Third Edition

Critical Heart Disease in Infants and Children

Ross M. Ungerleider
Jon N. Meliones
Kristen Nelson McMillan
David S. Cooper
Jeffrey P. Jacobs

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Ross M. Ungerleider, MD, MBA

Director, Heart Center
Driscoll Children's Hospital
Corpus Christi, Texas

Jon N. Meliones, MD, MS, FCCM

Professor of Pediatrics Section Chief
Divisions of Critical Care and Hospitalists Medicine
Children's Memorial Herman Hospital
UT Health McGovern Medical School
Houston, Texas

Kristen Nelson McMillan, MD

Assistant Professor of Anesthesiology and Critical Care Medicine and Pediatrics
Division of Pediatric Anesthesia and Critical Care Medicine
Director, Pediatric Cardiac Critical Care
Medical Director, Pediatric Ventricular Assist Device Program
The Johns Hopkins University School of Medicine
Baltimore, Maryland

David S. Cooper, MD, MPH

Medical Director, Cardiac Intensive Care Unit
The Heart Institute
Center for Acute Care Nephrology
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Jeffrey P. Jacobs, MD, FACS, FACC, FCCP

Professor of Surgery and Pediatrics
The Johns Hopkins University
Deputy Director, John's Hopkins All Children's Heart Institute
Surgical Director of Heart Transplantation
Johns Hopkins All Children's Hospital
Saint Petersburg, Florida

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

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To our readers, whose dedication to learning, commitment to caring, and passion to constantly improving our profession gives us all great hope.

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Dedicated to my children, Susan, Peter, Graham, Brynn, and Worth, without whom I would never have been able to fully comprehend why we in this field often exhaust ourselves making sure we do our best; and to my wife, Jamie, who has helped nourish and nurture the spirit called by my name with love, knowledge, wisdom, and joy.

RMU

To my incredible wife, Christine—thank you for the love, advice, and support—and to all my amazing children; you inspire me every moment of every day!

JNM

To my father, Lesley Nelson: Thank you for being my lifelong hero and for always being there, supporting, encouraging, and loving me.
To my husband, William McMillan: Thank you for your service to our country and for your endless and unwavering dedication and love to me and to our families. You are what makes all of this possible every day.
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To all of my patients and their families: There are not enough words to say what a privilege it has been to be a part of your lives. Thank you for all you have taught me.

KNM

In memory of my father, Hy, for teaching me the value of hard work. To my mother, Irene, for imparting unto me a love of learning and teaching. To my wife, Lisa, for her love and unwavering support. To my children, Michael, Adam, and Daniel, for reminding me why I do what I do and inspiring me to be better than I am.

DSC

To my parents, David and Marilyn Jacobs, for giving me the opportunity; to my wife, Stacy, for supporting and loving me; to my children, Jessica and Joshua, for making me proud and motivated; and to my patients, who represent the rationale for this initiative.

JPJ

Contributors

Mubbasheer Ahmed, MD
Assistant Professor of Pediatrics
Baylor College of Medicine
Texas Children's Hospital
Houston, Texas

Samuel M. Alaish, MD
Associate Professor of Surgery
The Johns Hopkins University School of Medicine
Surgical Director, THRIVE Center for Pediatric Intestinal Rehabilitation
The Johns Hopkins Children's Center
Baltimore, Maryland

Euleche Alanmanou, MD, FAAP
Clinical Professor of Anesthesiology
University of Texas Medical Branch
Galveston, Texas
Clinical Coordinator of Pediatric Cardiac Anesthesiology
Department of Anesthesiology and Critical Care
Driscoll Children's Hospital
Corpus Christi, Texas

Plato Alexander, MD, MBA
Associate Director
Cardiovascular Intensive Care Unit
Johns Hopkins All Children's Hospital
St. Petersburg, Florida

Alaa Aljiffry, MBBS
Assistant Professor of Pediatrics
Pediatric Cardiology
Emory University
Pediatric Cardiac Intensivist
Children's Health Care of Atlanta
Atlanta, Georgia

Melvin C. Almodovar, MD
University of Miami
Miami, Florida

Bahaaldin Alsoufi, MD
Professor of Surgery
University of Louisville School of Medicine
Director of Pediatric Cardiac Surgery
Norton Children's Hospital
Louisville, Kentucky

Marc M. Anders, MD
Assistant Professor of Pediatrics
Texas Children's Hospital
Houston, Texas

Nicholas D. Andersen, MD
Chief Resident, Congenital Cardiac Surgery
Department of Cardiac Surgery
Boston Children's Hospital
Boston, Massachusetts

Judith Ascenzi, DNP, APRN-CNS, RN, CCRN
Nurse Manager
Pediatric Intensive Care Unit
The Johns Hopkins Hospital
Baltimore, Maryland

Scott I. Aydin, MD
Assistant Professor of Pediatrics
Division of Pediatric Critical Care Medicine and Cardiology
Icahn School of Medicine
Kravis Children's Hospital at Mount Sinai
New York, New York

Matthew K. Bacon, MD
Assistant Professor of Pediatrics
UK Healthcare
University of Kentucky
Kentucky Children's Hospital
Lexington, Kentucky

David J. Barron, MD, FRCP, FRCS(CT)
Consultant Cardiac Surgeon
Department of Cardiac Surgery
Birmingham Children's Hospital
Birmingham, United Kingdom

Amy Basken, MS
Director of Programs
Pediatric Congenital Heart Association
Madison, Wisconsin

Kimberly D. Beddows, NP
Nurse Practitioner, Pediatric Heart Transplant
Pediatric Heart Center
The Children's Hospital at Montefiore
New York, New York

Melania M. Bembea, MD, MPH, PhD
Associate Professor of Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Alexis L. Benscoter, DO
Assistant Professor of Cardiology
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Charles P. Bergstrom, MD
Assistant Professor of Pediatric Critical Care Medicine
Medical College of Wisconsin
Milwaukee, Wisconsin

Meghan Bernier, MD
Instructor of Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Steve Bibevski, MD, PhD
Section of Pediatric and Congenital Cardiac Surgery
The Heart Institute
Joe DiMaggio Children's Hospital
Hollywood, Florida

David Bichell, MD
William S. Stoney Jr. Chair in Surgery
Professor of Surgery
Division of Cardiac Surgery
Vanderbilt University
Nashville, Tennessee

Geoffrey L. Bird, MD, MSIS
Assistant Professor of Pediatrics, Critical Care Medicine, and Anesthesiology
Cardiac Critical Care Medicine
Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

Konstantinos Boukas, MD
Assistant Professor of Pediatrics
Division of Critical Care Medicine
UTHealth McGovern Medical School
Houston, Texas

Edward L. Bove, MD
Helen and Marvin Kirsh Professor of Surgery
Professor of Cardiac Surgery
Section of Pediatric Cardiovascular Surgery
University of Michigan Medical School
Ann Arbor, Michigan

Ken Brady, MD
Associate Professor of Pediatric Anesthesiology
Texas Children's Hospital
Houston, Texas

Craig S. Broberg, MD
Associate Professor of Cardiology and Radiology
Knight Cardiovascular Institute
Oregon Health and Science University
Portland, Oregon

Ronald A. Bronicki, MD, FCCM, FACC
Professor of Pediatrics
Sections of Critical Care Medicine and Cardiology
Baylor College of Medicine
Texas Children's Hospital
Houston, Texas

Julie A. Brothers, MD
Associate Professor of Pediatrics
Perelman School of Medicine
University of Pennsylvania
Attending Physician
Division of Cardiology
The Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

Kristen M. Brown, DNP, CRNP, CPNP-AC
Acute Care Pediatric Nurse Practitioner
Anesthesia and Critical Care Medicine
The Johns Hopkins University School of Medicine
Instructor
Advanced Practice Simulation Coordinator
Acute and Chronic Care
The Johns Hopkins University School of Nursing
Baltimore, Maryland

John R. Brownlee, MD
Pediatric Cardiology
Driscoll Children's Health System
Corpus Christi, Texas

Roosevelt Bryant III, MD
Assistant Professor of Surgery
University of Cincinnati College of Medicine
Surgical Director, Pediatric Heart Transplant Services
The Heart Institute
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Amulya Buddhavarapu, MD
Resident
Department of Pediatrics
Driscoll Children's Hospital
Texas A&M University
Corpus Christi, Texas

Duke E. Cameron, MD
Professor of Surgery
Harvard Medical School
Division of Cardiac Surgery
Massachusetts General Hospital
Boston, Massachusetts

Paul J. Chai, MD
Associate Professor of Surgery
Department of Pediatric Cardiac Surgery
Columbia University Medical Center
Morgan Stanley Children's Hospital
New York, New York

Paul A. Checchia, MD, FCCM, FACC
Professor of Pediatrics
Sections of Critical Care Medicine and Cardiology
Baylor College of Medicine
Texas Children's Hospital
Houston, Texas

Ira M. Cheifetz, MD
Chief Medical Officer
Children's Services
Duke Children's Hospital
Associate Chief Medical Officer
Duke University Hospital
Division Chief, Pediatric Critical Care Medicine
Professor of Pediatrics and Anesthesiology
Duke University Medical Center
Durham, North Carolina

Clifford Chin, MD
Professor of Pediatrics
University of Cincinnati College of Medicine
Medical Director, Pediatric Heart Transplant Services
The Heart Institute
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Jill Marie Cholette, MD
Associate Professor of Pediatrics
University of Rochester
Rochester, New York

Charles R. Cole, MD
Fellow
Department of Cardiothoracic Surgery
University of Colorado
Aurora, Colorado

David S. Cooper, MD, MPH
Medical Director, Cardiac Intensive Care Unit
The Heart Institute
Center for Acute Care Nephrology
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

John D. Coulson, MD
Clinical Associate
Assistant Professor, Part-Time Faculty
Department of Pediatrics
Division of Pediatric Cardiology
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Ralph J. Damiano Jr., MD
Evarts A. Graham Professor of Surgery
Chief, Division of Cardiothoracic Surgery
Washington University School of Medicine
Barnes-Jewish Hospital
Saint Louis, Missouri

Miguel DeLeon, MD
Medical Director, Neonatal Intensive Care Unit
Department of Neonatology
Driscoll Children's Hospital
Medical Director, Neonatal Intensive Care Unit
Department of Neonatology
Corpus Christi Medical Center
Corpus Christi, Texas

Holly C. DeSena, MD
Assistant Professor
The Heart Institute
Cincinnati Children's Hospital
Cincinnati, Ohio

Nina Deutsch, MD
Associate Professor of Anesthesiology and Pediatrics
Children's National Medical Center
George Washington University
Washington, D.C.

Pirooz Eghtesady, MD, PhD
Emerson Chair in Pediatric Cardiothoracic Surgery
Chief, Section of Pediatric Cardiothoracic Surgery
Washington University School of Medicine
St. Louis Children's Hospital
St. Louis, Missouri

Branden Engorn, MD
Fellow
Department of Anesthesiology Critical Care Medicine
Children's Hospital Los Angeles
Fellow
Department of Anesthesiology Critical Care Medicine
Keck School of Medicine of the University of Southern California
Los Angeles, California

Allen Everett, MD
Professor of Pediatrics
Division of Pediatrics and Cardiology
The Johns Hopkins University
Baltimore, Maryland

Lloyd Felmly, MD
Resident Physician
Department of Surgery
Division of Cardiothoracic Surgery
Medical University of South Carolina
Charleston, South Carolina

Andrew C. Fiore, MD
Professor of Surgery
Division of Pediatric Cardiovascular Surgery
Cardinal Glennon Children's Hospital
Saint Louis University School of Medicine
St. Louis, Missouri

Gregory A. Fleming, MD, MSCI
Assistant Professor of Pediatrics
Division of Pediatric Cardiology
Duke University Medical Center
Durham, North Carolina

Saul Flores, MD
Assistant Professor of Pediatrics
Section of Critical Care
Texas Children's Hospital
Baylor College of Medicine
Houston, Texas

Rodney Franklin, MD
Department of Pediatric Cardiology
Royal Brompton Hosptal
London, United Kingdom

Charles D. Fraser III, MD
Resident
Department of Surgery
The Johns Hopkins Hospital
Baltimore, Maryland

Michael Gaies, MD, MPH, MS
Assistant Professor of Pediatrics and Communicable Diseases
University of Michigan
Ann Arbor, Michigan

James J. Gangemi, MD
Associate Professor of Surgery and Pediatrics
Division of Thoracic and Cardiovascular Surgery
University of Virginia Health System
Charlottesville, Virginia

Lasya Gaur, MD
Assistant Professor of Pediatric Cardiology
The Johns Hopkins Hospital
Baltimore, Maryland

Nancy S. Ghanayem, MD
Professor of Pediatrics (Critical Care)
Baylor College of Medicine
Texas Children's Hospital
Houston, Texas

Salil Ginde, MD
Assistant Professor of Internal Medicine and Pediatrics (Cardiology)
Medical College of Wisconsin
Milwaukee, Wisconsin

Katja M. Gist, DO, MSc
Assistant Professor
Department of Pediatrics
Heart Institute
Children's Hospital Colorado
Denver, Colorado

Allan Goldman, MRCP, MBBcH, MSc
Great Ormond Street Hospital for Children
NHS Foundation Trust
London, United Kingdom

Stuart L. Goldstein, MD
Director, Center for Acute Care Nephrology
Department of Pediatrics
The Heart Institute
Division of Nephrology and Hypertension
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Dheeraj Goswami, MD
Assistant Professor of Anesthesia and Critical Care Medicine
The Johns Hopkins Hospital
Baltimore, Maryland

Eric M. Graham, MD
Professor of Pediatrics
Chief, Division of Pediatric Cardiology
Medical University of South Carolina
Charleston, South Carolina

Michelle A. Grenier, MD
Director of Imaging
Pediatric Cardiology
Driscoll Children's Hospital
Corpus Christi, Texas

Stephanie S. Handler, MD
Assistant Professor of Pediatrics (Cardiology)
Medical College of Wisconsin
Milwaukee, Wisconsin

James R. Herlong, MD
Division Chief, Pediatric Cardiology
Sanger Heart and Vascular Institute
Charlotte, North Carolina

Kevin D. Hill, MD, MSCI
Associate Professor of Pediatrics
Division of Pediatric Cardiology
Duke University Medical Center
Durham, North Carolina

Jennifer C. Romano, MD, MS
Assistant Professor of Cardiac Surgery and Pediatrics
Section of Pediatric Cardiovascular Surgery
University of Michigan Medical School
Ann Arbor, Michigan

Siew Yen Ho, PhD
Cardiac Morphology Unit
Royal Brompton Hospital
Imperial College London
London, United Kingdom

