Critical Care Handbook of the Massachusetts General Hospital
To Our Patients
The *Critical Care Handbook of the Massachusetts General Hospital* is a pragmatic review of the basis of adult critical care, designed for all trainees and practitioners who are interested in working in an intensive care unit (ICU). Although our practice over many years has consisted primarily of surgical patients, we always ensured that learning, teaching, and clinical plans of care be developed with a multidisciplinary approach. For this reason, this *Handbook* is authored by intensivists from anesthesia, surgery, and medicine, as well as critical care nurses, respiratory therapists, and pharmacists. Over the years, the glue that has kept this diverse faculty together has been *physiology*, because the body works the same way in patients admitted to a surgical, medical, or neurological ICU. The principles of physiology applied to critical care are illustrated in the chapters that open the *Handbook*, including hemodynamic and respiratory monitoring, acid—base, principles of mechanical ventilation, and the bases of antimicrobial therapy and nutritional support. However, as the practice of critical care evolves, we now have *evidence* from a number of well-designed trials to guide our therapeutic choices, so the *Handbook* emphasizes the evidence that exists behind our recommendations. Further progress in patient outcomes has been achieved by implementing *safety* in the ICU, where the fast pace and invasive procedures may at times hurt our patients. We have added chapters on prophylaxis of nosocomial complications, on the safe transport of critically ill patients, and on what intensivists offer outside the ICU.

As the *Handbook* has evolved over the years, its authors and its contents have changed, but part of the older information has been conserved, sometimes even verbatim. Here, we acknowledge all the authors of the past editions, many of whom have moved on to successful professional careers, and hopefully still cherish the chapters they wrote during their busy times of residency and fellowship.

Finally, as I leave this famed institution after nearly 20 years, I thank the innumerous individuals who have made our Ellison 4 Surgical ICU (and her various previous incarnations) an extraordinary place to work. First, I thank our patients and their families, who, through their suffering, have taught us about their illness, allowing us to save some of those who followed. Then, I thank our incredible staff—the nurses, doctors, respiratory therapists, unit assistants, students, and anyone of the thousands who over the years have worked in this unit, not as spectators but as protagonists of this dream.

Luca M. Bigatello
Hasan B. Alam, MD
Program Director, Fellowship in Surgical Critical Care
Department of Surgery
Massachusetts General Hospital
Associate Professor of Surgery
Harvard Medical School
Boston, Massachusetts

Rae M. Allain, MD
Director, Vascular Anesthesia
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Assistant Professor of Anesthesia
Harvard University
Boston, Massachusetts

Kathrin Allen, MD
Clinical Fellow in Critical Care
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Harvard Medical School
Boston, Massachusetts

Theodore A. Alston, MD, PhD
Associate Anesthetist
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Assistant Professor of Anesthesia
Harvard Medical School
Boston, Massachusetts

Houman Amirfarzan, MD
Resident in Anesthesiology
Anesthesia Department
Tufts New England Medical Center
Boston, Massachusetts
Emily A. Apsell, MD
Resident in Anesthesiology
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Clinical Fellow in Anesthesiology
Harvard Medical School
Boston, Massachusetts

Aranya Bagchi, MD
Resident in Anesthesiology
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Clinical Fellow in Anesthesia
Harvard Medical School
Boston, Massachusetts

Karsten Bartels, MD
Resident in Anesthesiology
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Clinical Fellow in Anesthesia
Harvard Medical School
Boston, Massachusetts

William J. Benedetto, MD
Assistant in Anesthesia
Massachusetts General Hospital
Instructor in Anesthesia
Harvard Medical School
Boston, Massachusetts

Lorenzo Berra, MD
Resident in Anesthesiology and Beecher Research Scholar
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Harvard Medical School
Boston, Massachusetts

Luca M. Bigatello, MD
Chief, Anesthesia and Critical Care Service
Veterans Administration Boston Healthcare System
Associate Vice Chairman
Massachusetts General Hospital
Associate Professor of Anesthesia
Harvard Medical School
Boston, Massachusetts
Edward A. Bittner, MD, PhD
Program Director, Anesthesia-Critical Care Fellowship
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Instructor in Anesthesia
Harvard Medical School
Boston, Massachusetts

