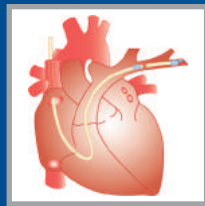
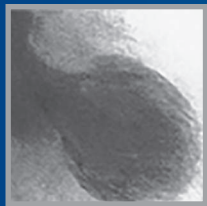
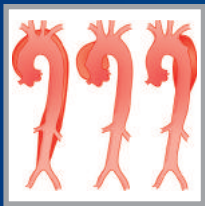


CARDIAC INTENSIVE CARE



David L. Brown, MD

Professor of Medicine (Cardiovascular Disease)

Washington University School of Medicine

St. Louis, Missouri

THIRD EDITION

ELSEVIER

Get more medical books and resources at

www.medicalbr.com

 UpToDate®

DynaMed Plus®

 Lexicomp

ScienceDirect®

ClinicalKey®

STAT!Ref

BMJ Best Practice

MICROMEDEX

BMJ Learning

OvidToday™

ACCESS ▶ Medicine™

ACCESS ▶ Surgery®

ACCESS ▶ Pharmacy™

ACCESS ▶ Pediatrics®

ACCESS ▶ Emergency Medicine®

ACCESS ▶ **PREMIUM
PACKAGE**

CASE FILES®
COLLECTION

CARDIAC INTENSIVE CARE

ELSEVIER

1600 John F. Kennedy Blvd.
Ste 1600
Philadelphia, PA 19103-2899

CARDIAC INTENSIVE CARE, THIRD EDITION

ISBN: 978-0-323-52993-8

Copyright © 2019 by Elsevier, Inc.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: www.elsevier.com/permissions.

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

With respect to any drug or pharmaceutical products identified, readers are advised to check the most current information provided (i) on procedures featured or (ii) by the manufacturer of each product to be administered, to verify the recommended dose or formula, the method and duration of administration, and contraindications. It is the responsibility of practitioners, relying on their own experience and knowledge of their patients, to make diagnoses, to determine dosages and the best treatment for each individual patient, and to take all appropriate safety precautions.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

Previous editions copyrighted 2010, 1998.

Library of Congress Control Number: 2018944851

Executive Content Strategist: Robin Carter
Senior Content Development Specialist: Jennifer Shreiner
Publishing Services Manager: Catherine Jackson
Senior Project Manager/Specialist: Carrie Stetz
Design Direction: Amy Buxton

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1



Working together
to grow libraries in
developing countries

www.elsevier.com • www.bookaid.org

This edition of *Cardiac Intensive Care* is dedicated to the students, residents, and fellows who teach and inspire me much more than I do in return.

“If you always do what you always did, you will always get what you always got.”

Albert Einstein

With the aim of improving survival from in-hospital cardiac arrest after myocardial infarction, in 1961, Desmond Julian, the legendary British cardiologist, proposed a “special intensive-care unit...staffed by suitably experienced people throughout 24 hours, since it is unreasonable to expect good results when the care of patients is entrusted to [the] inexperienced.” With central tenets of regionalized specialty care, collaborative teamwork with specialized nursing, and continuous physiologic monitoring, the initial coronary care units were reported to achieve impressive reductions in mortality after myocardial infarction. Since then, the characteristics of the patients we care for, the medical problems that we encounter, and the technologies that we deploy in the cardiac intensive care unit (CICU) have all changed radically. The fast-paced progression of cardiac critical care toward increasing complexity requires that those who oversee or practice in the CICU embrace a forward-looking culture of continuous redesign and quality improvement; to do so effectively also requires the practitioner to maintain a broad fund of knowledge that keeps to the cutting edge while building on the fundamentals of cardiovascular medicine and critical care.

Now in its third edition, *Cardiac Intensive Care*, edited by David L. Brown, MD, is uniquely positioned with a focus on cardiac critical care, distilling more than a half century of advances in state-of-the-art contemporary cardiac intensive care. This

textbook delivers a comprehensive and deep treatment of the pathophysiologic principles, foundational basic and clinical science, and pragmatic clinical practice essential to the diagnosis, assessment, and treatment of patients with cardiac critical illness. From the basics of recognition and management of mechanical complications of myocardial infarction and cardiogenic shock to the essential topics of medical ethics and end-of-life care in the CICU, authoritative experts present the landmark studies, latest advances, and practical pearls in the field. The liberal incorporation of figures and videos enhances the accessibility of the material to the reader.

While advances in practice have markedly improved survival and quality of life in many domains of cardiovascular medicine, the nature of the conditions and severity of illness encountered in the CICU continue to confer unacceptably high rates of morbidity and mortality. These facts challenge the field to respond with new research and insightful attention to evolving organizational models and individual processes of care. This textbook is a welcomed companion for practitioners seeking to provide state-of-the-art care in the high-stakes environment of cardiac intensive care.