George M. Hoffman, MD
Professor of Anesthesiology and Pediatrics
Medical Director, Pediatric Anesthesiology
Medical College of Wisconsin and Children's Hospital of Wisconsin,
Milwaukee, Wisconsin

Osami Honjo, MD, PhD
The Hospital for Sick Children
University of Toronto
Toronto, Canada

Christoph P. Hornik, MD, MPH
Associate Professor
Division of Pediatric Critical Care Medicine
Department of Pediatrics
Duke University
Durham, North Carolina

Daphne T. Hsu, MD
Professor of Pediatrics
Albert Einstein College of Medicine
Chief, Pediatric Cardiology
Co-Director, Pediatric Heart Center
The Children's Hospital at Montefiore
New York, New York

Charles B. Huddleston, MD
Professor of Surgery
Division of Pediatric Cardiology
Saint Louis University School of Medicine
St. Louis, Missouri

Christin Huff, MSN, CPNP-AC
Nurse Practitioner
Cardiac Critical Care
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Elizabeth A. Hunt, MD, MPH, PhD
Director, Johns Hopkins Medicine Simulation Center
Associate Professor of Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Salim F. Idriss, MD, PhD
Associate Professor
Departments of Pediatrics, Pediatric Cardiology, and Pediatric Electrophysiology
Duke University
Durham, North Carolina

Ilias Iliopoulos, MD, FRCPCH, FRCPC, FAAP
Cardiac Critical Care
The Heart Institute
Cincinnati Children's Hospital Medical Center
Assistant Professor
Department of Pediatrics
University of Cincinnati
Cincinnati, Ohio

Kimberly Ward Jackson, MD
Director, Pediatric Emergency Response
Assistant Professor of Pediatrics
Duke University
Durham, North Carolina

Jeffrey P. Jacobs, MD, FACS, FACC, FCCP
Professor of Surgery and Pediatrics
The Johns Hopkins University
Deputy Director, John's Hopkins All Children's Heart Institute
Surgical Director of Heart Transplantation
Johns Hopkins All Children's Hospital
Saint Petersburg, Florida

Marshall L. Jacobs, MD
Professor of Surgery
Division of Cardiac Surgery
The Johns Hopkins School of Medicine
Baltimore, Maryland

James Jaggers, MD
Chief, Congenital Cardiac Surgery
Professor of Surgery
Barton Elliman Chair of Pediatric Cardiac Surgery
University of Colorado
Aurora, Colorado

Laura N. Jansen, PA-C
Physician Assistant
Pediatric Cardiothoracic Surgery
Levine Children's Hospital
Charlotte, North Carolina

Christopher M. Janson, MD
Assistant Professor of Pediatrics
Children's Hospital of Philadelphia, Cardiac Center
The Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

Robert Jaquiss, MD
Pogue Distinguished Chair in Pediatric Cardiac Surgery Research
Departments of Cardio Thoracic Surgery and Pediatrics
The University of Texas Southwestern Medical Center
Dallas, Texas

Emily Johnson, MSN, RN, CPNP-PC/AC
Nurse Practitioner
Pediatric Palliative Care
Bloomberg Children's Center
The Johns Hopkins Hospital
Baltimore, Maryland

Melissa B. Jones, MSN, APRN, CPNP-AC
Nurse Practitioner Team Lead for Critical Care
Cardiac Critical Care
Children's National Health System
Washington, D.C.

Lindsey Justice, DNP, RN, CPNP-AC
Cardiac Intensive Care Unit Nurse Practitioner
The Heart Institute
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Patricia L. Kane, MSN, CNS, CPNP
Lead Nurse Practitioner
Pediatric Cardiology/Cardiac Surgery
The Johns Hopkins Hospital
Baltimore, Maryland

Tara Karamlou, MD, MSc
Associate Professor of Surgery
Mayo Clinic
Cardiothoracic Surgeon
Western Regional Medical Center
Goodyear, Arizona

Vyas M. Kartha, MD, FAAP
Director, Pediatric Cardiac Anesthesia
Department of Anesthesiology
Johns Hopkins All Children's Hospital
St. Petersburg, Florida

Minoo N. Kavarana, MD, FACS
Associate Professor of Surgery
Medical University of South Carolina
Charleston, South Carolina

Abigail May Khan, MD
Assistant Professor of Medicine
Knight Cardiovascular Institute
Oregon Health and Science University
Portland, Oregon

Valerie King, BS
Parent as Collaborative Leader Educator
Parent Advocate
Yadkinville, North Carolina

Roxanne E. Kirsch, MD, MBE
Cardiac Intensivist
Department of Pediatric Critical Care and Anesthesiology
Critical Care Bioethics Associate
Department of Bioethics
The Hospital for Sick Children
Toronto, Ontario, Canada

Paul M. Kirshbom, MD
Chief, Pediatric Cardiac Surgery
Department of Surgery
Carolinas Healthcare System
Charlotte, North Carolina

Christopher J. Knott-Craig, MD
Professor of Surgery
Chief, Cardiovascular Surgery
Director,Heart Institute
University of Tennessee Health Sciences Center
Le Bonheur Children's Hospital
Memphis, Tennessee

Jeannie Koo, MSN, BSN
Nurse Practitioner
Pediatric Critical Care
Duke University Medical Center
Durham, North Carolina

Jennifer Kramer, MD
Pediatric Cardiology and Pediatric Critical Care Fellow
Department of Pediatrics
Division of Pediatric Cardiology
Department of Anesthesiology and Critical Care Medicine
Division of Pediatric Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Catherine D. Krawczeski, MD
Medical Director, Cardiovascular Intensive Care Unit
Department of Pediatrics
Division of Cardiology
Stanford University
Palo Alto, California

Ganga Krishnamurthy, MBBS
Garrett Isaac Neubauer Associate Professor of Pediatrics
Director of Neonatal Cardiac Intensive Care
Columbia University Medical Center
Morgan Stanley Children's Hospital
New York, New York

Sapna R. Kudchadkar, MD, PhD
Associate Professor
Department of Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Karan R. Kumar, MD
Pediatric Critical Care Fellow
Division of Pediatric Critical Care Medicine
Duke University
Durham, North Carolina

T.K. Susheel Kumar, MD
Assistant Professor
Pediatric Cardiothoracic Surgery
Le Bonheur Children's Hospital
Memphis, Tennessee

David M. Kwiatkowski, MD, MS
Assistant Professor
Department of Pediatrics
Division of Cardiology
Stanford University
Palo Alto, California

Jacqueline M. Lamour, MD
Professor of Pediatrics
Albert Einstein College of Medicine
Pediatric Heart Center
The Children's Hospital at Montefiore
Bronx, New York

Timothy S. Lancaster, MD
Fellow in Cardiothoracic Surgery
Washington University School of Medicine
St. Louis Children's Hospital
Barnes-Jewish Hospital
St. Louis, Missouri

Benjamin J. Landis, MD
Assistant Professor of Pediatrics and Medical and Molecular Genetics
Indiana University School of Medicine
Indianapolis, Indiana

Javier J. Lasa, MD, FAAP
Assistant Professor of Pediatrics
Sections of Critical Care Medicine and Cardiology
Baylor College of Medicine
Texas Children's Hospital
Houston, Texas

Matthew H.L. Liava'a, FRACS
Assistant Attending
Department of Pediatric Cardiac Surgery
Columbia University Medical Center
Morgan Stanley Children's Hospital
New York, New York

Daniel J. Licht, MD
Associate Professor of Neurology and Pediatrics
Department of Pediatrics
Division of Neurology
Children's Hospital, Philadelphia
Associate Professor
Department of Neurology
Perelman School of Medicine
The University of Pennsylvania
Philadelphia, Pennsylvania

Matthew T. Lisi, MD
Assistant Professor of Pediatric Cardiology
Wake Forest University School of Medicine
Winston Salem, North Carolina

Ryan Loftin, MD
Medical Director, Maternal Fetal Medicine
Driscoll Health System
Corpus Christi, Texas

Rohit S. Loomba, MD, MS
Clinical Fellow
Division of Cardiology
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Bradley S. Marino, MD, MPP, MSCE
Professor of Pediatrics and Medical Social Sciences
Northwestern University Feinberg School of Medicine
Co-Director, Research and Academic Affairs
Divisions of Cardiology and Critical Care Medicine
Ann and Robert H. Lurie Children's Hospital of Chicago
Chicago, Illinois

Thomas S. Maxey, MD
Pediatric Heart Surgeon
Levine Children's Hospital
Charlotte, North Carolina

Karen McCarthy, PhD
Cardiac Morphology Unit
Royal Brompton Hospital
Imperial College London
London, United Kingdom

Michael C. McCrory, MD, MS
Associate Professor of Anesthesiology and Pediatrics
Wake Forest School of Medicine
Winston-Salem, North Carolina

Inder D. Mehta, MD
Congenital Cardiovascular Surgeon
Driscoll Children's Hospital
Corpus Christi, Texas

Christopher Mehta, MD
Cardiothoracic Surgery Fellow
Department of Surgery
Northwestern University
Chicago, Illinois

Jon N. Meliones, MD, MS, FCCM
Professor of Pediatrics Section Chief
Divisions of Critical Care and Hospitalists Medicine
Children's Memorial Herman Hospital
UT Health McGovern Medical School
Houston, Texas

Christine Meliones, MSN, CPNP-AC/PC, FNP
Pediatric and Adult Congenital Electrophysiology Nurse Practitioner
Pediatric Cardiology/Electrophysiology
Duke University
Durham, North Carolina

Alison Miles, DO
Assistant Professor
Department of Pediatric Anesthesiology and Critical Care Medicine
Johns Hopkins Medicine
Baltimore, Maryland

Michael E. Mitchell, MD
Professor of Pediatric Cardiothoracic Surgery
Department of Surgery
Children's Hospital of Wisconsin
Professor of Surgery
Medical College of Wisconsin
Milwaukee, Wisconsin

Erica Molitor-Kirsch, MD
Medical Director, Cardiac Critical Care
Children's Mercy Hospital
Professor of Pediatrics
University of Missouri–Kansas City
Kansas City, Missouri

Jenny A. Montgomery, RN, MSN, CPNP-AC
Cardiovascular Nurse Practitioner Coordinator
Pediatric Heart Center
Driscoll Children's Hospital
Corpus Christi, Texas

Lisa Moore, RN, MSN, MHA, NEA-BC
Senior Director, Nursing
Heart Institute
Johns Hopkins All Childrens Hospital
St. Petersburg, Florida

David L.S. Morales, MD
Chief, Pediatric Cardiothoracic Surgery
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Cara Morin, MD, PhD
Clinical Fellow
Cincinnati Children's Hospital
Cincinnati, Ohio

Nicholas Morin, MD, PhD
Johns Hopkins Medicine
Baltimore, Maryland

Steven S. Mou, MD
Associate Professor of Anesthesiology and Pediatrics
Wake Forest School of Medicine
Winston-Salem, North Carolina

Ashok Muralidaran, MD
Assistant Professor of Surgery and Pediatrics
Oregon Health and Science University
Portland, Oregon

Raghav Murthy, MD, DABS, FACS
Assistant Clinical Professor of Cardiovascular Surgery
Rady Children's Hospital
University of California, San Diego
San Diego, California

Joseph R. Nellis, MD, MBA
Resident
Department of Surgery
Duke University
Durham, North Carolina

Jennifer S. Nelson, MD, MS
Associate Professor of Surgery
University of Central Florida College of Medicine
Department of Cardiovascular Services
Nemours Children's Hospital
Orlando, Florida

Kristen Nelson McMillan, MD
Assistant Professor of Anesthesiology and Critical Care Medicine and Pediatrics
Division of Pediatric Anesthesia and Critical Care Medicine
Director, Pediatric Cardiac Critical Care
Medical Director, Pediatric Ventricular Assist Device Program
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Melanie Nies, MD
Department of Pediatric Cardiology
The Johns Hopkins University
Baltimore, Maryland

John Nigro, MD
Cardiothoracic Surgery
Rady Children's Hospital–San Diego
San Diego, California

Corina Noje, MD
Assistant Professor of Anesthesiology and Critical Care Medicine
The Johns Hopkins University
Medical Director, Pediatric Transport
The Johns Hopkins Hospital
Baltimore, Maryland

Sarah E. Norris, MD
Assistant Professor of Pediatrics
Albert Einstein College of Medicine
Pediatric Heart Center
The Children's Hospital at Montefiore
Bronx, New York

James O'Brien, MD
Co-Director, The Ward Family Heart Center
Chief, Cardiothoracic Surgery
Children's Mercy Hospital
Kansas City, Missouri

George Ofori-Amanfo, MD
Chief, Divsion of Pediatric Critical Care Medicine
Professor of Pediatrics
Icahn School of Medicine
Kravis Children's Hospital at Mount Sinai
New York, New York

Richard G. Ohye, MD, CS
Professor and Associate Chair of Cardiac Surgery
Head, Section of Pediatric Cardiovascular Surgery
University of Michigan Medical School
Ann Arbor, Michigan

Yoshio Ootaki, MD, PhD
Departments of Pediatric Cardiothoracic Surgery and Pediatric Cardiology
Wake Forest Baptist Health
Winston Salem, North Carolina

Caroline P. Ozment, MD
Assistant Professor
Department of Pediatrics
Division of Pediatric Critical Care Medicine
Duke University
Durham, North Carolina

Giles J. Peek, MD
Professor of Clinical Cardiovascular and Thoracic Surgery
Division of Pediatric Cardiac Surgery
Albert Einstein College of Medicine
Pediatric Heart Center
The Children's Hospital at Montefiore
Bronx, New York

Autumn K. Peterson, BSN, MSN, CPNP-AC
Critical Care Pediatric Nurse Practitioner
Pediatric Critical Care Medicine
Duke Children's Pediatric and Congenital Heart Center
Duke University Medical Center
Durham, North Carolina

Renuka E. Peterson, MD
Associate Professor of Pediatric Cardiology
Division of Pediatric Cardiology
Cardinal Glennon Children's Hospital
Saint Louis University School of Medicine
St. Louis, Missouri

John K. Petty, MD
Associate Professor of Surgery and Pediatrics
Wake Forest School of Medicine
Winston-Salem, North Carolina

Prashob Porayette, MD, MSc
Pediatric Cardiologist
Driscoll Children's Hospital
Adjunct Assistant Professor of Pediatrics
Texas A&M College of Medicine
Corpus Christi, Texas

David E. Procaccini, PharmD
Clinical Pharmacy Practitioner
Pediatric Intensive Care and Pediatric Cardiology/Heart Transplant
The Johns Hopkins Hospital
Baltimore, Maryland