Ross Blank, MD
Clinical Lecturer
Division of Critical Care
Department of Anesthesiology
University of Michigan Health System
Ann Arbor, Michigan

Jonathan D. Bloom, MD
Resident in Anesthesiology
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Clinical Fellow in Anesthesia
Harvard Medical School
Boston, Massachusetts

Sharon E. Brackett, RN, BS
Staff Nurse, Surgical ICU
Massachusetts General Hospital
Boston, Massachusetts

Jonathan E. Charnin, MD
Assistant in Anesthesia
Department of Anesthesia and Critical care
Massachusetts General Hospital
Instructor in Anesthesia
Harvard Medical School
Boston, Massachusetts

Sherry Chou
Staff Physician
Department of Neurology
Brigham and Women's Hospital
Instructor
Harvard Medical School
Boston, Massachusetts
Claudia Crimi  
Research Fellow  
Department of Anesthesia and Critical Care  
Massachusetts General Hospital  
Harvard Medical School  
Boston, Massachusetts

Ettore Crimi, MD  
Resident in Anesthesiology  
Department of Anesthesia and Critical Care  
Massachusetts General Hospital  
Harvard Medical School  
Boston, Massachusetts

Marc A. de Moya, MD, FACS  
Director of Surgical Core Clerkship  
Department of Surgery  
Massachusetts General Hospital  
Assistant Professor of Surgery  
Harvard Medical School  
Boston, Massachusetts

Alan DiBiasio, RPh  
Senior Attending Pharmacist  
Department of Pharmacy  
Massachusetts General Hospital  
Boston, Massachusetts

Anahat Dhillon, MD  
Staff Anesthesiologist  
Department of Anesthesiology  
Ronald Regan Medical Center  
Assistant Professor  
University of California Los Angeles  
Los Angeles, California

Michael G. Fitzsimons, MD  
Operations Director, Cardiac Anesthesia  
Department of Anesthesia and Critical Care  
Massachusetts General Hospital  
Assistant Professor of Anesthesia  
Harvard Medical School  
Boston, Massachusetts

Jonathan Frederick Fox, MD  
Clinical Fellow in Critical Care  
Department of Anesthesia and Critical Care  
Harvard Medical School  
Massachusetts General Hospital  
Boston, Massachusetts
Eugene Y. Fukudome, MD
Clinical Fellow in Surgery
Department of Surgery
Harvard Medical School
Massachusetts General Hospital
Boston, Massachusetts

Henning A. Gaissert, MD
Associate Visiting Surgeon
Division of Thoracic Surgery
Massachusetts General Hospital
Associate Professor of Surgery
Harvard Medical School
Boston, Massachusetts

Cosmin Gauran, MD
Staff Anesthesiologist
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Instructor in Anesthesia
Harvard Medical School
Boston, Massachusetts

Edward E. George, MD, PhD
Medical Director
Post Anesthesia Care Units
Massachusetts General Hospital
Assistant Professor of Anesthesia
Harvard Medical School
Boston, Massachusetts

Fiona K. Gibbons, MD
Assistant in Medicine
Pulmonary and Critical Care Unit
Massachusetts General Hospital
Instructor in Medicine
Harvard Medical School
Boston, Massachusetts

Jeremy W. Goldfarb, MD
Resident in Anesthesiology
Department of Anesthesia and Critical Care
Harvard Medical School
Massachusetts General Hospital
Boston, Massachusetts
Contributors

Robert L. Goulet, MS, RRT
Senior Respiratory Therapist
Respiratory Care Services
Massachusetts General Hospital
Boston, Massachusetts

David M. Greer, MD, MA
Assistant in Neurology
Department of Neurology
Massachusetts General Hospital
Assistant Professor of Neurology
Harvard Medical School
Boston, Massachusetts

