medical Center, 1959 Pacific Street NE, Seattle, WA 98195, USA

Ana Luisa Trejos
Department of Mechanical & Materials Engineering, Department of Electrical & Computer Engineering, The University of Western Ontario, London, Ontario, Canada N6A 5B9; Lawson Health Research Institute (LHRI), Canadian Surgical Technologies & Advanced Robotics (CSTAR), 339 Windermere Road London, Ontario, Canada N6A 5A5

Pietro Valdastri
Scuola Superiore Sant’Anna, Pisa, Italy

Lawton N. Verner
Johns Hopkins University, Baltimore, MD 21218, USA

Sandrine Voros
Computer Science Department, Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218, USA

Christopher Wottawa
Center for Advanced Surgical and Interventional Technology (CASIT), UCLA, Los Angeles, CA 90095, USA; Department of Bioengineering, UCLA, Los Angeles, CA 90095, USA

Cornell Wright
The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA 15213, USA

Tomonori Yamamoto
Johns Hopkins University, Baltimore, MD 21218, USA

Andrew C. Yoo
University of Cincinnati Department of Surgery, 231 Albert Sabin Way, P.O. Box 670558, Cincinnati, OH 45267-0558, yooaw@ucmail.uc.edu
Marco A. Zenati
Division of Cardiothoracic Surgery, University of Pittsburgh, Pittsburgh, PA 15213, USA

Brett Zubiate
Bioengineering Department, University of Pittsburgh, Pittsburgh, PA 15213, USA