James Quintessenza, MD
Professor and Chief of Pediatric Cardiac Surgery
Kentucky Children's Hospital, University of Kentucky
Lexington, Kentucky
Professor and Attending Pediatric Cardiac Surgeon
Cincinnati Children's Hospital Medical Center
University of Cincinnati
Cincinnati, Ohio

William S. Ragalie, MD
Cardiothoracic Surgery Resident
Ronald Regan UCLA Medical Center
Los Angeles, California

William Ravekes, MD
Assistant Professor of Pediatrics
Division of Pediatric Cardiology
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Tia T. Raymond, MD
Pediatric Cardiac Intensivists of North Texas, PLLC
Congenital Heart Surgery Unit
Medical City Children's Hospital
Dallas, Texas

Andrew Redington, MD
Chief, Pediatric Cardiology
Executive Co-Director, The Heart Institute
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Kyle J. Rehder, MD
Associate Professor of Pediatrics
Duke Children's Hospital
Physician Quality Officer
Duke Patient Safety Center
Duke University Health System
Durham, North Carolina

Becky Riggs, MD
Assistant Professor of Pediatric Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Ramon Julio Rivera, MD
Associate Professor of Anesthesiology
University of Texas Medical Branch
Driscoll Children's Hospital
Corpus Christi, Texas

Jennifer Roark, MSN, FNP-C
Nurse Practitioner
Department of Pediatrics
Division of Pediatric Cardiology
Duke University Medical Center
Durham, North Carolina

Lewis H. Romer, MD
Professor of Anesthesiology and Critical Care Medicine, Cell Biology, Biomedical Engineering, and Pediatrics
Center for Cell Dynamics
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Amy Ryan, MSN, RN, CPNP-AC
Nurse Practitioner
Cardiac Intensive Care Unit
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Thomas D. Ryan, MD, PhD
Assistant Professor of Pediatrics
University of Cincinnati College of Medicine
Director of Clinical Operations, Cardiomyopathy/Heart Failure
The Heart Institute
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Beth A. Rymeski, DO
Assistant Professor of General and Thoracic Surgery
Cincinnati Children's Hospital
Cincinnati, Ohio

Peter Sassalos, MD
Assistant Professor of Cardiac Surgery
Section of Pediatric Cardiovascular Surgery
University of Michigan Medical School
Ann Arbor, Michigan

Jaclyn E. Sawyer, PharmD
Clinical Pharmacy Specialist, Cardiology
Division of Pharmacy
Cincinnati Children's Hospital Medical Center
Cincinnati, Ohio

Frank Scholl, MD
Chief, Pediatric and Congenital Heart Surgery
Surgical Director, Pediatric Heart Transplant
Memorial Healthcare System
Joe DiMaggio Children's Hospital
Hollywood, Florida

Kevin Patrick Schooler, MD, PhD
Associate Professor of Anethesiology and Critical Care Medicine
Driscoll Children's Hospital
Corpus Christi, Texas

Jennifer Schuette, MD, MS
Program Director, Pediatric Critical Care Medicine Fellowship
Assistant Professor of Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Jamie McElrath Schwartz, MD
Section Chief, Pediatric Critical Care
Director, Pediatric Cardiac Anesthesia
Pediatric Anesthesia and Critical Care Medicine
The Johns Hopkins University School of Medicine
Batimore, Maryland

Daniel R. Sedehi, MD
Assistant Professor of Medicine
Knight Cardiovascular Institute
Oregon Health and Science University
Portland, Oregon

Priya Sekar, MD, MPH
Assistant Professor of Pediatrics
Division of Pediatric Cardiology
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Donald H. Shaffner, MD
Associate Professor of Anesthesiology and Crtical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Sanket Shah, MD, MHS
Assistant Professor of Pediatrics
Department of Pediatric Cardiology
Children's Mercy Hospital
Kansas City, Missouri

Irving Shen, MD
Professor of Surgery and Pediatrics
Doernbecher Children's Hospital
Oregon Health and Science University
Portland, Oregon

Avinash K. Shetty, MD
Professor of Pediatrics
Associate Dean for Global Health
Wake Forest School of Medicine
Winston-Salem, North Carolina

Edd Shope, ADN
Staff Nurse
Duke Life Flight
Duke University Medical Center
Durham, North Carolina

Darla Shores, MD
Associate Professor of Pediatric Gastroenterology
The Johns Hopkins University
Baltimore, Maryland

Ming-Sing Si, MD
Assistant Professor of Cardiac Surgery
Section of Pediatric Cardiovascular Surgery
University of Michigan Medical School
Ann Arbor, Michigan

Nida Siddiqi, PharmD
Clinical Pharmacy Specialist
Pediatric Critical Care and Transplantation Sidra Medicine
Doha, Qatar

Leah Simpson, RD
Clinical Dietitian Specialist III
Pediatric Nutrition
The Johns Hopkins Hospital
Baltimore, Maryland

Zdenek Slavik, MD
Department of Pediatric Cardiology
Royal Brompton Hospital
London, United Kingdom

Heidi A.B. Smith, MD, FAAP, MSCI
Department of Anesthesiology and Pediatrics
Vanderbilt University Medical Center
Nashville, Tennessee

Zebulon Z. Spector, MD
Medical Instructor
Division of Pediatric Cardiology and Electrophysiology
Department of Pediatrics
Duke University
Durham, North Carolina

Allison L. Speer, MD
Assistant Professor of Pediatric Surgery
McGovern Medical School
The University of Texas Health Science Center at Houston
Houston, Texas

Philip Spevak, MD, MPH
Associate Professor of Pediatrics
Johns Hopkins Medicine
Baltimore, Maryland

Dylan Stewart, MD, FACS
Assistant Professor of Surgery
The Johns Hopkins University
Baltimore, Maryland

Robert D. Stewart, MD
Staff, Pediatric and Congenital Heart Surgery
Heart and Vascular Institute
Cleveland Clnic
Cleveland, Ohio

James St. Louis, MD
Professor of Surgery
Children's Mercy Hospital
Kansas City, Missouri

Matthew L. Stone, MD, PhD
Fellow
Department of Surgery
Division of Thoracic and Cardiovascular Surgery
University of Virginia School of Medicine
Charlottesville, Virginia

Erik Su, MD
Director, Critical Care Ultrasound
Department of Anesthesiology and Critical Care Medicine
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Kelly A. Swain, MSN, CPNP-AC
Critical Care Pediatric Nurse Practitioner
Pediatric Critical Care Medicine
Duke Children's Pediatric and Congenital Heart Center
Duke University Medical Center
Durham, North Carolina

Cliff M. Takemoto, MD
Associate Professor
Department of Pediatrics
Division of Pediatric Hematology
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Sarah Tallent, BSN, MSN, CPNP-AC
Division of Pediatric Critical Care Medicine
Duke University Hospital
Durham, North Carolina

Ravi R. Thiagarajan, MBBS, MPH
Senior Associate in Cardiology
Associate Professor of Pediatrics
Boston Children's Hospital
Boston, Massachusetts

Chani Traube, MD, FAAP, FCCM
Department of Pediatrics
Weill Cornell Medical College
Department of Pediatrics
Memorial Sloan Kettering Cancer Center
New York, New York

Ephraim Tropp
MPH Student
Department of Epidemiology and Biostatistics
Graduate School of Public Health and Health Policy
City University of New York
New York, New York

Rocky Tsang, MD
Department of Pediatrics
Baylor College of Medicine
Texas Children's Hospital
Houston, Texas

Sebastian C. Tume, MD
Assistant Professor of Pediatrics
Baylor College of Medicine
Houston, Texas

Joseph W. Turek, MD, PhD
Chief, Pediatric Cardiothoracic Surgery
Department of Surgery
Duke University
Durham, North Carolina

Jennifer L. Turi, MD
Associate Professor of Pediatric Critical Care Medicine
Duke Children's Pediatric and Congenital Heart Center
Medical Director, Pediatric Cardiac Intensive Care Unit
Duke University Medical Center
Durham, North Carolina

Immanuel I. Turner, MD
Pediatric and Congenital Heart Surgery
Cardiac Center at Joe DiMaggio Children's Hospital
Hollywood, Florida

James S. Tweddell, MD
Chair, Cardiothoracic Surgery
Cincinnati Children's Hospital Medical Center
Professor of Surgery and Pediatrics
University of Cincinnati
Cincinnati, Ohio

Chinwe Unegbu, MD
Assistant Professor of Anesthesiology and Pediatrics
Division of Cardiac Anesthesiology
Division of Anesthesiology, Sedation, and Perioperative Medicine
Children's National Medical Center
Washington, District of Columbia

Ross M. Ungerleider, MD, MBA
Director, Heart Center
Driscoll Children's Hospital
Corpus Christi, Texas

Jamie Dickey Ungerleider, MSW, PhD
Coach and Wellness Consultant
Driscoll Children's Hospital
Corpus Christi, Texas

Graham D. Ungerleider, MD
Resident
Cardiothoracic Surgery
Keck School of Medicine of the University of Southern California
Los Angeles, California

Luca A. Vricella, MD
Professor of Surgery and Pediatrics
Director, Pediatric Cardiac Surgery and Transplantation
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Eric L. Vu, MD
Assistant Professor of Anesthesiology and Perioperative and Pain Medicine
Baylor College of Medicine
Texas Children's Hospital
Houston, Texas

Rajeev S. Wadia, MD
Assistant Professor
Pediatric Cardiac Anesthesiologist and Critical Care Intensivist
The Johns Hopkins University School of Medicine
Baltimore, Maryland

Michael J. Walsh, MD
Associate Professor of Pediatrics
Wake Forest School of Medicine
Winston-Salem, North Carolina

Kevin M. Watt, MD, PhD
Department of Pediatrics
Duke Clinical Research Institute
Duke University
Durham, North Carolina

Karl Welke, MD, MS
Congenital Cardiac Surgeon
Sanger Heart and Vascular Institute
Levine Children's Hospital
Charlotte, North Carolina

Renée Willett, MD
Pediatric Cardiology Fellow
Boston Children's Hospital
Boston, Massachusetts

Derek A. Williams, DO
Associate Professor of Pediatric Cardiology
Wake Forest Baptist Health–Brenner Children's Hospital
Winston-Salem, North Carolina

Ronald K. Woods, MD, PhD
Associate Professor of Surgery
Division of Pediatric Cardiothoracic Surgery
Medical College of Wisconsin
Children's Hospital of Wisconsin
Milwaukee, Wisconsin

Charlotte Woods-Hill, MD
Pediatric Critical Care Attending
Anesthesia and Critical Care Medicine
Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

Tharakanatha R. Yarrabolu, MD
Adjunct Assistant Professor
Texas A&M Health Science Center College of Medicine
Pediatric Cardiologist
Driscoll Health System
Driscoll Children's Hospital
Corpus Christi, Texas

Preface

Ring the bells that still can ring
Forget your perfect ending
There's a crack in everything
That's how the light gets in
That's how the light gets in

–LEONARD COHEN

This third edition of *Critical Heart Disease in Infants and Children* is written for the learner in each of you.Your learning part is connected to your courage piece—the element in you that is curious and willing to admit that you might "not know," and that is open to struggle as you grapple with new ways of thinking that sometimes challenge your well-groomed paradigms.Learners know that there is no single CAPITAL T Truth—that the truth is actually the consensus of numerous perspectives.This book is designed to offer numerous perspectives and invites you to take the ones that fit and that expand your ability to take care of children with complex heart disease.

The last edition of *Critical Heart Disease in Infants and Children* was published in 2006.The book, which was originally developed by David Nichols (now chair of the American Board of Pediatrics) was successful beyond expectations.It has served as a major resource for medical students, residents, faculty physicians, nurses, and other important health care providers who comprise the team of multidisciplinary providers who have helped advance the profession of pediatric cardiac critical care.For those of us who have participated in the development of this textbook, it has been a joy to see it on the shelves and countertops of intensive care units around the world.

Over the past few years, several of us have been asked why we haven't created a third edition.As if anything has changed since 2006!During the preparation and planning of this edition, we wanted to honor the enormous progress in our profession by creating a textbook with attention to numerous new topics (this edition has 28 more chapters than the second edition) while still keeping the material manageable. The first section of the book is devoted to the evolution of our specialty with regard to big picture thinking—leadership, systems, evaluation of outcome data, safety and quality collaboratives, ethics and decision making, family needs and expectations, and even training and mentoring.These are all new and unique and alone may help distinguish the value of this edition.Throughout the textbook, all chapters have been updated and, in many cases, we have invited new authors (not because of dissatisfaction with the previous authors—whose contributions we greatly appreciate and value—but because we wanted to invite new and emerging perspectives from others). In addition to updates on previous chapters, we have included chapters on low-birth-weight infants; bridging the fetus with critical heart disease to delivery and care; common general surgery issues for children with critical heart disease; management of common postoperative complications; the use of bedside ultrasound; biomarkers, transport, and stabilization of the newborn with critical heart disease; and adult congenital heart disease.

We have also created access to an online component that will provide the reader with the opportunity to view more expanded bibliographies, additional information (in appendix format), and even videos and other expanded media content.

You picked up this book to fill some of the "cracks" in you hungering for knowledge, and we, the editors, hope we have compiled a feast of helpful and useful information.We hope you enjoy letting in some of the light.

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Video Contents

1

Whole Brain Leadership for Creating Resonant Multidisciplinary Teams

ROSS M. UNGERLEIDER, MD, MBA; JAMIE DICKEY UNGERLEIDER, MSW, PHD

The animals decided they must do something to distinguish themselves and meet the challenges of a "new world" that demanded perfection. After consultation with experts, it was determined that development of universal expertise would be in their best interests, so they formed a leadership academy and adopted a curriculum consisting of running, climbing, digging, swimming, and flying. In order to produce the kind of expertise that would lead to best outcomes, all animals were mandated to take all the courses.

The duck was excellent in swimming. In fact, better than his instructor. But he made only passing grades in running and was very poor in climbing. He felt ashamed of his inability to climb and practiced until his webbed feet and wings were torn to a point where his swimming began to suffer.

The rabbit started at the top of the class in running but after an accident trying to fly from the "green" level takeoff platform, he had to go to a veterinarian, who placed his hind legs in a cast, and he was no longer able to run.

The squirrel was excellent in climbing but nearly drowned in the beginner's swimming class and was ridiculed by the fish, who told him he would never be able to swim due to his short arms and fluffy tail (which they felt was a disability) that when wet got heavy and weighed him down.

The eagle had a behavioral issue for which he was disciplined severely. In the climbing class, he beat all the others to the top of the tree but insisted on using his own way to get there and did not follow the "rules."