David A. Morrow, MD, MPH

Professor of Medicine

Harvard Medical School;

Director, Levine Cardiac Intensive Care Unit

Brigham and Women’s Hospital

Boston, Massachusetts

The first edition of *Cardiac Intensive Care* was published in 1998 and the second in 2010. New editions of textbooks attempt to keep pace with the rapid changes in patient demographics, new understanding of pathophysiology, and advances in treatment. Formats of textbooks evolve as technology improves and our understanding grows regarding how and where learners do the actual learning. The third edition of *Cardiac Intensive Care* is no exception. As all patient care begins with a grounding in ethics and the ability to perform an accurate history and physical exam, those topics are covered in the beginning of the book. I continue to believe that a strong grounding in the pathophysiology of cardiovascular disease is mandatory to make accurate diagnoses and appropriate treatment decisions. Thus the first chapters of the new edition focus on the scientific underpinnings of cardiac intensive care. However, as the field has evolved, chapters on specific topics such as non-ST segment myocardial infarction, unstable angina, coronary spasm, complications of interventional procedures, emergency coronary bypass surgery—all common admission diagnoses to the cardiac intensive care unit (CICU) in the past—are no longer pertinent to the current CICU and have been omitted. The new edition has chapters on takotsubo cardiomyopathy, acute myocarditis, cardiorenal syndrome, electrical storm, distributive shock, and temporary mechanical circulatory support devices—all of which are commonly encountered in today's CICU. In recognition of the complexity and advanced illness of current CICU patient populations, along with the recognition of the limitations of care and our obligation to ensure quality of life as opposed to quantity of life, we have added a chapter on palliative care. We have also added audio clips of heart sounds and videos of procedures and diagnostic imaging in the online version of this book, available at Expert-Consult.com. My hope is to make this textbook more of a living document than previous editions, with online and social media discussions of topics relevant to cardiac intensive care.

At the twentieth anniversary of the publication of the first edition, the loss of contributors to earlier editions is inevitable. Giants of cardiology who contributed their time and expertise to writing chapters in earlier editions who are no longer with us include H.J.C. Swan, Kanu Chatterjee, Bill Little, Ralph Shabetai, Burt Sobel, Bob O'Rourke, and Mark Josephson. Their contributions to teaching, mentoring, research, and patient care continue to live on and inspire the next generations of physicians.

A project of this magnitude would not be possible without the contributions of many. I would be remiss if I did not acknowledge the critical contributions of Jennifer Shreiner and Carrie Stetz from Elsevier, whose tireless efforts along with constant but gentle encouragement have kept the third edition (more or less) on schedule. The artists and copyeditors at Elsevier are the best in the business. Responsibility for any mistakes or typographical errors that find their way into the finished book falls on my shoulders, not theirs. In addition, I am deeply indebted to the contributing authors. Book chapters do not return much in the way of academic currency, but I am eternally grateful to the selfless chapter authors who contributed their time and expertise without the expectation of anything in return other than a free copy of the book. Without them, this book would not have been possible. I would also like to express my heartfelt gratitude to my boss, Doug Mann (who also edits a cardiology textbook for Elsevier that you may have heard of), for hiring me to work at Washington University, for always supporting my various academic endeavors, and for being a superb role model as a person and an academic cardiologist. Finally, I thank my family for tolerating the time I spent working on this and other projects.

David L. Brown

**Masood Akhtar, MD, FHRS, MACP,
FACC, FAHA**

Aurora Cardiovascular Services
Director of Electrophysiology Research
Aurora Sinai/Aurora St. Luke's Medical
Centers;
Adjunct Clinical Professor of Medicine
University of Wisconsin School of Medicine
and Public Health
Milwaukee, Wisconsin

William R. Auger, MD

Professor of Clinical Medicine
UCSD Healthcare
La Jolla, California

Richard G. Bach, MD

Professor of Medicine
Washington University School of Medicine;
Director, Cardiac Intensive Care Unit
Director, Hypertrophic Cardiomyopathy
Center
Barnes-Jewish Hospital
St. Louis, Missouri

Raquel R. Bartz, MD, MMCI

Division Chief, Critical Care Medicine
Department of Anesthesiology
Duke University School of Medicine
Durham, North Carolina

Eric R. Bates, MD

Professor of Internal Medicine
Department of Internal Medicine
Division of Cardiovascular Diseases
University of Michigan
Ann Arbor, Michigan

Brigitte M. Baumann, MD, MSCE

Professor
Department of Emergency Medicine
Cooper Medical School of Rowan University
Camden, New Jersey

Richard C. Becker, MD

Professor
Department of Internal Medicine
University of Cincinnati College of
Medicine
Cincinnati, Ohio

Dmitri Belov, MD

Assistant Professor of Medicine
Director, Advanced Heart Failure
Department of Cardiology
Albany Medical Center
Albany, New York

Andreia Biolo, MD, ScD

Professor of Medicine
Coordinator, Post-Graduate Program in
Cardiology
Federal University of Rio Grande do Sul;
Heart Failure and Cardiac Transplant Group
Section of Cardiology
Hospital de Clinicas de Porto Alegre
Porto Alegre, Brazil

Daniel Blanchard, MD

Professor of Medicine
Director, Cardiology Fellowship Program
University of California–San Diego
La Jolla, California