Robin K. Guillory, MD
Assistant Professor of Anesthesiology
Department of Anesthesiology
Washington University in St. Louis School of Medicine
St. Louis, Missouri

Robert Hallisey, MS, RPh
Director, Clinical Systems
Department of Pharmacy
Massachusetts General Hospital
Assistant Professor of Clinical Pharmacy
Massachusetts College of Pharmacy and Health Sciences
Boston, Massachusetts

Bishr Haydar, MD
Resident in Anesthesiology
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Boston, Massachusetts

Judith Hellman
Department of Anesthesia and Perioperative Care
Associate Professor
University of California, San Francisco
San Francisco, California
Dean R. Hess, PhD, RRT  
Assistant Director  
Respiratory Care Services  
Associate Professor of Anesthesia  
Harvard Medical School  
Boston, Massachusetts

Daniel W. Johnson, MD  
Clinical Fellow in Critical Care  
Department of Anesthesia and Critical Care  
Massachusetts General Hospital  
Harvard Medical School  
Boston, Massachusetts

Kathryn Davis Kalafatas, RPh  
Senior Attending Pharmacist  
Department of Pharmacy  
Massachusetts General Hospital  
Boston, Massachusetts

Erik B. Kistler, MD, PhD  
Assistant Professor  
Department of Anesthesia  
University of California, San Diego  
San Diego, California

Corry "Jeb" Kucik, MD  
Clinical Fellow in Critical Care  
Department of Anesthesia and Critical Care  
Massachusetts General Hospital  
Instructor in Anesthesia  
Harvard Medical School  
Boston, Massachusetts

Jean Kwo, MD  
Director, Pre-Admission Testing Clinic  
Department of Anesthesia and Critical Care  
Massachusetts General Hospital  
Assistant Professor in Anesthesia  
Harvard Medical School  
Boston, Massachusetts
Laura H. Leduc, MD
Resident in Anesthesiology
Department of Anesthesia and Critical Care
Harvard Medical School
Massachusetts General Hospital
Boston, Massachusetts

Nicolas Melo
Resident in Surgery
Department of Surgery
Harvard Medical School
Massachusetts General Hospital
Boston, Massachusetts

Beverly J. Newhouse, MD
Instructor in Anesthesia and Critical Care
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Clinical Instructor in Anesthesiology
Harvard Medical School
Boston, Massachusetts

Ara Nozari, MD, PhD
Instructor in Anesthesia
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Instructor in Anesthesia
Harvard Medical School
Boston, Massachusetts

Amy Ortman, MD
Chief Resident
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Instructor in Anesthesia
Harvard Medical School
Boston, Massachusetts

Robert L. Owens, MD
Clinical and Research Fellow
Pulmonary and Critical Care Unit
Massachusetts General Hospital
Instructor in Anesthesiology
Harvard Medical School
Boston, Massachusetts
Contributors

Richard M. Pino, MD, PhD
Associate Anesthetist
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Associate Professor
Harvard Medical School
Boston, Massachusetts

Steven J. Russell, MD, PhD
Assistant in Medicine
Department of Medicine, Endocrine Division
Massachusetts General Hospital
Instructor of Medicine
Harvard Medical School
Boston, Massachusetts

Elizabeth A. Sailhamer, MD, MMSc
Resident in General Surgery
Department of Surgery
Massachusetts General Hospital
Harvard Medical School
Boston, Massachusetts

Ulrich Schmidt, MD, PhD
Director, Surgical Intensive Care Unit
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Assistant Professor of Anesthesia
Harvard Medical School
Boston, Massachusetts

Lee H. Schwamm, MD, FAHA
Vice-Chairman
Department of Neurology
Massachusetts General Hospital
Associate Professor
Harvard Medical School
Boston, Massachusetts

Todd A. Seigel, MD
Clinical Associate
Department of Anesthesia and Critical Care
Massachusetts General Hospital Assistant Professor in Emergency Medicine
Brown University
Providence, Rhode Island
Robert L. Sheridan, MD
Chief, Burn Surgery Service
Shriners Hospitals for Children—Boston
Associate Professor of Surgery
Harvard Medical School
Boston, Massachusetts