The birds all did great in flying, but many of them broke their beaks in digging, became unable to eat, and almost starved.

At the end of the year an abnormal frog that could swim exceeding well and also run, climb, and fly a little had the highest average and was declared valedictorian and the leader.

Modified from original fable by George Reavis

None of us is as smart as all of us.

Kenneth Blanchard

The culture of health care creates important challenges for health care professionals. In particular, we work in a culture that is (1) *hierarchical,* (2) *competitive,* and (3) *perfectionistic*. Unfortunately, the tendency of acquiescing to those demands is contrary to promoting resonant teamwork,[1] and it is important for leaders of multidisciplinary teams to understand how to create environments that flatten the hierarchy (by encouraging all members of the team to contribute and to genuinely seek the wisdom and knowledge of their colleagues); environments that encourage collaboration and cooperation (emphasizing collective "wins" and "losses" both for the immediate team and for all of us, as a profession); and environments that invite excellence (which is a process) versus expectation of perfection (which is an unrealistic outcome).

The concepts described in this brief chapter emanate from our work coaching health care leaders (both authors are certified professional coaches and specialize in leadership coaching); consulting for health care systems and working for a variety of hospitals, academic medical centers, and medical schools; and from our training and experience in medicine (one author is a practicing pediatric cardiac surgeon), business, psychology, and interpersonal neurobiology (the science of relationships). Where appropriate, we provide references. Also, many of these concepts are nicely depicted in videos that accompany our presentations (some of which are linked in this chapter), and we encourage readers to watch them as they read.

Whole Brain Leadership

There is an increasing amount of information linking leadership to a combination of task and relational skills.[2-4] Information about brain function would attribute task-oriented focus to *left-brain* function and relationship-oriented focus to *right-brain* function. Interestingly, this dichotomy has been alluded to in health care as the difference between mechanical (predictable, linear) systems versus complex adaptive (unpredictable, nonlinear) systems.[5] In mechanical systems, behavior (and expected outcomes) conforms to reproducible patterns, and emergent (innovative) behavior is discouraged. For example, a ventilator is a mechanical system, and if it does not perform according to its settings, a repair person is called to *interrogate, judge, and fix* the system. Complex adaptive systems are unpredictable, and emergent (creative and innovative) behaviors can be welcomed with enthusiasm. In complex adaptive systems, differences are *explored* to be *understood and connected* (joined). A growing body of literature on leadership (far too expansive to reference here, but virtually every issue of *Harvard Business Review* for the past several years has articles on leadership)

• BOX 1.1 Qualities Attributed to Leadership Skill

Ability to be logical and realistic	Invites possibilities
Big picture orientation	Intuitive
Relationship focused	Task focused
Strategic/past aware	Good with numbers
Detailed	Values stories as information
Values facts as information	Good with concepts
Imaginative/creative	Analytical

TABLE 1.1 Leadership Qualities From Box 1.1 Reorganized Into "Whole Brain" Capacity

Left Brain	Right Brain
Ability to be logical and realistic	Invites possibilities
Detailed	Big picture orientation
Task focused	Relationship focused
Values facts as information	Values stories as information
Analytical	Intuitive
Good with numbers	Good with concepts
Strategic/Past aware	Imaginative/Creative

offers a variety of leadership traits such as many listed in Box 1.1. These leadership traits can be reorganized (Table 1.1) to better demonstrate the importance of what we refer to as *whole brain leadership*.

To develop and promote this kind of leadership, this chapter will outline a few areas for leadership development.

Integration

We define integration as the linkage of differentiated parts. That is essentially what great leaders do—they link differentiated parts. Integration is a delicate process. It is a dynamic and ever-changing challenge. Dan Siegel describes an integrated state as FACES (Flexible, Adaptive, Coherent, Energized, and Stable). Coherence is in itself an acronym[6] (Connected, Open, Harmonious, Engaged, Receptive, Emergent [creative], Noetic [inviting spontaneity and newness], Compassionate, Empathic), and all of these are important characteristics for a whole brain leader. Using this concept of integration, it is helpful to think of integration as the flowing of a river. Integrated states (FACES) are found in the middle of the river. On one riverbank is rigidity (linkage without differentiation), and on the other is chaos (differentiation without linkage). In rigid systems there is no allowance or acceptance for individual differences. A mechanical system is rigid. It is predictable and linear. Protocols and checklists can be rigid, and there is a space for them in all health care practices. Protocols and checklists prevent errors of omission, but they will not prevent errors of commission, as well as technical errors or errors of judgment. Protocols and checklists create conformity for tasks that lend themselves to conformity, but they do not necessarily create safety. (For instance, if the system is so rigid that no one is allowed to speak up to challenge a protocol—even when they see something that concerns them or when they have an "emergent" idea that might be better—because it challenges a well-ingrained protocol, then the system becomes less flexible, unadaptive, and unsafe.) The animal school parable at the beginning of this chapter is an example of rigidity—making one size fit all and abolishing the unique and variable experiences and abilities of the differentiated members of a group. In chaotic systems there is no conformity. Differentiation abounds, and there is nothing linking the group—no common purpose or goal, no common beliefs, leaving no one to lead. Chaotic systems can be rich with ideas and energy, but without linkage through integrated leadership, there is no way to harness this "collective wisdom." The eventual outcome for these teams is *dis-integration*.

Whole brain leaders possess knowledge and awareness of the allure of these two riverbanks and try to keep their teams flowing in the river of integration.

Whole brain leaders can integrate their systems and create resonance in many ways, and some of these are described in the following sections.

Avoid Dissonance

To describe whole brain leadership in practical terms, we like to imagine that whole brain leaders are integrating three primary elements: self, others, and context, and we have described this in previous publications.[7,8] The challenges faced on teams generally revolve around these three entities.

Self. What are my needs? What are my opinions? What do I think I know, and what am I very committed to? What are my fears, and do I have enough self-awareness and comfort to be able to acknowledge them? What are my biases? Can I access any potential "unconscious biases" (see Chapter 9)? There is voluminous literature citing the importance of leaders having impeccable self-awareness and willingness to learn and to grow, and some ways that this can be manifested are described later in this chapter. Self-awareness is the first element for emotional intelligence, and whole brain leaders are emotionally intelligent.

Others. Whole brain leadership is relational leadership and requires the ability and willingness to value the perspectives of others. Resonant, whole brain leaders understand that just like themselves, all individuals in the system have needs, opinions, knowledge, and commitments. Whole brain leaders create resonance by making it apparent to team members that their individual and collective needs, values, opinions, ideas, and information are also known and considered as important. Leaders can do this by asking questions, being curious, and simply caring about the needs of others. This ability to develop genuine caring for the members of the team is considered by many successful leaders to be the keystone of successful leadership,[9,10] and it is an essential cultivator for resonance within the system. Whole brain leaders *genuinely care,* and they also *care in general,* meaning that they understand the power of story. Everyone in the system has a "story," and when we can know the story, then the system and how people are behaving or what they are wanting makes more sense. A powerful example of "caring in general" was created by the Cleveland Clinic Foundation in their video on empathy (https://www.youtube.com/watch?v=cDDWvj_q-o8). Valuing and tapping into the needs, knowledge, and experience of others is what makes whole brain leaders powerful and resonant. Whole brain leaders genuinely care, and they do this by exhibiting four major qualities that drive connection: (1) perspective taking (inquiring with curiosity to try and understand the experiences of others); (2) avoiding judgment regarding someone else's "truth"; (3) recognizing emotion in other

people (which requires being "present" to the felt experience of others—having a sense for what might be happening for them "below the surface" that might not be expressed by their words); and (4) communicating and validating the importance of those emotions. These traits can be both learned and developed and are essential for whole brain leadership. The difference between empathy and sympathy is also beautifully described by Brené Brown (https://www.youtube.com/watch?v=1Evwgu369Jw) as the difference between driving disconnection versus driving connection. Creating connection is an essential component of resonant teamwork. In resonant teams all members are important and valuable; the team is a single organism, and when one part is affected, the entire organism is affected. Whole brain leaders understand this and cultivate that oneness through genuine caring.

Context. Context is the elephant in the room for health care. Context is the patient, the situation, the reason for us working together, the ever-present "need" that drives our health care world. Context is huge and just like each of us, has needs that must be acknowledged and valued. Teamwork would be difficult enough if it simply required us to "get along" with each other; it becomes daunting when we have to do this in the shadow of urgent, life-threatening, win-or-lose situations that challenge all that we might know and be capable of doing. Add to that challenge the perceived need for perfection, and we have the perfect storm. It is no wonder that many health care teams dis-integrate into rigidity (there is a single answer, and, by the way, it is the one espoused by the leader) or chaos (there is no way we can work together because we all have different opinions about how to get better results). Resonant teams understand that outcomes are an *indicator* of process *drivers*. Paul Baltaldan states that "every system is perfectly designed to give you the results you get," and some systems fall into chaos when the individuals disconnect from process and begin to focus solely on outcome.[11] Outcomes derive from structure and process (well described by the Donabedian model for health care quality or the Balanced Scorecard[12] approach to best outcomes) (see Chapter 2).

In their book *Primal Leadership,*[9] Daniel Goleman, Richard Boyatzis, and Annie McKee describe the concept of *resonant leadership* and provide a few examples of both resonant and dissonant leadership styles. Boyatzis and McKee went on to write an entire book on resonant leadership,[13] and their work is incorporated in our concept of whole brain leadership for creating resonant teamwork.[1,8] (Our work is also based on contributions from *many* others we have studied [and in some cases worked with] over the course of almost two decades, including Dan Siegel, Virginia Satir, Jean McLendon, Sidney Dekker, Don Beck, John Gottman, Doug Silsbee, Brené Brown, and Richard Strozzi-Heckler to name just a few).[1,3,4,10,14-32]

Whole brain leaders create resonance by understanding that *rigid* adherence to certain styles might fail to integrate the competing needs of self, others, and context, and over time this will lead to dissonance within a system. When there is dissonance, there is lack of positive energy, and members of these teams describe their working environment as follows: "sucking the energy from me," "oppressive," "it feels unsafe," "there is no point to my being here because no one cares what I think," "I just show up and do what I'm told" (which is symptomatic of a system that has disregarded someone's potential for unique contribution), "I'm looking for another job somewhere" (I'm checking out), or "I just come to work to make money so I can have a life outside of here" (I've checked out). Any of these, and other comments that we have collected and reported,[11] are indicative that the system (team) is dissonant. We have now "collected" seven behaviors that we have observed in health care leaders that are dissonant leadership styles when used exclusively and exhaustively over time. We have also observed these behaviors in health care professionals. They are human behaviors inherent not just to leaders (who are every bit as human as the people they lead). Each of these behaviors shares lack of integration of self, other, and context. They are briefly described in the following sections.

Dissonant Styles in Which the Leader Fails to Integrate Others as Valuable Contributors to the Team

Commanding. These leaders are typically always "in charge" and lack curiosity to explore the stories of others. They commonly blame others or circumstances when things go wrong, have difficulty accepting any accountability, and exhibit little capacity for listening, asking, inquiring. They already know. Commanding leaders simply say, "Do it because I say so." The Federal Aviation Administration created cockpit resource management[33] to counteract the potential damage that can be done by a commanding leader who is unable or unwilling to access ideas, opinions, or information from others. Likewise, Karl Weick has written about how High Consequence Organizations can become High Reliability Organizations[34] by "flattening the hierarchy" to protect against commanding leaders when there are unexpected and potentially catastrophic events. In Weick's model the most important person on a team, at any moment in time, is the person with the most important and relevant information. It is the role of the leader to access that information, wherever and in whomever it resides. An example of a commanding leader is nicely demonstrated in this video (https://www.youtube.com/watch?v=sYsdUgEgJrY).

Pacesetting. This term was suggested in *Primal Leadership,*[9] and we have found it to be especially prevalent in cardiac teams, where perfection is often the goal. Pacesetting can be extremely dangerous because it always seems to be motivated by a "noble" need to do things right. Ironically, many people who have trained in medicine have been taught that "if you want a job done right, do it yourself." That is pacesetting. (Actually, if you want a job done *your way,* do it yourself; if you want it done "right," then it can be done by many people as long as you can accept that the "right" way will look different, and often unique and innovative, when you can let go of only one way being "right.") Pacesetters discourage emergent behaviors because their way is the right way, and this ultimately creates an environment of *mistrust* (a general sense of unease with someone or something) or *distrust* (lack of trust based on experience with someone or something). Pacesetters demand perfection (meaning the outcome must be precisely their way), and it is often simply not possible to satisfy them, so team members simply stop trying (and this leads to the experience of being no longer valuable to the team because one's opinions, knowledge, experience, and ideas are simply not welcomed). Pacesetters see themselves as being indispensable leaders because without their expertise, everything would fall apart. Ironically, pacesetters often become blamers when things do fall apart, despite their best intentions. Pacesetting can be insidious. Although pacesetting might be manifested by open disregard for the ideas of others, it can also be conveyed by the leader who simply comes along and does everything their way, even after the team has already agreed on a different plan. See if you can recognize the pacesetting in this video (https://www.youtube.com/watch?v=ZZv1vki4ou4).

Manipulating. Manipulation is the ultimate creator of mistrust. Leaders who manipulate are typically dishonest and unable or unwilling to communicate their needs. They typically abuse their position of authority to simply "trick" people into giving in to what they, the leader, wants. Leaders can gain insight that they are possibly being motivated to manipulate when they approach a dialogue, conflict, or problem with a predetermined conclusion regarding what they want and they begin thinking of strategies to get their needs met without wanting to directly express those needs. Manipulators are master strategists, and they are often fairly remorseless about the impact of their strategies on others. Their end justifies their means. They are driven solely by making sure they get their needs met, and they are never transparent.[35]

Dissonant Styles in Which the Leader Fails to Integrate Self as a Valuable Contributor to the Team

Placating. Placaters are driven by the need to be liked and to also make people on the team happy. Ironically, they generally fail at both. They become nontrusted because they do not express genuinely consistent values that team members know the leader is committed to. Instead, they seem to be constantly influenced by the last person who has talked with them. They can be paralyzed from making critical decisions because they are constantly worried about how they might be perceived or judged by others, particularly if they fail (and failure is common because little that these leaders do is an expression of their authentic skill set). Placaters invite chaos because rather than knowing how to "link," they give in to the constant demands of unending differentiation in the system. In trying to keep everyone happy, they become exhausted and frustrated; a sign of placating is occasional emotional explosion as the exhausted placater erupts against the disorganized demands coming at the leader from every insatiable source. Unfortunately, our health care culture risks the development of placating as a cultural norm as we are constantly reminded "to put the needs of others before our own."[36] In fact, the Accreditation Council for Graduate Medical Education (ACGME) definition of professionalism uses those precise words as an example of what professionalism requires. The conundrum is that we are all human and we have needs, and sometimes those needs, when they are not appropriately acknowledged and valued, continue to express themselves "below the surface" until they simply come out sideways or explode out the top. The antidote for placating is unflinching self-awareness to know what is important to us; self-compassion[37-39] for ourselves as learners and as valuable members of the team; and to constantly develop mindfulness around our evolving selves. Whereas commanding, pacesetting, and manipulating eradicate others, placating eradicates the self; it creates a form of relational suicide, and it is simply nonsustainable. In our work with (and in our own development as) leaders, this insatiable need to please others has created a common challenge, and the solution is simply to gently reacquaint ourselves with our humanness, the validity of our needs (values, opinions, knowledge, and skills), and some tools for integrating ourselves into a culture that has normalized disregard of the self. The patient (our context) always comes first. And so do you. And so do others. Whole brain leaders recognize the challenge of linking those differentiated parts without excluding the part that is themselves. It is a constant challenge to hang on to the self, and it is necessary to simply know that, because your team needs YOU and all the unique and extraordinary features that an authentic YOU can bring to the team.