David L. Brown, MD

Professor of Medicine (Cardiovascular
Disease)
Washington University School of Medicine
St. Louis, Missouri

Clifton W. Callaway, MD, PhD

Professor of Emergency Medicine
Executive Vice-Chairman of Emergency
Medicine
Ronald D. Stewart Endowed Chair of
Emergency Medicine Research
University of Pittsburgh School of Medicine
Pittsburgh, Pennsylvania

Matthew J. Chung, MD

Interventional Cardiology Fellow
Department of Internal Medicine
Cardiovascular Division
Washington University School of Medicine
St. Louis, Missouri

Richard F. Clark, MD

Professor
Department of Emergency Medicine
University of California–San Diego School
of Medicine;
Director
Division of Medical Toxicology
UCSD Medical Center;
Medical Director, San Diego Division
California Poison Control System
San Diego, California

Wilson S. Colucci, MD

Professor of Medicine and Physiology
Boston University School of Medicine;
Chief, Section of Cardiovascular Medicine
Co-Director, Cardiovascular Center
Boston Medical Center
Boston, Massachusetts

Leslie T. Cooper Jr, MD

Chair
Cardiovascular Department
Mayo Clinic
Jacksonville, Florida

Harold L. Dauerman, MD

Division of Cardiology
University of Vermont Larner College of
Medicine
Burlington, Vermont

Elyse Foster, MD

Professor of Medicine
Department of Cardiology
University of California–San Francisco
San Francisco, California

Stephanie Gaydos, MD

Congenital Cardiology Fellow
Medical University of South Carolina
Charleston, South Carolina

Mark Gdowski, MD

Cardiology Fellow
Barnes-Jewish Hospital
Washington University School of Medicine
St. Louis, Missouri

Timothy Gilligan, MD, MS, FASCO

Associate Professor of Medicine
Department of Hematology and Medical
Oncology
Vice-Chair for Education, Taussig Cancer
Institute
Director of Coaching, Center for Excellence
in Healthcare Communication
Cleveland Clinic
Cleveland, Ohio

Michael M. Givertz, MD

Medical Director, Heart Transplant and
Circulatory Support Program
Brigham and Women's Hospital;
Professor of Medicine
Harvard Medical School
Boston, Massachusetts

Prospero B. Gogo Jr, MD

Division of Cardiology
University of Vermont Larner College of
Medicine
Burlington, Vermont

Sarah J. Goodlin, MD

Chief of Geriatrics
VA Portland Health Care System
Associate Professor of Medicine
Oregon Health & Science University
Portland, Oregon

Barry Greenberg, MD

Distinguished Professor of Medicine
Director, Advanced Heart Failure Treatment
Program
University of California—San Diego
La Jolla, California

David Gregg IV, MD

Associate Professor of Medicine and
Cardiology
Medical University of South Carolina
Charleston, South Carolina

George Gubernikoff, MD

Director, Noninvasive Cardiology
Medical Director, Center for Aortic Diseases
NYU Winthrop Hospital
Mineola, New York

Colleen Harrington, MD

Assistant Professor of Medicine
Division of Cardiovascular Medicine
UMass Memorial
Worcester, Massachusetts

Nazish K. Hashmi, MD

Assistant Professor
Department of Anesthesiology
Duke University Medical Center
Durham, North Carolina

Alan C. Heffner, MD

Director of Critical Care
ECMO Medical Director
Pulmonary and Critical Care Consultants
Carolinas Medical Center
Charlotte, North Carolina

Bettina Heidecker, MD

Head, Heart Failure and Cardiomyopathies
Charité, Campus Benjamin Franklin
Berlin, Germany

Maureane Hoffman, MD, PhD

Pathology and Laboratory Medicine Service
Durham Veterans Affairs Medical Center;
Department of Pathology
Duke University Medical Center
Durham, North Carolina

Brian D. Hoit, MD

Professor of Medicine, Physiology, and
Biophysics
Case Western Reserve University;
Director of Echocardiography
Harrington Heart & Vascular Center
University Hospital Cleveland Medical
Center
Cleveland, Ohio

Ruth Hsiao, MD

Chief Medical Resident
Department of Internal Medicine
University of California—San Diego
La Jolla, California

Robert C. Hyzy, MD

Medical Director, Critical Care Medicine
Unit
Professor of Medicine
Division of Pulmonary and Critical Care
Medicine
University of Michigan Medical School
Ann Arbor, Michigan

Jacob C. Jentzer, MD

Assistant Professor of Medicine
Department of Cardiovascular Diseases
Division of Pulmonary and Critical Care
Medicine, Department of Internal
Medicine
Mayo Clinic
Rochester, Minnesota

Joyce Ji, MD

Resident Physician
Department of Internal Medicine
Barnes-Jewish Hospital
St. Louis, Missouri

Lauren H. Jones, MD

Anesthesiology Resident
Department of Anesthesiology
Duke University Medical Center
Durham, North Carolina