Kevin N. Sheth, MD
Assistant Professor
Departments of Neurology
University of Maryland School of Medicine
Baltimore, Maryland

Jagmeet Singh
Cardiac Arrhythmia Service
Massachusetts General Hospital
Assistant Professor
Harvard University
Boston, Massachusetts

David J. R. Steele, MD
Assistant Physician
Department of Medicine
Massachusetts General Hospital
Assistant Professor
Harvard Medical School
Boston, Massachusetts

H. Thomas Stelfox, MD, PhD
Departments of Critical Care Medicine
Medicine and Community Health Sciences
Foothills Medical Centre
Assistant Professor
University of Alberta
Calgary, Alberta

Dorothea Strozyk, MD
Vascular Neurology and Critical Care Fellow
Department of Neurology
Massachusetts General Hospital
Clinical and Research Fellow
Harvard Medical School
Boston, Massachusetts
B. Taylor Thompson, MD
Chief, Medical Intensive Care Unit
Pulmonary and Critical Care Unit
Massachusetts General Hospital
Associate Professor of Medicine
Harvard Medical School
Boston, Massachusetts

Arthur J. Tokarczyc, MD
Assistant Anesthesiologist
Department of Anesthesiology
North Shore University Health System
Clinical Instructor
University of Chicago
Chicago, Illinois

Jeffrey S. Ustin, MD, MS
Fellow
Trauma, Emergency Surgery, Surgical Critical Care
Massachusetts General Hospital
Instructor in Surgery
Harvard Medical School
Boston, Massachusetts

Jason A. Wertheim, MD, PhD
Resident in Surgery
Department of Surgery
Harvard Medical School
Massachusetts General Hospital
Boston, Massachusetts

Susan R. Wilcox, MD
Clinical Fellow in Critical Care
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Harvard Medical School
Boston, Massachusetts
Preface vi
Contributors vii

PART I: GENERAL PRINCIPLES 1

1 Hemodynamic Monitoring 1
   Erik Kistler and Luca Bigatello

2 Respiratory Monitoring 17
   Ettore Crimi and Dean Hess

3 Use of Ultrasound in the ICU 39
   Robin Guillory and Marc de Moya

4 Airway Management 50
   Jonathan Charnin, Robert Goulet, and Richard Pino

5 Principles of Mechanical Ventilation 78
   Claudia Crimi and Dean Hess

6 Hemodynamic Management 100
   Jonathan Fox and Edward Bittner

7 Sedation and Analgesia 113
   Houman Amirfarzan, Ulrich Schmidt, and Luca Bigatello

8 Fluids, Electrolytes, and Acid–Base Management 127
   Cosmin Gauran and David Steele

9 Critical Care of the Trauma Patient 150
   Jeffrey Ustin and Hasan Alam
10 Critical Care of the Neurologic Patient
Kevin Sheth and Lee Schwamm