Dissonant Styles in Which the Leader Fails to Integrate Context as a Valuable Component of the Team

Super Reasonable. We have seen this dissonant style most frequently when we have measured dissonant styles in medical systems. It seems to be the most convenient style that satisfies the need for our systems to be predictable and reproducible. It is a mechanical style because it disregards our human needs and variables. Mechanical focus works for mechanical systems (ventilators, heart lung machines, elevators, airplanes) that can be interrogated (inspected) and fixed. Human systems are complex adaptive systems, and the beauty of complex adaptive systems is that they express emergent (innovative) and unique behaviors that are not always predictable. None of us wants to be "fixed." We would rather be "explored and understood." Super reasonable dissonance treats people like robots (https://www.youtube.com/watch?v=753eH92u2B0), and a machine cannot give you what a person can. When leaders treat people like machines, they essentially are devaluing and dismissing the importance of our human factor. The only thing that is important is the *context.* Context is ubiquitous. There is always a sick patient, a chapter that needs to be written, a lecture to prepare, teaching rounds to attend, a meeting for making an important decision … always something to occupy us and distract us from our humanness. (Ironically, in recent years, "human factor" has become a phrase that connects our human capacity for making mistakes to the risk of error in medical systems. However, it is also our human capability for innovating, observing, and preventing mistakes that can lead to extraordinary advances and safety in medical systems. We have found ways to measure the lives *lost* through "human error,"[5] but how do we measure the lives *saved* because of our incredible human contributions?)

The insidious impact of denying our humanness is commonplace in medicine when super reasonable becomes the driving force. This is beautifully and poignantly portrayed in the movie *The Doctor* with William Hurt. In this movie William Hurt is a heart surgeon (how ironic) who develops cancer, and when his physician is informing him that he can begin radiation therapy on Thursday, he states that he cannot do that because he "has a heart surgery scheduled for Thursday." It takes his wife, sitting next to him, to overrule that objection and state, "No, Thursday is fine." He has cancer. He is human. He is attentive to context. That is super reasonable. (A bit later in this movie, he comes home early from work, and his wife calls their son, Nick, to come down and say hi to his father. Nick runs downstairs and picks up the phone and says, "Hi Dad" without even noticing his father standing there in the room. Of course, there is no one on the phone, and Nick says, "Mom, we got disconnected." Then Nick looks up and is totally surprised to see his father, in the flesh.) Super reasonable is a sure way to disconnection.

In Chapter 9 the syndrome of physician burnout is described, and one of the factors associated with burnout is *depersonalization*, which is a measured consequence of our medical education process. We have recorded a progressive increase in depersonalization across 4 years of medical school education for one group of students at a nationally recognized medical school. The class cohort shows an increase of depersonalization from approximately 10% of students at the beginning of medical school—during orientation—to approximately 45% of students at the completion of 4 years of medical school. Most disturbingly, depersonalization, unlike feelings of depression, anxiety, and other factors linked to burnout (which exhibit phasic increases and decreases throughout medical education), progressively increases and does not regress once it occurs. From this one medical school, almost half the graduating physicians

are depersonalized at the time they begin their medical residency training.[40] Depersonalized physicians have just as many needs as they had before they became depersonalized; they are simply less aware of and less compassionate toward them. Ultimately, they begin to treat all people in the system (including their patients) as they have learned to treat themselves. Depersonalized (super reasonable) systems are subject to an 11-fold increase in medical errors, as well as to unprofessional and immoral acts, in addition to ultimate dis-integration from people who want more for their lives than burnout. Systems with depersonalized leaders feel oppressive and dehumanized. It is not possible to exist in them over the long haul, and they exhibit frequent turnover. Team members find ways to "check out," and there have also been reported examples of some leaders who have committed suicide because they cannot be perfect.

Dissonant Styles in Which the Leader Fails to Integrate Self, Others, and Context—A Totally Chaotic and Differentiated Team That Has No Linkage

Irrelevant. Irrelevance occurs when people become overwhelmed and are no longer capable of accessing their own needs or being available to the needs of others or the context. Irrelevance is nonattuned leadership; it is not focused, and it fails to connect. These are simply leaders who have "checked out" and who are no longer available. Unlike invisible leaders (described in the next paragraph), these leaders are often distracting with their presence. An example might be the leader who continually cracks jokes even when things are falling apart and need their attention. Irrelevant leaders tend to try to "minimize" problems and are not available to hear the very real concerns of their team members. Likewise, they tend to minimize important context issues and might not respond appropriately. Charles Bosk[41] termed the kind of errors these leaders make as "normative errors," meaning they fail to perform the normal duties and responsibilities of their leadership role. Irrelevance creates dissonance because the members of the team become discouraged that their leader is not "available" to connect with them around their concerns and instead is a distracting presence when they need to have focus. At an extreme the irrelevant leader has given in to substance abuse as a form of escape from the demands of the job. Irrelevance might seem funny and creative to the leader, but the leader is not attuned to the needs of the team.[1]

Invisible. Invisible leaders are not present for their "leadership moments." This is nicely described by Sidney Dekker in his work on "Just Culture."[29] The members of the team become secondary victims of an unexpected or untoward event. There are times when the team needs a leader to "step up" and take accountability for the team or to make a critical decision or to simply be "the leader." Invisible leaders tend to hide at these times in the hope that the moment will pass (unnoticed) or that they might escape unscathed. Many years ago the national media covered an "error" at a major medical center.[42] The hospital leader was not visible on the newscasts. Ultimately, an individual on the team got the majority of the blame. How different it might have been had the leader been immediately present and made a statement such as "This was a terrible tragedy for this patient; AND (we find it is always useful to insert "and" in place of "but," so as not to diminish the value of the immediately preceding statement; try it sometime) this was also a terrible tragedy for our extraordinary health care team—some of the best doctors and nurses in the world; AND this was a terrible tragedy for our hospital that this happened, and we commit to trying to understand how these things happen so that we can, as a health care system—as a really exceptional health care system experiencing a terrible tragedy—help prevent this from happening again—here or elsewhere." But the leader was not visible. He was nowhere to be found, and the events unfolded differently. Some of the members of that team are still affected by that lack of leadership.

TABLE 1.2 Beneficial Leadership Traits When Strengths Used Appropriately

Strength Overdone	Strength Used Appropriately
Dissonant version	Resonant version
Commanding	Assertiveness
Pacesetting	Competence
Manipulating	Strategic
Placating	Genuine caring
Super reasonable	Logical
Irrelevant	Creative and fun
Invisible	Self-protective

All of these styles become dissonant when they are used exclusively, over time, as the most predictable response by the leader to a problem. The dissonance is created by the lack of FACES that resonant, whole brain leaders require in order to navigate the river of integration. Ironically, leaders (all of us) have access to each of these styles and, when integrated into a complete repertoire of response, can create a more vibrant ability to adapt and perform effectively. Each of these styles actually exists on a *continuum* or *spectrum* of strengths. When the strengths are overdone, they can lead to dissonance, but a strength used appropriately can be a powerful tool or style. In Table 1.2 we demonstrate how the style might look along this spectrum, with the "strength overdone" being represented as the dissonant style and the strength being used when needed and at appropriate times representing the more resonant version.

Whole brain leaders create resonance through their ability to integrate the various and changing needs of self, others, and context into a dynamic and stable system. They access a wide range of possibilities that include tasks that need to be accomplished, problems that need to be solved, and the needs of the people in the system that need to be valued. An example of this is nicely portrayed in the story of a young surgeon on vacation with his wife published many years ago when the ACGME first introduced their duty hour restriction, and we recommend reading it now so that you can integrate the information about resonance into your understanding of the story.[7]

Avoid the Four Horsemen of the Apocalypse

Several decades ago, a (then) young researcher in Seattle began investigating how couples managed conflict and how their management styles were connected with the ultimate fate of their marriage. John Gottman was a mathematician who believed that he could find logical explanations for how relationships thrived or disintegrated. His first book, *Why Marriages Succeed or Fail,* was a seminal work and becomes particularly relevant to teams taking care of critically ill infants when the word *Teams* is inserted in place of the word *Marriages.* Gottman's extraordinary work (based on extensive quantitative and qualitative research) became nationally prominent when it was recognized that he could watch a couple

in conflict for approximately 2 minutes and then predict (with 95% accuracy over 15-year follow-up) whether they would stay married or end up divorced. He could even predict whether they would divorce early (within 4 years) or late (after 8 years) with the same 95% accuracy. His work was mentioned by Malcolm Gladwell in his book, *Blink,* and it has long served an important role in our own work with resonance in medical teams and the development of whole brain leadership. In his book, Gottman described the "four horsemen of the Apocalypse," and what he noticed as destroyers of couples relationships are every bit as relevant for team relationships. Whole brain leaders need to be aware of these four destructive influences and acquainted with the antidotes for them. We briefly describe them in the following paragraphs (and recognize that there is a lot of information around these factors that cannot be covered in the scope of this chapter).

Criticism. Criticism is poison, and it is ubiquitous on medical teams. Criticism is personal, and it is designed to identify a culprit and let that person know how much he or she is to blame. Criticism is the finger pointing at someone, chastising the person for a mistake. (Notice that when you are pointing a finger at someone, where your other three fingers are pointing!) Criticism is a form of punishment doled out to the offending party, and research on punishment is consistent—punishment does not work in technical fields. It only creates more of the undesirable behavior as people begin to focus more on how to avoid punishment rather than engaging in the more challenging process of trying to understand the driving force for their behavior. Punishment creates fear of future punishment, and the undesirable consequences of this have been well described by others as creating a proclivity to "choke"[43] or to disengage from the team or simply to find clever ways to disguise action to avoid more punishment. Regardless, criticism is destructive, and it generally makes everyone on a team feel demoralized and either afraid that they may be next to be criticized or simply feel badly for their colleague and teammate who is the recipient of the criticism. Criticism rarely creates problem solving as much as it creates polarization into the people who are "right" versus the people who are "wrong." The antidote for criticism is *complaint.* A complaint is not personal, and it invites ALL team members to engage in problem solving. Problems do not have names—they are gender neutral. Imagine the difference between criticism and complaint as if the problem is represented as a soccer ball. Criticism is like putting the soccer ball inside someone and then kicking the person around. A complaint is like putting the soccer ball on the floor and letting everyone kick it around. The problem is not "why do *YOU* keep killing all my neonates with your poor management?" (personal—ouch!) The problem is "*WE* keep struggling with our neonatal outcomes. What kinds of things should *WE* try to do differently?"

Contempt. Of the four horsemen, contempt may be the most destructive. Contempt does not necessarily require words; contempt can be conveyed by an expression (such as a slight tilt of the head and a rolling of the eyes). Contempt is a total annihilation of an "other." Contempt is essentially a way of discrediting the value of another team member and minimizing that member's importance to the team. Whole brain leaders develop antennae for contempt, and they do everything they can to remove it. The antidote for contempt is appreciation for what others know and can bring to the system. It has been written that great leadership requires great followership, meaning there are times to stop pacesetting and commanding and let another team member do what that person does best. Pacesetting is a subtle form of contempt because pacesetters have a belief that there is only one way to do a job—their way. When contempt is expressed openly as disdain for the abilities of someone in the system, the system will need intervention to heal or it will disintegrate. One way to create this anticontempt energy in a system is to have team members identify the strengths of each member of the team and to make sure that those strengths are expressed as appreciations publicly and openly. Quin Studer describes a process of "managing up,"[44] which is a way of spreading positive stories about other people on the team. Notice the times that contempt appears in your system, either subtlety or overtly. And imagine how it might be different if the perspective of the recipient of the contempt were understood.

Defensiveness. Defensiveness is the other side of "blame." It is in effect the same as saying, "I didn't do it. She did it." Defensiveness is often found in systems in which the leader has allowed punishment and criticism to exist, so defensiveness is expressed as a way to avoid these consequences. The problem with defensiveness is that it creates divisiveness. Defensiveness does not need to exist in resonant systems where accountability is a part of problem solving as opposed to a part of the blame-seeking process. The antidote to defensiveness is self-accountability. Next time you have a quality improvement conference (morbidity and mortality conference) and a difficult outcome is being examined, try going around the room and, instead of assigning blame (root cause analysis), have each team member courageously take accountability for some piece of the outcome. What would each member have done differently, in retrospect? Have each team member imagine something he or she might wish he or she could have done now that the team member knows what happened. This creates a culture that reinforces our connectedness and dependence on one another. This interconnectedness of random events—often seemingly unrelated—contributing to one single occurrence is important for us to understand as we try to make sense of the overwhelming nature of what we experience. It is beautifully portrayed in the accident scene from Benjamin Button (https://www.youtube.com/watch?v=mTDs0lvFuMc#t=32.076865449). In many of our programs, the taxi driver (often the surgeon) who is at the end of a series of events gets the "blame" for an event, but "life, being what it is, a series of interconnected events," can sometimes result in an outcome that is the result of so many small events along the line. The power of self (and shared) accountability is enormously helpful to us as we attempt to put these events into perspective so that we can create resonance; understand interconnectedness; and remove blame and defensiveness as blockades to team understanding, improvement, and growth.