Ulrich Jorde, MD

Professor of Medicine
Section Head
Heart Failure, Cardiac Transplantation, and
Mechanical Circulatory Support
Vice-Chief, Division of Cardiology
Montefiore Medical Center
Albert Einstein College of Medicine
New York, New York

Rochelle Judd, NP

Adult Congenital Cardiology Nurse
Practitioner
Medical University of South Carolina
Charleston, South Carolina

Jason N. Katz, MD, MHS

Associate Professor of Medicine
Associate Professor of Surgery
Divisions of Cardiology and Pulmonary &
Critical Care Medicine
University of North Carolina School of
Medicine;
UNC Health Care System Director,
Cardiovascular Critical Care, Mechanical
Circulatory Support, and the
Cardiogenic Shock Program
Medical Director, UNC Mechanical Heart
Program
Medical Director, Cardiac Intensive Care
Unit
Medical Director, Cardiovascular and
Thoracic Surgical Intensive Care Unit
and Critical Care Service
UNC Center for Heart and Vascular Care
Chapel Hill, North Carolina

Mohamad Kenaan, MD

Clinical Assistant Professor
Michigan State University College of
Human Medicine
Division of Cardiovascular Medicine
Spectrum Health—Meijer Heart Center

Briana N. Ketterer, MD

Hospice and Palliative Care Fellow
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Holly Keyt, MD

Assistant Professor of Medicine
University of Texas Health San Antonio
San Antonio, Texas

Jon A. Kobashigawa, MD

Associate Director
Cedars-Sinai Heart Institute;
Director, Advanced Heart Disease Section
Director, Heart Transplant Program
Cedars-Sinai Medical Center
Los Angeles, California

Richard Koch, MD

Fellow
Medical Toxicology
University of California—San Diego
San Diego, California;
Staff Physician
Naval Hospital Sigonella
Sigonella, Italy

Sándor J. Kovács, PhD, MD

Professor of Medicine, Physiology,
Biomedical Engineering, and Physics
Washington University in St. Louis
St. Louis, Missouri

Alexander Kuo, MD

Instructor
Harvard Medical School;
Physician
Department of Anesthesia, Critical Care,
and Pain Medicine
Massachusetts General Hospital
Boston, Massachusetts

Milla J. Kviatkovsky, DO, MPH

Assistant Clinical Professor of Medicine
Department of Hospital Medicine
University of California–San Diego
La Jolla, California

A. Michael Lincoff, MD

Vice Chairman
Department of Cardiovascular Medicine
Cleveland Clinic
Cleveland, Ohio

Mark S. Link, MD

Professor of Medicine
Director, Cardiac Electrophysiology
Department of Internal Medicine
Division of Cardiology
University of Texas Southwestern Medical
Center
Dallas, Texas

Jacob Luthman, MD

Cardiology Fellow
Department of Internal Medicine
University Hospitals Cleveland Medical
Center
Cleveland, Ohio

Judith A. Mackall, MD

Director
Cardiac Device Clinic
Division of Cardiology
University Hospitals Cleveland Medical
Center;
Associate Professor of Medicine
Case Western Reserve University
Cleveland, Ohio

Rohit Malhotra, MD

Associate Professor
Department of Internal Medicine
Division of Cardiology
University of Virginia
Charlottesville, Virginia

Pamela K. Mason, MD

Associate Professor
Department of Internal Medicine
Division of Cardiology
University of Virginia
Charlottesville, Virginia

Jason Matos, MD

Clinical and Research Fellow
Department of Medicine
Division of Cardiology
Beth Israel Deaconess Medical Center
Boston, Massachusetts

Sharon McCartney, MD

Assistant Professor
Department of Anesthesiology
Duke University Medical Center
Durham, North Carolina

Theo E. Meyer, MD, DPhil

Professor of Medicine
Chief, Clinical Cardiology
University of Massachusetts Medical School
UMass Memorial Medical Center
Worcester, Massachusetts

Alicia Minns, MD

Assistant Clinical Professor of Emergency
Medicine
University of California–San Diego
La Jolla, California

Joshua D. Mitchell, MD

Cardiology Fellow
Washington University Medical Center
St. Louis, Missouri

**Narain Moorjani, MB ChB, MRCS, MD,
FRCS(C-Th), MA**

Consultant Cardiac Surgeon and Clinical
Lead for Cardiac Surgery
Royal Papworth Hospital;
Associate Lecturer
University of Cambridge
Cambridge, United Kingdom

Jonathan D. Moreno, MD, PhD

Cardiology Fellow
Department of Medicine
Division of Cardiology
Washington University in St. Louis
St. Louis, Missouri

Michael S. O'Connor, DO, MPH

Staff Anesthesiologist
Assistant Professor
Cleveland Clinic Lerner College of
Medicine;
Department of Cardiothoracic
Anesthesiology
Anesthesia Institute
Cleveland Clinic
Cleveland, Ohio

Marlies Ostermann, PhD, MD, FICM

Department of Nephrology
King's College London
Guy's & St. Thomas' Hospital & Critical
Care
London, United Kingdom