11 Nutrition
Elizabeth Sailhamer and Hasan Alam

12 Infectious Disease—General Considerations
Laura Leduc and Judith Hellman

13 Quality Improvement and Prophylaxis
Karsten Bartels and Ulrich Schmidt

14 Ethical and Legal Issues in ICU Practice
Rae Allain and Sharon Brackett

15 Evidence-Based Practice and Basic Statistics in Critical Care
Ala Nozari, H. Thomas Stelfox, and Edward Bittner

16 Transport of the ICU Patient
Emily Apsell and Michael Fitzsimons

PART II: SPECIFIC CONSIDERATIONS

17 Coronary Artery Disease
Corry "Jeb" Kucik and Michael Fitzsimons

18 Valvular Heart Disease
Jonathan Bloom and Theodore Alston

19 Cardiac Dysrhythmias
Cosmin Gauran and Jagmeet Singh

20 The Acute Respiratory Distress Syndrome
Kathrin Allen and Luca Bigatello

21 Chronic Obstructive Pulmonary Disease and Asthma
Robert Owens and Fiona Gibbons

22 Pulmonary Embolism and Deep Venous Thrombosis
B. Taylor Thompson
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Discontinuation of Mechanical Ventilation</td>
<td>322</td>
</tr>
<tr>
<td></td>
<td>Bishr Haydar and Jean Kwo</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Acute Kidney Injury</td>
<td>333</td>
</tr>
<tr>
<td></td>
<td>Beverly Newhouse</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Liver Dysfunction</td>
<td>353</td>
</tr>
<tr>
<td></td>
<td>Daniel Johnson and William Benedetto</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Coagulopathy and Hypercoagulability</td>
<td>364</td>
</tr>
<tr>
<td></td>
<td>Lorenzo Berra and Rae Allain</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Acute Gastrointestinal Diseases</td>
<td>379</td>
</tr>
<tr>
<td></td>
<td>Eugene Fukudome and Jean Kwo</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Endocrine Disorders and Glucose Management</td>
<td>398</td>
</tr>
<tr>
<td></td>
<td>Steven Russell and B. Taylor Thompson</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Infectious Diseases—Specific Considerations</td>
<td>424</td>
</tr>
<tr>
<td></td>
<td>Aranya Bagchi and Judith Hellman</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Nonantibiotic Therapies for Sepsis</td>
<td>447</td>
</tr>
<tr>
<td></td>
<td>Anahat Dhillon and Edward Bittner</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Stroke, Seizures, and Encephalopathy</td>
<td>456</td>
</tr>
<tr>
<td></td>
<td>Dorothea Strozyk and Lee Schwamm</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Acute Weakness</td>
<td>478</td>
</tr>
<tr>
<td></td>
<td>David Greer and Edward George</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Drug Overdose, Poisoning, and Adverse Drug Reactions</td>
<td>487</td>
</tr>
<tr>
<td></td>
<td>Susan Wilcox and Richard Pino</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Adult and Pediatric Resuscitation</td>
<td>505</td>
</tr>
<tr>
<td></td>
<td>Arthur Tokarczyk and Richard Pino</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Transfusion Medicine</td>
<td>521</td>
</tr>
<tr>
<td></td>
<td>Jeffrey Ustin and Hasan Alam</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Neurological Trauma</td>
<td>532</td>
</tr>
<tr>
<td></td>
<td>Sherry Chou and Marc de Moya</td>
<td></td>
</tr>
<tr>
<td>Chapter</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>37</td>
<td>The Burned Patient</td>
<td>551</td>
</tr>
<tr>
<td></td>
<td>Nicolas Melo and Rob Sheridan</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Disaster Preparedness in the ICU</td>
<td>566</td>
</tr>
<tr>
<td></td>
<td>Todd Seigel and Edward George</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>ICU Care After Vascular Surgery</td>
<td>579</td>
</tr>
<tr>
<td></td>
<td>Ross Blank and Rae Allain</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>ICU Care After Thoracic Surgery</td>
<td>593</td>
</tr>
<tr>
<td></td>
<td>Kathrin Allen, Henning Gaissert, and Luca Bigatello</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>ICU Care Following Liver, Kidney, and Lung Transplantation</td>
<td>605</td>
</tr>
<tr>
<td></td>
<td>Jason Wertheim and William Benedetto</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>ICU Care of the Obese Patient</td>
<td>616</td>
</tr>
<tr>
<td></td>
<td>Jeremy Goldfarb and Jean Kwo</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>The Intensivist Outside the ICU</td>
<td>626</td>
</tr>
<tr>
<td></td>
<td>Edward George and Edward Bittner</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Obstetric Critical Care</td>
<td>636</td>
</tr>
<tr>
<td></td>
<td>Amy Ortman and Richard Pino</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Appendix A: Supplemental Drug Information</td>
<td>653</td>
</tr>
<tr>
<td></td>
<td>Alan DiBiasio, Robert Hallisey, Jr., and Kathryn Kalafatas Davis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Index</td>
<td>701</td>
</tr>
</tbody>
</table>