Flooding. Flooding refers to emotional overload. When we get flooded, we simply want to shut down and not address the moment. This can leave others on the team feeling abandoned, unheard, or ignored. When I (RMU) finish a challenging operation and return to my office, I am sometimes "flooded," and if my administrative assistant bombards me with a lot of requests—phone calls to return, tasks that need attention—I just want to ignore them. She might take this personally, when actually the person with the immediate need is me. So I have told my assistant that when I come back from the operating room and close the door to my office, it has nothing to do with her—I simply need time to recenter myself so that I am ready to be available. We have found that this works well, and the antidote for flooding is "self-soothing," which can simply be acknowledging as a leader that people (including the leader) have needs to center and reconnect to their internal resources so that they can move on to the next demand. We have described

internal resources in previous publications,[45] and they can serve as a useful source for resilience and integration.

In the Prochaska change model, growth and change occur as we move from unconscious incompetence to conscious incompetence. That is a huge move—we simply become aware of our limitations and challenges. For whole brain leaders, this is a necessary movement. Nothing really changes. We are still incompetent, AND we are now available to learn tools to move us, slowly but inexorably, toward conscious competence and eventually (with practice and mastery—internal integration) to unconscious competence—and that is transformational change from which we never go back.

The following sections describe, briefly, a few leadership tools to consider. There are many, and we are simply presenting a few.

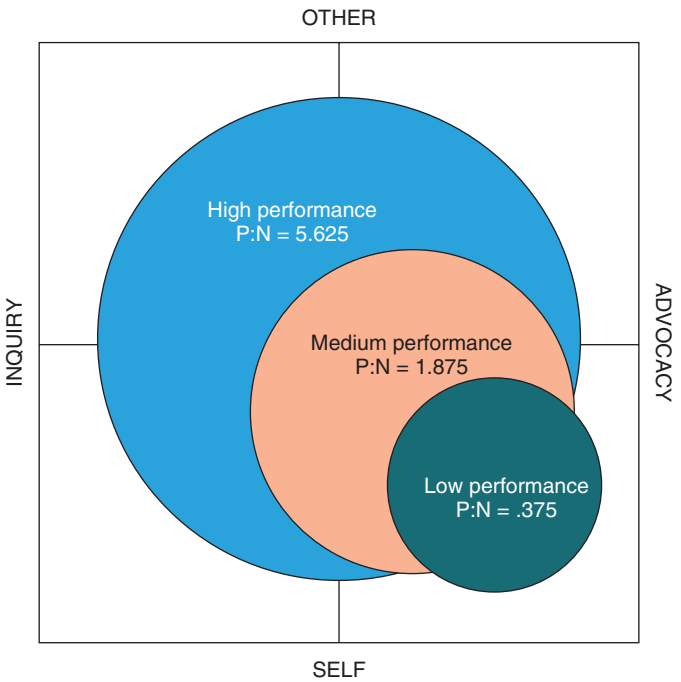
Accept Influence

In his work with couples, Gottman described (for his interview with the *Harvard Business Review*) the ability to "accept influence" as one of the most important elements for creating healthy relationships.[46] We have found this to be especially effective for medical teams. Accepting influence invites all the members of the team to be engaged and valued and to participate. By nature, leaders who accept influence have found a way to abolish contempt and to "push the up button" as they create joy and resourcefulness for their team, as well as a culture that promotes learning, growth, and change.[1] Accepting influence is a cultural change as much as it is a leadership tool. Imagine that in your organization you have a saltshaker full of "yes" crystals that you can sprinkle around liberally: "Yes, that is a good idea. Let's try it." "Yes, please keep calling me when you have concerns." "Yes, that would be great if you would present that information at our next conference." "Yes, I appreciate your thoughts on this." "Yes." "Yes" creates a different culture than the more typical "No" culture, where the saltshaker sprinkles around: "No, we don't do things that way around here." "No, when I want your opinion, I'll ask for it." "No, that is not something we're going to try." "No, I don't want your help." "No, I don't really care what you think." Which culture would feel more attractive to you? Furthermore, when we hear (or even feel or sense) "no," it often invites implicit memories of not getting our needs met. Consistent "no" might lead members of a team to give up and stop trying because trying will only bring on another "no." Leaders who emphasize accepting influence can do this in numerous ways—allowing others in the system to make suggestions and then taking those suggestions, even (especially) when they are different than the cultural "norm." This indicates to the team members that change is valued and ideas are respected.

There is a very instructive scene in the movie *Master and Commander* with Russell Crowe. He is the captain of a ship and is called to the deck because the person on watch "thinks" he saw an enemy ship through his spyglass. "You think you saw it?" asks Crowe. "Yes, I think so. I can't be sure. It was only for a moment—through the fog." Crowe then asks another member of the crew if he saw it. "No, sir. I didn't." Now this is a situation that would be ripe for contempt (disdain) and dismissal of the experience of the person in the minority opinion—in this case the person who "thinks" he "might" have seen something. In some dissonant teams there might be a sneering diminishment of the crew member who "thought" he saw something "only for a moment," unconfirmed by a more "trusted" team member. But Crowe does not take the bait. Instead he says, "Well, you did the right thing." (That is a way of sprinkling a "yes.") "Go back to your posts. Thank you." (another "yes") Then he (the captain) begins looking to verify if there is an enemy ship. He sees it and provides the warning in time to save the crew—all because he "accepted influence." We can all do this. In a presidential address to the Southern Thoracic Surgical Association, a virtually uninterpretable photo of a cow is displayed by the speaker.[47] Only a few members of the audience even recognize it for what it is. If the leader simply ignores their perspective because he or she does not see what they see, then he or she misses out on valuable information because when the photo is redisplayed without the confusing background, the cow is readily apparent and can be seen by everyone in the audience. Accepting influence is a powerful tool for a leader to introduce into the system. It gives permission for people to speak up without fear of being ridiculed, ignored, or dismissed, and it allows the system to be greater than the limitations of any one person. If only one person sees something and the rest of the team is willing to accept the reality that someone is seeing something they themselves have not seen and they become curious to know more about what was seen and how they, too, might be able to see it, then the entire team becomes more powerful. Whole brain leaders accept influence because they genuinely value the perspectives of others, and they make their teams powerful as a result.

Be Ratio Minded

In an elegant investigation of the role of positivity and connectivity for business teams, Losade and Heaphy, from the University of Michigan School of Business, described the interrelationship between a variety of parameters to quality of performance.[48] Connectivity (an essential trait for whole brain leaders) became a control parameter that was linked to various ratios that were associated with whether the teams performed at a high, medium, or low level. A graph of their findings is displayed in Fig.1.1.



• **Figure 1.1** Emotional space projected over Inquiry/Advocacy and Other/Self. (Modified from Losade M, Heaphy E. The role of positivity and connectivity in performance of business teams: a nonlinear dynamic model. *Am Behav Sci.* 2004;47:740-765.)

TABLE 1.3 Team Function Ratios

Ratio	High	Medium	Low
P:N	5.6:1	1.8:1	1:20
I:A	1:1	2:3	1:3
O:S	1:1	2:3	1:30

P:N, Positive versus Negative; *I:A,* Inquiry versus Advocacy; *O:S,* Other versus Self
From Losade M, Heaphy E. The role of positivity and connectivity in performance of business teams: a nonlinear dynamic model. *Am Behav Sci.* 2004;47:740-765.

What is remarkable about their findings is that the increasing ratio of positive to negative emotions (often referred to as essential for high performance) is interrelated to the ratio of "other-focus" versus "self-focus" and to the ratio of "inquiry" (curiosity about the perspectives of others) versus "advocacy" (fixed commitment to one's own perspective). The remarkable association of these three ratios to performance is displayed in Table 1.3.

Positive Versus Negative. The ratio and importance of positive to negative has long been emphasized by some organizations as crucial to high performance. What is more difficult to understand is that the relationship between positive and negative is very complex. Some teams have stated that it is easier to feel positive when things are going well and that therefore this ratio is really the result of how well the team is performing, not the other way around. However, Losade and Heaphy's research, as well as research by Gottman,[21,49] Fredrickson,[19,50,51] and others has demonstrated that it is actually the ability to create positivity that far exceeds negativity that leads to the better outcomes for teams. This is a ratio that is generated by whole brain leaders and in its most mature forms, is associated with high performance. The actual desired ratio varies from 3:1 (Fredrickson) to 5:1 (Gottman) to Losade and Heaphy's 5.6:1, likely depending on the type of team and what is being measured. However, three things are important to take away from this research. The first is the power of negativity. It takes much more positive to overcome the negative to produce high performance. The second is the absolute necessity for negativity to be present. Negative experience is important to acknowledge in a system. Without the negative there is a risk for false harmony,[52] and this would ultimately eradicate any credibility to positivity. Finally, from Losade and Heaphy's work is the critical interdependence of P:N with O:S and I:A. In the figure (see Fig. 1.1), P:N increases as the axis moves to the upper left quadrants ("other-focus" and "inquiry") and away from the lower right quadrant ("self-focus" and "advocacy"). High performance is a complex result of tools that whole brain leaders can employ to create more space for the perspectives of others (versus considering only their own self-perspective to have merit) as well as inquiring (with curious exploration, as one would for complex adaptive systems) to learn more about the opinions, perspectives, and knowledge of others rather than constantly advocating their own beliefs (and limiting the team to only what they know or believe). There are numerous techniques that leaders who are aware of these ratios can employ to improve performance of their teams.

Other Versus Self. A few things that leaders can do to improve the O:S ratio include cultivating connections among team members. One way to do this is to expand awareness of who the "others" are and appreciation for the wide array of talents, interests, and passions that we each bring to our teams. In our work with teams, we have sometimes referred to this as "attunement" (Dan Siegel would call this "mindsight").[1,28] Typically in our professional cultures, we refer to each other with titles (e.g., professor and chief of cardiothoracic surgery, nurse manager, director of in-patient services, lead perfusionist, assistant professor, staff nurse, chief executive officer, grand master), and these titles are often displayed on our name badges as if that defines who we really are. We have introduced to some teams the concept of slash IDs—that is, after our official title, there is a slash and then the rest of who we are, such as avid golfer, fisherman, reader, sports fanatic, and father of five children; or dog lover, cook, and stargazer—anything that tells our team we are more than a title. We have seen people actually inadvertently try to accomplish this when they have placed photos of their children or pets over their own on their name badge. The slash ID simply expands this to provide a larger window into the world of those wonderful "others" who are on our team. Another way whole brain leaders validate the perspectives of others is by accepting influence and cultivating a culture that invites engagement by all the members of the team. Finally, whole brain leaders validate the value of others by both "making" and "accepting" repair attempts. There has been a lot of work demonstrating that our most positive mentors have been the ones who have supported and nurtured us when we made mistakes. Mistakes made in an environment of support and caring are commensurate with learning.[53] In our systems we encounter errors, and sometimes this leads to "ruptured" relationships. One of the most powerful tools for healing these ruptures is to offer a repair attempt (a genuine, sincere apology), and more important than that (particularly for the leader to model) is to accept the repair attempt with compassion and understanding that ruptures and errors are a necessary part of our learning and growing processes. The power of an accepted repair is enormous, and the damage from a cursorily dismissed repair is equally important to appreciate. When a team member musters the courage to offer a repair, we serve our teams by stopping and simply noticing that this tender moment is an opportunity for us to heal (when we accept the repair with kindness and sensitivity) and with that healing, move forward to our next challenges.

Inquiry Versus Advocacy. There are many ways a leader can cultivate inquiry. One of the most powerful is to invite learning into the team. Carol Dweck has spent a lifetime describing the difference between learners (growth mindset) versus knowers (fixed mindset). Her work is beautifully portrayed in her book *Mindset,*[17] and we have referred to it in previous publications.[1,11,53] All of our teams are rich with talented, knowledgeable, capable, and passionate members who want the same thing: to do a great job taking care of sick patients. Each team member brings a unique set of information, experience, and ability. Whole brain leaders recognize that every one of us is an expert in something, so we are not afraid to ask for advice or for help. Inquiry is manifested as genuine, curious exploration to understand the perspectives and actions of another. Too often on medical teams, we observe inquiry as "inquisition"—the grilling of someone (who likely is about to be criticized, blamed, or disdained) to demonstrate that they are wrong—as opposed to genuine curious exploration to try and understand another's perspective. We can—should—imagine how to ask questions that help us understand rather than accuse, embarrass, or destroy. This is a difficult technique to learn. However, with commitment, training, and practice, whole brain leaders can achieve conscious competence and uncover new ways of connecting to their team member's ideas and to each other.

Learning is hard. We get stuck in schema (our strongly held belief in something), and then we evaluate information as either

correct (it validates our belief) or as incorrect (it contradicts our belief). Ironically we can often find validation in the literature to support our strongly held beliefs; there is almost always a study to support or to contradict what we want to believe is true. Inquiry permits us to practice finding alternative information and other ways of managing a difficult problem. Inquiring leaders expand rather than contract the scope of their team's repository of possibilities and create opportunities that are flexible, adaptive, coherent, energized, and stable. In this sense, whole brain leaders promote the very nature of complex adaptive systems and permit growth, change, and learning, and with that, joy and positivity that lead to high performance.

Awareness of the impact of positivity, inquiry, and valuing the experience of others is a key ingredient for developing team resonance versus dissonance. Teams have an emotional culture[54] that whole brain leaders are attentive to. Emotional culture influences employee satisfaction, burnout, teamwork, and even hard measures such as financial performance and absenteeism. Positive emotions are consistently associated with better performance, quality, and customer service. Negative emotions such as group anger, sadness, fear, and the like usually lead to negative outcomes, including poor performance and high turnover.[54] Most people can generally distinguish as many as 135 different emotions, and even when this is occurring at a level below conscious awareness, these emotions can greatly affect how we feel or behave. We are all greatly influenced by what is happening around us through our mirror neurons.[55] Our ability to "attune" to the energy in our environment is what has helped to keep us "safe" through evolution. Notice your ability to be aware when you walk into a room of what the "energy" is in that room—is it safe, or tense, or joyful? Whole brain leaders remain attuned to and understand the importance of emotions such as joy, love, anger, fear, and sadness. These emotions become a valuable "dipstick" for team performance for leaders who are able to cultivate access to them.