Demosthenes G. Papamtheakis, MD

Assistant Professor
Department of Medicine
UC San Diego Health
La Jolla, California

Nimesh Patel, MD

Cardiology Fellow
Department of Internal Medicine
University of Texas Southwestern Medical
Center
Dallas, Texas

Richard M. Pescatore II, DO

Chief Resident
Department of Emergency Medicine
Cooper Medical School of Rowan University
Camden, New Jersey

Jay I. Peters, MD

Professor and Chief
Pulmonary and Critical Care Medicine
University of Texas Health Science Center
San Antonio, Texas

**Abhiram Prasad, MD, FRCP, FESC,
FACC**

Professor of Medicine
Department of Cardiovascular Diseases
Mayo Clinic
Rochester, Minnesota

**Susanna Price, MBBS, BSc, MRCP,
EDICM, PhD, FFICM, FESC**

Consultant Cardiologist and Intensivist
Royal Brompton Hospital;
Honorary Senior Lecturer
Imperial College
London, United Kingdom

Thomas M. Przybysz, MD

Critical Care Physician
Carolinas Medical Center
Charlotte, North Carolina

Claudio Ronco, MD

Director
Department of Nephrology, Dialysis, and
Transplantation
Director
International Renal Research Institute
San Bortolo Hospital
Vicenza, Italy

Michael Shehata, MD

Associate Professor of Medicine
Program Director, Cardiac
Electrophysiology Fellowship
Heart Rhythm Center
Cedars Sinai Heart Institute
Los Angeles, California

Jeffrey A. Shih, MD

Assistant Professor
Department of Internal Medicine
Division of Cardiovascular Medicine
University of Massachusetts
Worcester, Massachusetts

Daniel M. Shivapour, MD

Interventional Cardiology Fellow
Department of Cardiovascular Medicine
Cleveland Clinic
Cleveland, Ohio

Adam Shpigel, MD

Cardiology Fellow
Washington University School of Medicine
St. Louis, Missouri

Bryan Simmons, MD

Staff Anesthesiologist and Intensivist
Aurora St. Luke's Medical Center
Milwaukee, Wisconsin

Daniel B. Sims, MD

Assistant Professor of Medicine
Director, Moses Cardiac Intensive Care Unit
Department of Cardiology
Montefiore Medical Center
Albert Einstein College of Medicine
New York, New York

Hal A. Skopicki, MD, PhD

Chief of Cardiology
Director, Heart Failure and Cardiomyopathy
Center
Co-director, Ventricular Assist Device
Program
Stony Brook University Heart Institute
Stony Brook University School of Medicine
Stony Brook, New York

Martin L. Smith, STD

Director of Clinical Ethics
Department of Bioethics
Cleveland Clinic
Cleveland, Ohio

Burton E. Sobel, MD†

Division of Cardiology
University of Vermont Larner College of
Medicine
Burlington, Vermont

Nishtha Sodhi, MD

Structural Heart Disease Fellow
Cardiovascular Department
Barnes-Jewish Hospital of Washington
University
St. Louis, Missouri

Ali A. Sovari, MD, FACC, FHRS

Cardiac Electrophysiologist
Cedars-Sinai Medical Center
Oxnard, California

Dina M. Sparano, MD

Assistant Professor of Medicine
Case Western Reserve University School of
Medicine
Director, Lead Management Program
Associate Program Director,
Electrophysiology Fellowship Program
University Hospitals Cleveland Medical
Center
Harrington Heart & Vascular Institute
Cleveland, Ohio

Peter C. Spittell, MD

Consultant
Department of Cardiology
Mayo Clinic
Rochester, Minnesota

Christie Sun, MD

Toxicology Fellow
Department of Emergency Medicine
University of California—San Diego
La Jolla, California

Roderick Tung, MD, FACC, FHRS

Associate Professor of Medicine
Director, Cardiac Electrophysiology & EP
Laboratories
University of Chicago Medicine
Center for Arrhythmia Care/Heart and
Vascular Center
Chicago, Illinois

Peter D. Wagner, MD

Distinguished Professor of Medicine and
Bioengineering
University of California—San Diego School
of Medicine
La Jolla, California

Daniel E. Westerdahl, MD, FACC

Advanced Heart Failure Cardiologist
Chair, Department of Cardiology
Providence St. Vincent Medical Center
Portland, Oregon

Ryan E. Wilson, MD

Interventional Cardiology Fellow
Gill Heart Institute
University of Kentucky
Lexington, Kentucky

Jonathan D. Wolfe, MD

Cardiology Fellow
Department of Cardiology
Barnes-Jewish Hospital
Washington University in St. Louis
St. Louis, Missouri

Paria Zarghamravanbakhsh, MD

Department of Medicine
Mount Sinai-Queens Hospital
New York, New York

Shoshana Zevin, MD

Internal Medicine
Shaare Zedek Medical Center
Jerusalem, Israel

Khaled M. Ziada, MD, FACC, FSCAI

Gill Heart Institute
University of Kentucky
Lexington, Kentucky

Jodi Zilinski, MD

Aurora Cardiovascular Services
Aurora Sinai/Aurora St. Luke's Medical
Centers;
Adjunct Assistant Clinical Professor of
Medicine
University of Wisconsin School of Medicine
and Public Health
Milwaukee, Wisconsin

Peter Zimetbaum, MD

Richard and Smith Professor of
Cardiovascular Medicine
Harvard Medical School;
Associate Chief and Clinical Director of
Cardiology
Beth Israel Deaconess Medical Center
Cambridge, Massachusetts

†Deceased.