Create Vision (Discover the "And")

Some of the best work we have encountered on teamwork relates to the importance of discovering the shared purpose and meaning for the team.[30] There are many ways for leaders to do this, and in the most effective circumstances, the shared mission is real and meaningful for all team members. This means that leaders cannot simply insert their vision as the team vision. The team vision needs to be crafted and constructed through exploration and understanding of what the organization is uniquely positioned to produce and what the team members value. All programs that deliver care to children with critical heart disease want to be "excellent," but excellence is a very general word and can manifest differently in a variety of programs. Some programs may define excellence as uniqueness, emphasizing techniques or procedures that they offer and in which they truly excel. Others may point to the volume of cases they perform and their outcomes for those cases (measured as Society of Thoracic Surgeons outcomes). Other programs may consider the nature of the procedures they perform and how they produce outcomes with best long-term quality of life. Finally, some programs may consider excellence to be manifested as being a truly great place in which to work (e.g., a J.D. Power top 100 place to work). Collins addresses this in his book, *Good to Great,* when he describes the "hedgehog principle." Basically, the hedgehog is really good at rolling up into a ball to protect itself. No animal is better at protecting itself in this manner from being eaten by predators. Collins encourages organizations to also discover what they are uniquely positioned and resourced to be great at. Every organization, every team, can be exceptional at something, but discovering that something takes time, effort, and whole brain leadership. We like to think of it as "discovering the *and*" as portrayed in this link (https://www.youtube.com/watch?v=srHDgimlgTQ). We all want and expect to be excellent. Be aware that excellence is different than perfect. Excellence is a process that we can control. Perfection is an outcome that is not only out of our control but also impossible to attain. Wherever you see a commitment to perfection, as opposed to excellence, you will find shame and often the consequences of shame, which include blame, dishonesty, and unhappiness—all leading to poor performance. Discovering the "and" invites teams to be more than excellent and to encourage development of the team's "hedgehog product." It is a way for a team to develop uniqueness that is authentic and linked to its core strengths and talents. These teams discover how they are both "excellent at providing children's heart care" *and*. … The "and" is what else they do or offer that is unique and that distinguishes them. Great teams discover this additional area for performance around which they are able to be truly great. Whole brain leaders mine for uniqueness and authenticity to help craft organizational excellence by harnessing the strengths of the organization to a shared mission and purpose that is meaningful and achievable for the team. This generates *system esteem* and ultimately high performance.

Commitment

No matter where you work and what team you work with, the very nature of delivering care to neonates, infants and children, and adults with complex congenital heart disease is hard, unpredictable, and fraught with challenge. Plans do not always work out the way we hope, the team may encounter "clusters" of bad outcomes, or fractures in relationships from disagreements. The major difference between resonant and dissonant teams is that resonant teams find a way to work through these difficulties as a natural part of being in relationship. Members of resonant teams know—they have trust—that no matter what, their team will stand by them. Team members remain *committed* to the team and to each other, even (especially) when times are challenging. Ultimately, the best teams find ways to work through these times without destroying each other or disintegrating the team. They look at problems as challenges that all members can address, not as people who need to be "fixed" or removed. Research on relationships has emphasized the importance of commitment,[56,57] and teams are complex, adaptive relationships. There is likely no problem a team cannot solve if the team members view the problem as the challenge as opposed to each other as the challenge. Unfortunately, when caught up in the "amygdala hijacking" of intense difficulties, people tend to revert to some of their more primitive "survival" styles (exhibiting their strengths as overused) such as those outlined as dissonant styles earlier in this chapter, and most commonly this appears as blame (others do not count, "I need to protect myself") or super reasonable (people do not matter—only patients matter—which by the way is wrong. People do matter, and if we do not attend to our ability to work well together and support one another, the patients will suffer). However, you may recognize any or all of the dissonant coping styles, and simply being able to recognize them might be helpful. These styles tend to appear during times of stress, and they can also be simply termed "stress stances"—they are postures we exhibit when we become anxious and stressed.[26,58]

Whole brain leaders first need to recognize within themselves which of these coping styles they are most likely to adopt and simply acknowledge that when they are beginning to use this style, it is an indicator that they, too, are feeling stressed. It is a very useful *early warning sign*. They may also recognize these coping styles in members of the team and know that those team members are feeling stressed. If the team can become educated in this phenomenon, then the team can likely move from unconscious to conscious incompetence. (Nothing changes—the stress stances are still present—but they can now be named [what we name we tame] and acknowledged—not as something "wrong" with people, but rather as indicators that these team members feel stressed or anxious.) Tools for managing these situations are abundant and can be cultivated by whole brain leaders who appreciate the reality that their teams are composed of people and that people have needs and emotions and that people are not machines and cannot be managed like a mechanical system.

Among the tools that we have found helpful is to *solve the moment, not the problem.* It is often likely that the problem is bigger than the moment and will require an energized, engaged, and fully resourced team to be curious and open to potential solutions. (Dan Siegel refers to this state as COAL—Curious, Open, Accepting [the problem is the problem and it is here; the root of unhappiness is wanting things to be different than they are], and Loving [meaning have compassion for oneself and others on the team as learners, who, when they can, will try to do better].) The moment is more manageable and can be addressed with dialogue that simply acknowledges that the members of the team are wishing for something to be different.

One way to dialogue is to learn techniques for Nonviolent Communication.[25] These techniques can transform the way members of a team converse with one another around difficult situations. There are other methods for communicating that are taught in workshops on *Crucial Conversations, TeamSTEPPS, Cockpit Resource Management,* and a variety of communication tools. Regardless of which ones the team chooses, going through these trainings together is a growing and learning process that can be more valuable than the techniques themselves. Regardless of which techniques the team chooses to learn, however, the most important tool to implement is genuine caring and compassion for each member of the team.[59,60] Without this level of caring, tools are simply techniques that have no magic or soul.

Many problems that occur in our profession are unavoidable—patients bring us incredible challenges, and not all of these challenges are surmountable. All our team members come from differing backgrounds (cultural, family, and professional training). As leaders, we can help our team understand this and try not to take it personally. We can begin to see our organizations, not as problems to be solved, but rather as mysteries to be explored. When we fail, it is not because we are bad doctors. We simply had a bad outcome. This is how teams can try to stay connected. Commitment is staying connected as a team: through better and through worse, through sickness and in health, through paralyzed hemidiaphragm and recurrent arch obstruction.

Promote Work-Life Balance

Many of us trained in a time of relentless emphasis on work. It still is commonplace to attend a medical meeting and have a colleague ask, "Are you busy?" We rarely respond by saying, "No, I'm trying to spend more time with my family." It is a cultural value in our profession to be busy. How often do you think of taking a day off to spend doing something unrelated to work? And when you do, how do you feel about it? Guilty? Refreshed? Embarrassed? Secretive? Just notice. Whole brain leadership requires the ability to access emotions (attuning to both one's own emotions and the emotions of the team—mindsight) and to value them as important and meaningful. There is a younger generation arriving at our workplace—physicians and other health care professionals who may not share our cultural value of "busyness" as the proper spelling of our "business." Leadership for the future will likely need to find a way to tap into flexible, adaptive, coherent, energized, and stable ways to link this emerging culture with our goals for our teams. There is ample research documenting that work and life cannot be "balanced," but they can be *integrated* through *choice* into a life that is intentional, rewarding, and perfectly suited to how we want our individual lives to be. Leaders for the next generation of health care, particularly in the high-stakes, high-stress environment of managing patients with critical congenital heart disease will be obligated to emphasize ways to integrate work with life in some nonformulaic, individualized manner that attunes to the three elements demanding our attention mentioned at the beginning of this chapter: Self, Others, and Context. All three are valuable, important, and irrepressible. Honoring the needs of each creates balance, and ignoring any to the repeated exclusion of one over the others will create dis-ease. Whole brain leadership is a learning process that begins (and ends) with cultivation of the self, appreciation for others, and remarkable diligent attentiveness to context.

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2

Optimizing Care Delivery: Quality and Performance Improvement

KYLE J. REHDER, MD; SARAH TALLENT, BSN, MSN, CPNP-AC; JON N. MELIONES, MD, MS

With increased emphasis on tracking patient outcomes, reducing hospital-acquired conditions, promoting cost-conscious care, and inclusion of quality metrics as determinants of reimbursement, quality has become a major focus in health care. However, defining what *quality* means in any given health care setting can be challenging. An isolated decrease in patient mortality does not necessarily equate to quality care, nor does improvement in any one other metric, particularly if that improvement comes at the expense of another important outcome.

The Institute of Medicine (IOM) has provided six domains that define quality in the health care setting[1]:

- *Safe:* Avoiding harm to patients from the care that is intended to help them
- *Effective:* Providing services based on scientific knowledge to all who could benefit and refraining from providing services to those not likely to benefit (avoiding underuse and misuse, respectively)
- *Patient centered:* Providing care that is respectful of and responsive to individual patient preferences, needs, and values and ensuring that patient values guide all clinical decisions
- *Timely:* Reducing wait times and sometimes harmful delays for both those who receive and those who give care
- *Efficient:* Avoiding waste, including waste of equipment, supplies, ideas, and energy
- *Equitable:* Providing care that does not vary in quality because of personal characteristics such as gender, ethnicity, geographic location, and socioeconomic status

As health care providers, our primary goal is to deliver optimal outcomes to our patients, but this must be balanced with a fiscal responsibility to provide care that is both cost-conscious and sustainable. The primary tenet of medicine, "first do no harm," prioritizes patient safety in all that we do. In this manner the pursuit of quality care must consider not only singular patient outcomes but also other balancing measures, risk stratification and error proofing, and outcomes important to the greater populace. Similarly, attention must be paid to ensure this care is delivered in a consistent and equitable manner.

Quality Improvement/Performance Improvement

Determining the best medical treatments for patients has traditionally been driven by rigorous research in the form of basic science, translational research, and tightly controlled randomized clinical trials. Unfortunately, there is often a lag of more than a decade between new research defining a best practice and that practice becoming standard of care. Similarly, even when a best practice is known, it is commonly applied in an inconsistent fashion. This delivery gap is where quality improvement is an essential part of providing care (Fig. 2.1). Quality improvement methodologies are essential to ensuring consistent delivery of best care practices, particularly as patients' health issues have become more complicated and health care delivery systems have become more complex.

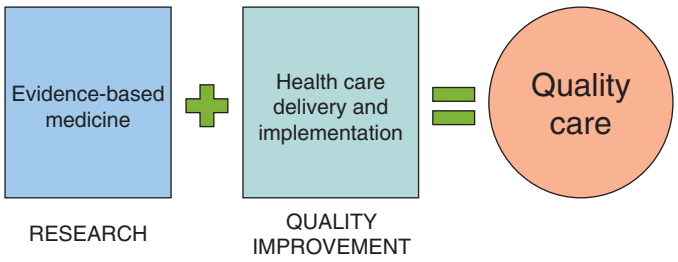
Although many of its concepts are relatively new to health care, the field and process of quality improvement should not be dismissed as a "soft science." Quality and performance improvement are built on proven strategies that have repeatedly enhanced patient care. Just as with traditional research, the best results in quality and performance improvement initiatives will be realized when rigorous methodology is applied.

Much of quality improvement science was developed and streamlined in business and manufacturing settings, with more recent introduction to the health care environment. The adaptation of these principles to the hospital setting may inherently lead to conflict and confusion, given the primary goal of business is to improve shareholder value, whereas the primary goal in medicine is to improve patient care. As a result, the direct translation of these business principles to health care can result in uncertainty as to the true focus of a given project, as well as which specific strategy is best suited for the problem being addressed. An added challenge to quality and performance improvement in the health care environment is the almost ubiquitous need for human factors management for successful project implementation. In the next several sections we describe some of the necessary strategies to achieve transformative care for patients.

Identifying Targets for Improvement

Health care is complex and constantly changing. Although providers and patients can typically identify many processes that either contribute to suboptimal outcomes or are substantial sources of dissatisfaction, determining specific targets for improvement can be challenging. It is also often unclear which improvement target should take priority at any given time and what resources might be available for the next improvement project.

The selection of improvement targets is generally achieved through the balance of two factors: those projects that can have



• **Figure 2.1** Combining evidence-based medicine and quality improvement to achieve optimal outcomes.

the greatest impact on patient care and those changes that can be easily made. The latter of these, often termed *low-hanging fruit,* often provide short-term projects with low resource requirements. Early "wins" with these projects can help bolster a culture of continuous improvement and gain momentum for those projects with the greatest potential impact. It is these impactful projects that will likely require greater resources and long-term commitment, and it is these projects where specific quality improvement methodologies and human factors engineering will be required to realize change.

Any quality improvement project should start with a clear statement of the project's goal. SMART statements are the generally accepted method for defining the aim and scope of the project:

Specific: Provide clear and unambiguous targets for improvement.
Measurable: Ensure that the outcome is objectively quantifiable and able to be tracked.
Achievable: Is the project goal attainable in terms of scope, resources, and time available?
Relevant: The "so-what" question. Is this an important initiative for the organization, the patients, or the staff? Is this the right intervention to affect the targeted outcome?
Time oriented: What time frame will this project span?

An example of a SMART statement with all the necessary elements might be: "We will reduce the number of pressure ulcers (grade 2 or higher) among patients in our unit to less than 2 ulcers per 1000 patient days by August 1st." This is a clearly measurable target with specific scope in terms of population and time frame. Of course, determination of "achievable" and "relevant" must be decided in collaboration with the unit leadership and with consideration for the current state as well as available resources for the project.

Leadership backing of quality improvement efforts is essential for several reasons. First, leadership can help prioritize those projects that are of greatest importance to the organization and, in the process, can also verify that necessary resources will be made available for project completion. The lack of such support can easily lead to project failure due to lack of means or inability to maintain momentum. Second, organizational leadership will be aware of other improvement initiatives that may be ongoing simultaneously. Coordinating these efforts can avoid confusion around institutional priorities and promote collaboration between medical teams. Finally, public affirmation by organizational leadership regarding the priority of an improvement project will help gain support from the staff and assist with sustainability after the initial intensive push for process change.

Early identification of key stakeholders and incorporation of these individuals into the planning process is essential to the success of any quality improvement effort. Building a multidisciplinary group of individuals with unique perspectives and priorities will help provide a clear and robust analysis of the problem at hand. Furthermore, inclusion of these individuals in development of interventions will bolster early multidisciplinary support for the project and potential solutions. Ideal project members are experienced frontline individuals with content expertise and strong teamwork skills who also hold significant influence in their work area (regardless of leadership titles or lack thereof). Paired with visible organizational leadership support, the buy-in of these influential frontline staff members will help garner widespread acceptance of new process flow or other solutions.

Defining project scope is another key ingredient to designing a successful improvement initiative. A natural tendency while assessing an array of issues in a given work area is to try to solve multiple problems at once. Unfortunately, this approach may lead to lack of clarity and spread resources too thin to accomplish project goals. Prioritization of a specific target outcome and use of a key driver diagram (Fig. 2.2) can help narrow the focus of the project to the most impactful interventions. Development of a SMART statement is then an ideal strategy to define clear boundaries and focus the scope of a given project.

Measurement/Metrics

Before starting any improvement project, it is essential to adequately capture the current state of the process or outcome of interest. Only by knowing the starting point will the project team know if change was achieved. Ideally, the outcome of interest should be easily measured, with high validity, and have a clear impact on patient outcomes.