Evolution of the Coronary Care Unit: Past, Present, and Future

Jason N. Katz, Richard C. Becker

OUTLINE

Origins of the Coronary Care Unit, 2

Early Days of Resuscitation, 2

A Paradigm Shift—Prevention of Cardiac Arrest, 3

Validating the Benefit of the Coronary Care Unit, 4

Economic Impact of the Cardiac Intensive Care Unit, 4

Patient Selection in the Cardiac Intensive Care Unit, 4

Defining the Contemporary Cardiac Intensive Care Unit, 4

Ongoing Evolution of Cardiac Intensive Care Units, 5

Multidisciplinary Clinical Integration and the Cardiac Intensive Care Unit Model, 5

Management Algorithms, 7

Education and Training in the Cardiac Intensive Care Unit, 7

Technology Needs in Contemporary Cardiac Intensive Care Units, 8

Research in the Cardiac Intensive Care Unit, 8

Research Processes, 9

Informed Consent, 10

Developing an On-site Research Program, 10

Conclusion, 10

Originating during a time of recognized unmet medical need and advances in medicine, the coronary care unit (CCU) emerged as one of the most important advances in the care of patients with life-threatening cardiovascular conditions. It has evolved further with technology, including mechanical circulatory support, to become a portal of entry for critically ill patients requiring a high level of support and vast resources. The emergence of contemporary cardiac intensive care units (CICUs) has introduced paradigm shifts in staffing, necessary skill sets, training, and cost for hospitals and health systems. This chapter offers a historical perspective of CCUs and their journey to the contemporary era of CICUs that provide high-acuity tertiary and quaternary care in the United States (Fig. 1.1). Also discussed are several pertinent constructs for academic medical centers with busy CICUs, including education, training of physician and nonphysician providers, and the importance of research as a vehicle to drive discovery and advanced care.

ORIGINS OF THE CORONARY CARE UNIT

Several seminal descriptions of acute myocardial infarction (MI)—a frequently fatal event at the time—underscored a clear medical unmet need.^{1,2} Other than morphine and supportive measures, there were very few options to effectively manage patients with acute MI.

Early Days of Resuscitation

The first impactful therapy to attenuate the most common and life-threatening complications of MI, ventricular tachycardia and

ventricular fibrillation, emerged with open-chest^{3,4} and, later, closed-chest defibrillation.^{5,6} Soon after these original descriptions,⁷ the overall construct of a CCU designed with specific goals to detect and treat fatal ventricular arrhythmias rapidly evolved.

Desmond Julian was the first to articulate the general construct of a CCU. In his original 1961 presentation to the Royal Thoracic Society,⁸ he described five cases of cardiac massage with the goal to resuscitate patients with acute MI. He came to the profound conclusion that “many cases of cardiac arrest associated with acute myocardial ischaemia could be treated successfully if all medical, nursing, and auxiliary staff were trained in closed-chest massage, and if the cardiac rhythm of patients...was monitored by an electrocardiographic link to an alarm system.” His vision for the CCU was founded on the following four basic principles:

- Continuous electrocardiogram monitoring with arrhythmia alarms
- Cardiopulmonary resuscitation with external defibrillator capabilities
- Admission of patients with acute MI to a single unit of the hospital where trained personnel, cardiac medications, and specialized equipment were readily available
- The ability of trained nurses to initiate resuscitation attempts in the absence of physicians

Approximately 3 years later, the first CCU was established at the Royal Infirmary of Edinburgh. Soon thereafter, several clinicians in North America developed specialized units devoted exclusively to the treatment of patients with suspected MI. Meltzer⁹ created a two-room research unit with an aperture in the wall

Keywords

Coronary Care Unit

Cardiovascular Intensive Care Unit

Resuscitation

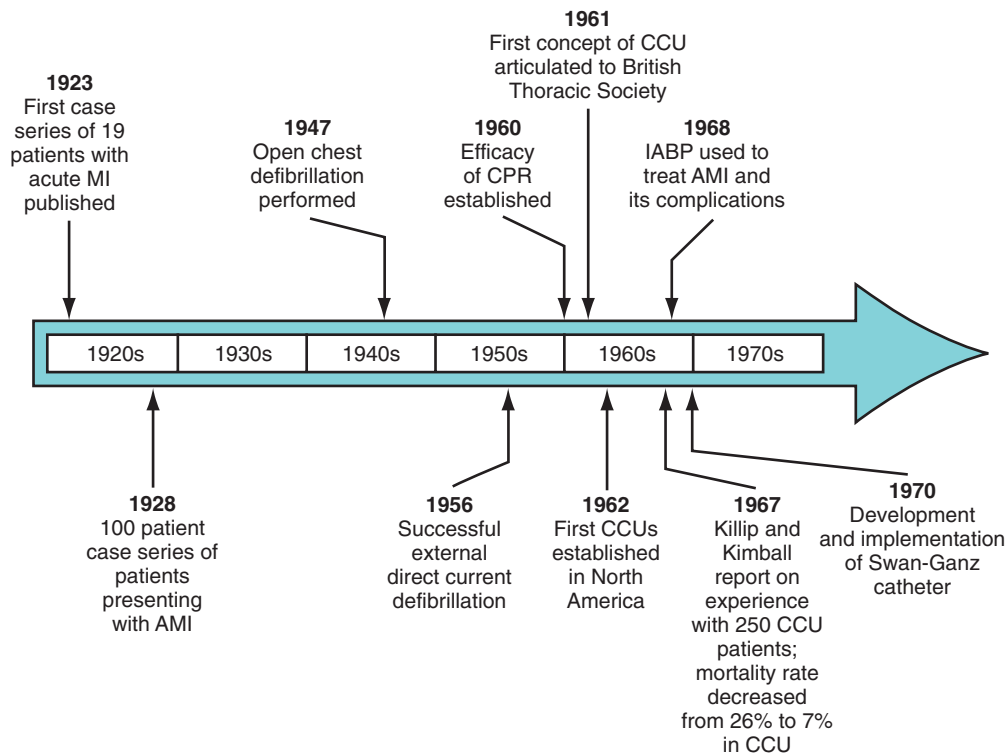


Fig. 1.1 Evolution of the coronary care unit over time. *AMI*, Acute myocardial infarction; *CCU*, coronary care unit; *CPR*, cardiopulmonary resuscitation; *IABP*, intraaortic balloon pump; *MI*, myocardial infarction.

through which defibrillator paddles could be passed from one patient to the other. Brown and associates¹⁰ established a four-bed unit with an adjacent nursing station and arrhythmia surveillance provided using a converted electroencephalogram unit with electrocardiogram amplifiers.

Day,¹¹ a contemporary of Meltzer, Brown, and Julian, built mobile “crash carts” in an attempt to resuscitate patients with acute MI who were admitted to general medical wards. He recognized that delays in arrhythmia detection significantly limited the success of subsequent resuscitation attempts. As a result of his observations, an 11-bed unit was established at Bethany Hospital in New York staffed by “specially trained nurses who could provide expert bedside attention, interpret signs of impending decompensation and quickly institute CPR.” Day is largely credited with introducing the term *code blue* to describe resuscitation efforts for cyanotic patients following cardiac arrest and the term *coronary care unit*.

A Paradigm Shift—Prevention of Cardiac Arrest

Julian¹² described the “second phase” of CCUs as an expansion from a sole focus on resuscitation to prevention of lethal arrhythmias and advanced care. Killip and Kimball¹³ published their experience of 250 patients with acute MI treated in a four-bed CCU at New York Hospital–Cornell Medical Center and reported that aggressive medical therapy reduced in-hospital mortality from 26% to 7%. This led Killip and Kimball to conclude that “the development of the coronary care unit represents one of the most significant advances in the hospital practice of

medicine.”¹³ Not only did it seem that patients with acute MI had improved survival if treated in a CCU, but also all in-hospital cardiac arrest patients seemed more likely to survive if geographically located in the CCU. “Although frequently sudden, and hence often ‘unexpected,’ the cessation of adequate circulatory function is usually preceded by warning signals.”¹³ Thus began the era of CCUs throughout the world, with a categorical focus on the prevention of cardiac arrest.

Lown and colleagues¹⁴ detailed the key components of the CCU at the Peter Bent Brigham Hospital in Boston. The foundation of their CCU centered on assembling a “vigilant group of nurses properly indoctrinated in electrocardiographic pattern recognition and qualified to intervene skillfully with a prerehearsed and well-disciplined repertoire of activities in the event of a cardiac arrest.”¹⁴ With a CCU mortality of 11.5% and an in-hospital mortality of 16.9%, these clinician-investigators hypothesized that an aggressive protocol for arrhythmia suppression after MI could virtually eradicate sudden, unexpected death. While cumulative data did not support routine preventive antiarrhythmic therapy in MI,¹⁵ the fundamental construct of advanced care for patients at risk for post-MI complications established a foundation for contemporary CCUs.

Additional developments in the care of patients with acute MI—including the use of intraaortic balloon counterpulsation,¹⁶ the implementation of flow-directed catheters for hemodynamic monitoring,¹⁷ and either pharmacologic or mechanical myocardial reperfusion therapy¹⁸—contributed to the advance and wide-scale availability of CCUs.

VALIDATING THE BENEFIT OF THE CORONARY CARE UNIT

With the advent of CCUs and recognition that intensive care rendered on a “24-7” basis required substantial resources with resulting cost, the medical community posed fundamental questions about outcomes. Early comparisons of CCUs and general medical wards suffered from their observational nature and lack of analytic rigor. For example, the previously described study performed by Killip and Kimball¹³ attributed a near 20% decline in mortality to the successful implementation of the CCU environment. Other observational studies conducted in the United States¹⁹ and Scandinavia^{20,21} drew similar conclusions, with lower mortality rates and greater resuscitation success in patients with acute MI treated in a CCU setting.

Several investigators²² attributed the decline in mortality rates from ischemic heart disease in the United States to the presence of CCUs. From 1968 to 1976, estimates suggested a decline in mortality of approximately 21%. This, in turn, translated to saving 85,000 lives over the observation period.^{23,24} The key to improved outcomes was likely the specialized care received in the CCU setting. This theme continued to play out during the era of reperfusion for acute MI.²⁵ Few would challenge the importance of specialized resources and care in the management of patients with complex cardiovascular disease.²⁶

Economic Impact of the Cardiac Intensive Care Unit

Intensive care units (ICUs) are places of high resource use and high expenditure. Accordingly, they contribute significantly to the economic burden of health care.²⁷ While ICUs constitute less than 10% of hospital beds in the United States, estimates suggest that they consume more than 20% of total hospital costs and nearly 1% of the US gross domestic product.^{28,29} It has been reported that ICU costs have increased by nearly 200% in the years 1985 to 2000.³⁰ These observations underscore the importance of patient selection and resource utilization. Contemporary data support similarities in resource use, morbidity and mortality, and in-hospital length of stay for ICUs and CICUs.³¹⁻³⁴

PATIENT SELECTION IN THE CARDIAC INTENSIVE CARE UNIT

The current cost of health care in the United States dictates utilization of services that are carefully aligned with patient needs. The \$3 trillion of health care expenditures suggests that this tenet is not being followed optimally. While CCUs were developed initially to manage arrhythmias among patients with acute MI, it is becoming increasingly clear that monitoring capabilities, staffing, and expertise can be provided on dedicated cardiology floors for many patients. Accordingly, each institution must establish metrics of acuity and complex care that take full advantage of CICUs and the resources therein.³⁵

The appropriate organizational structure is of great importance in contemporary CICUs. We believe that whether an open- or closed-unit model is employed, the key to delivering optimal care is aligning provider skill set with specific patient needs.

This is particularly important within an ICU where changes in patient status occur suddenly and require immediate recognition and action. While medical ICUs and CICUs may seem more similar than dissimilar, it is the responsibility of all institutions to recognize specific needs and staff their units accordingly³⁶ (Fig. 1.2).

The CCU landscape has evolved substantially over the past several decades to a unit better described as a CICU. As a result of diagnostic platforms, advanced pharmacotherapeutics, mechanical circulatory assist devices, and novel interventional techniques, cardiologists have impacted the natural history of MI significantly. Consequently, the mortality rates for acute MI have steadily declined.^{37,38} At the same time, however, the care of patients with other complex cardiovascular diseases and noncardiac critical illness is steadily increasing in the CICU. An aging US population, acute and chronic sequelae of nonfatal MI, comorbid medical conditions, and complications of implantable devices all result in increased susceptibility to critical illness in high-risk patients. Many, if not all, of these patients are likely to be admitted to the modern-day CICU. What were previously purely resuscitative and preventive units for patients with MI have now arguably transformed into critical care units for patients with cardiovascular disease. In fact, many institutions now refer, either formally or informally, to their CCU as the CICU.

In a descriptive analysis of US critical care units, Groeger and colleagues³⁹ highlighted mortality statistics, resource use data, and patient characteristics of modern CICUs; their results were remarkably comparable to composite data from contemporary medical ICUs.^{33,34} The severity of illness, quantified by a classic measure of critical illness (the APACHE [Acute Physiology, Age, and Chronic Health Evaluation] II score), was the greatest independent predictor of in-hospital mortality in a CICU cohort of patients—suggesting that risk stratification in the CICU could be conducted in a manner similar to other ICUs, where the APACHE II score is well established.

If the contemporary CICU has become an ICU for patients with complex cardiovascular disease, reassessment of patient selection, resources, cost, and required training for faculty, nurses, and support staff must be undertaken. A growing body of evidence supports the ability of critical care specialists to improve the care of ICU patients,⁴⁰⁻⁴² and it is anticipated that patients in the CICU would derive similar benefit.³⁹

DEFINING THE CONTEMPORARY CARDIAC INTENSIVE CARE UNIT

Several contemporary databases have been used to illustrate the demographic, clinical, and operational characteristics of ICUs in the United States.^{39,43,44} In turn, these datasets have been used to establish practice guidelines, generate hypotheses for clinical research undertakings, and accelerate quality improvement initiatives in critical care medicine. Our longitudinal assessment of Duke University Hospital provided an early glimpse of a sea change in academic CCUs.

We created a single-center, administrative database containing 2 decades of diagnostic, procedural, demographic, and outcome-related variables from the Duke CCU and clearly demonstrated