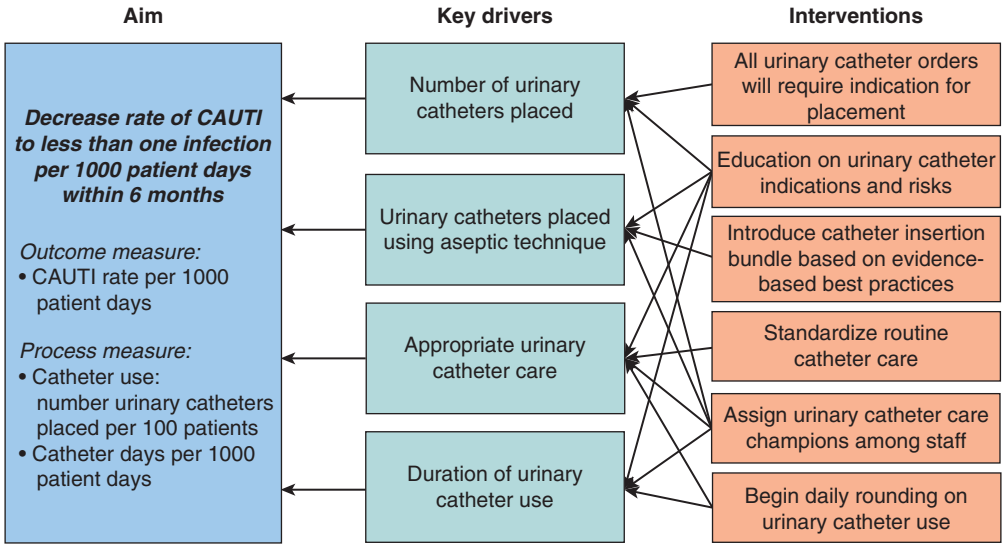
Data collection efforts (i.e., accurate measurement and analysis) in health care typically lag behind similar efforts in industry. This is a function of multiple issues, including, but not limited to, lack of contemporary information technology (IT), lack of IT investment, noncomplementary IT (i.e., systems that do not "speak" to each other), and conflicting priorities. Increased use of electronic medical record systems has allowed for simplified tracking of certain key outcomes in many institutions, but these data sources may require careful monitoring to ensure validity.

Any process change may have unintended consequences; therefore it is essential to also monitor a balancing outcome that may be negatively affected by the proposed solution or process change. For example, if a new protocol is implemented providing prophylactic anticoagulation to a high-risk population, it would be important to monitor the incidence of bleeding in these patients. Balancing measures for process changes often include cost, time, or an outcome for a conflicting process.

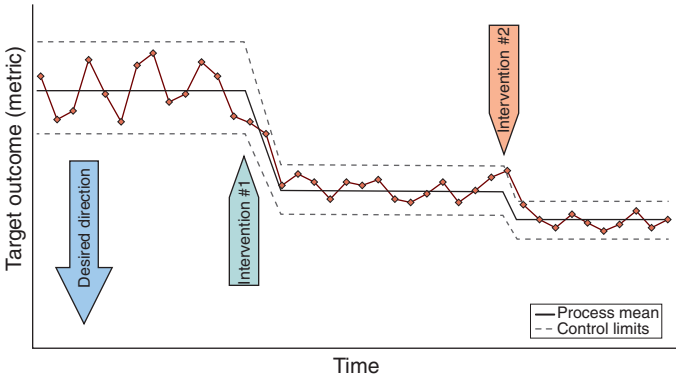
Tracking improvement progress is best achieved through the use of control charts (Fig. 2.3), where the identified primary outcomes are tracked as a function of time, with notations on the chart for specific interventions or external changes that might influence the outcome of interest. These charts provide a clear visual representation of improvement over time and can facilitate statistical analysis of a process that lies within or drifts out of control parameters. Control charts also allow for ongoing monitoring of the outcome once the improvement initiative has concluded.

Improving Care

A variety of quality management and performance improvement (PI) methodologies are readily available for use in the hospital



• **Figure 2.2** Example of a key driver diagram demonstrating an approach to reducing catheter-associated urinary tract infections *(CAUTIs)*. Once a project aim and primary outcome measure are identified, the key driver diagram identifies primary contributors to that outcome and potential interventions to promote change.



• **Figure 2.3** Sample control chart tracking impact of serial interventions on desired outcome.

setting. Most of these methodologies have been adapted from business and manufacturing and then successfully translated to health care.[1] Some of the more common quality improvement methodologies are summarized in Table 2.1, along with the tools commonly applied for each methodology. These methodologies often use similar tools, but each is suited for different aspects of process control or improvement across the continuum of health care delivery. Although an in-depth discussion of different methodologies is beyond the scope of this chapter, Table 2.1 highlights the primary utility of each strategy and principal strengths and weaknesses.

Not every process deficiency requires an intervention using in-depth quality improvement methodology. Many issues will have an obvious and simple solution and can best be addressed with a "just do it" approach. These changes are typically clearly needed and may not necessitate precise measurement of outcomes. However, if measurement is possible, the "just do it" approach may be the launching point for a series of Plan-Do-Study-Act cycles used in the Model for Improvement.[2]

Another strategy that will assist with acceptance of a new process is to make the "right" path the "easy" path. It is common for new initiatives to result in complex pathways to ensure the best outcome. However, the best-intentioned process will be ineffective if it is either too complex to follow or so onerous that staff develop work-arounds. Streamlining the new process, removing barriers to its implementation, or adding barriers to potential work-arounds can all act as forcing functions to help drive users of the process toward desired behaviors.

Following a period of intense focus on improvement, many processes and outcomes will drift back to their prior state, as attention is turned toward other issues and providers fall into old habits. During the development of improvement initiatives, attention must be paid to human factors that drive the process and potential strategies to increase sustainability. Six-Sigma methodology specifically addresses this issue with the "Control" phase of the DMAIC (Define, Measure, Analyze, Improve, and Control) model. Particular strategies that may be helpful include development of forcing functions that drive individuals to follow the desired process or protocol, hardwiring the new process into the existing work flow, making the desired process user friendly, and elimination of potential work-arounds. Continued monitoring of the outcomes of interest after conclusion of the improvement project will be important to confirm sustainability or to alert staff of process drift.

Given the detailed nature of improvement science, organizations or units looking to achieve real change will need to employ quality improvement experts or seek to attain quality improvement training for their staff. Identifying these quality leaders and supporting them with appropriate resources and data streams will be essential to achieving optimal patient outcomes.

Team Structure and Dynamics

Staffing models may vary widely among pediatric cardiac intensive care units (ICUs), and these staffing models may have significant effect on patient outcomes. Although many children are well cared for in combined medical-surgical units after congenital heart surgery,

TABLE 2.1 Common Quality Improvement Methodologies Used in Health Care

Methodology	Primary Role	Key Strengths	Potential Limitations	Tools Commonly Utilized
Model for Improvement (Institute for Healthcare Improvement)	Rapid process improvement	• Simplicity • Swift implementation	• Superficial analysis • Reliance on trial and error	PDSA cycles, key driver diagrams, process mapping, cause and effect diagrams
Six Sigma	Minimize variability, reduce defects	• Thorough analysis with focus on statistical change • Focus on maintaining gains	• Complex methodology • Time intensive	DMAIC, process mapping, Pareto charts, cause-and-effect diagrams, value stream mapping
LEAN	Reduce waste, increase efficiency	• Focus on efficiency	• Limited scope	Value stream mapping, process mapping
Failure modes effect analysis (FMEA)	Error proofing	• Proactive risk identification • Increases process reliability	• Focus on major failures • Often not comprehensive • Complex methodology	Process mapping, error proofing, FMEA worksheets, SWIFT analysis
Root cause analysis	Error investigation	• Identification of previously unidentified risk	• Retroactive analysis; analysis may be limited by recall bias	Process mapping, error proofing

DMAIC, Define, Measure, Analyze, Improve, Control; *PDSA,* Plan-Do-Study-Act; *SWIFT,* structured what-if technique.

an increasing number of institutions have moved toward a model with a separate cardiac ICU, modeling what is commonplace in adult centers. This strategy allows for focused expertise among physician, nursing, respiratory therapy, and ancillary staff around the unique population of children with congenital and acquired heart disease and is supported by improved outcomes in high-volume centers and dedicated cardiac ICUs.[3-7]

Physician staffing of pediatric cardiac ICUs should include individuals with a strong understanding of the unique physiology of the congenital heart population and, when possible, prior training in both intensive care and cardiology. Inclusion of trainees, to be expected at most academic centers, is essential for the training of the next generation of cardiac ICU providers, as well as providing baseline management knowledge of this population to pediatric intensivists and cardiologists. Although cycling trainees through the unit for short rotations may add undesirable variability to staffing, these trainees may also provide unique perspective and offer partnering opportunities for research and improvement activities. Disruptions from the rotational nature of trainees can be minimized with a detailed and consistent orientation to the unit protocols and culture.

Advanced practice practitioners (nurse practitioners and physician assistants) may provide unique expertise in caring for children with congenital and acquired heart disease as a potential bridge between physicians and nursing staff. The addition of these practitioners as long-term members of the team allows for ongoing development of their skill set unique to this population. Advanced practice providers also foster ongoing relationship building within the team and may add continuity for patients with prolonged or recurrent hospitalizations.

Regardless of the unit structure or specific providers involved in care, patient outcomes will be optimized only if the medical team displays strong teamwork. This includes clear communication, psychologic safety, and a culture of feedback. The latter directly ties into the capability of the team to continuously improve and is contingent on each of the former being in place. Specifically, use of debriefings as a feedback mechanism has been tied to improved outcomes in ICU patients. Proven team training strategies such as TeamSTEPPS[8] can be leveraged to teach other evidence-based tools to improve team behaviors and performance.

A growing body of evidence links local work culture to patient outcomes.[9-11] Teamwork scores, safety culture, staff burnout, and staff engagement scores have been linked to mortality, surgical complications, medical errors, and other hospital-acquired infections. To provide the best quality care to patients, unit leadership must recognize this link and foster a culture of strong teamwork and safety. In addition to focusing on optimal teamwork, Leadership WalkRounds is a specific tool that can be beneficial toward safety culture.[11] For WalkRounds, unit leaders circulate the unit on a biweekly or monthly basis during different shifts. During these rounds, they speak to as many frontline staff as possible, asking both "What is going well?" and "What could be better?" Feedback is then provided to all staff regarding findings, recognition of high points, and potential changes to address concerns. This interaction between leadership and staff builds psychologic safety, models effective feedback, proactively identifies issues before they affect patients, and highlights safety and quality as organizational priorities.

The impact of team dynamics and unit culture on patient outcomes demonstrates the comprehensive approach that must be taken to improve quality of care. Disease treatment must have a sound basis in evidence-based therapies, but enhancing health care delivery encompasses the entire process of caring for patients, including patients, providers, and staff, and the means by which care is supplied. This holistic approach to quality must be embraced to truly give our patients the pinnacle of care.

Monitoring Quality at a Unit and Organizational Level: The Balanced Scorecard

A common frustration of medical providers is the lack of meaningful feedback on their practice habits and a lack of transparency to organizational priorities. This lack of transparency often leaves providers feeling "kept in the dark" or asking "Is this the latest trend?" regarding strategic planning, quality management, and PI efforts.

To eliminate these questions and other impediments to success, clinical improvement strategies should be systematically implemented in a way that uses the advantages of each approach, while focusing on long-term goals. The balanced scorecard (BSC) can assist in aligning these goals.[12]

Originally developed to support PI in industry, the BSC has been touted as a strategic planning framework that consolidates multiple improvement projects into a single integrated platform.[12] As such, the scorecard is an integration of multiple interventions and keeps "score" of the success or failure of the strategic goals. This approach is fundamental to success, promotes balance in the organization, and aligns all disciplines around a focused strategic agenda.

BSC methodology starts with the development of the mission and strategic plan in conjunction with senior leadership.[1,2] Once the senior management team has defined the strategic goals, the key metrics that measure performance are developed. Finally, initiatives are developed to improve performance and support achievement of the strategic goals. As such, the scorecard functions as an important strategic platform that drives the integration of key initiatives, methodologies, and processes with focus on critical outcome measures. Although performance at the operational level frequently requires additional tools and techniques that bridge the gap between strategy and tactics, the BSC becomes the tool that identifies where initiatives should be focused and how these initiatives impact the whole organization.

The traditional health care BSC has the following perspectives: quality and safety, patient experience, work culture, and finance and growth (Table 2.2). In contrast to industry, which primarily focuses on financial performance, the quality and patient safety perspective is placed at the top of the health care BSC, indicating its priority importance.

Defining Goals Linking Performance Metrics

Once the strategic plan is defined, specific goals are determined by the team and linked to each strategic perspective. Limiting the goals to three or four per perspective is essential to maintaining focus on initiatives that will drive the strategic plan. After the goals are determined, specific metrics are defined and linked to each goal. The metrics must be measurable and collected at least quarterly. Performance targets are then defined and linked to each metric. It is best to pick targets from comparable institutions. If none are available, a modest improvement from baseline, such as 10% to 20% improvement is a good starting point. Many of the operational metrics that populate the BSC are derived from hospital operational and financial databases, patient safety data from internal safety reporting systems, patient satisfaction survey data, and work culture survey data. Validity of the data is key, and data accuracy must be ensured before presenting this to the team. Bad data will result in loss of confidence and can ruin the efforts before implementation.

Driving the Balanced Scorecard to Unit Levels

The performance on the scorecard rolls up to provide a single score for all goals and metrics. In this way it provides balance to the organization because the overall score will be low if the organization performs well in one perspective (e.g., finance and growth) and does poorly in another (e.g., quality and safety). The next step is to have individual scorecards at the service unit level and finally, at the individual operating unit level. This tiered approach encourages focused improvement efforts at the direct patient care level that are aligned with the strategic goals of the broader organization. Without this alignment, PI efforts are often reactionary and focused on local concerns that may have little impact on organizational outcomes. Aligning PI initiatives toward strategic goals provides a significant economy of scale and ensures that the entire organization benefits from collaborative efforts.

As an example, Duke Children's Hospital has used the BSC to drive systemic improvements in several areas.[13] Compared to the prior year in the quality and patient safety perspective, we witnessed a reduction in morbidity, a decrease in readmissions from 7% to 4%, a decrease in infection rates from 3% to 1%, and a decrease in length of stay by 0.6 days. These improvements were seen in conjunction with an increase in average daily census by 9% over the previous fiscal year.

In the finance and growth perspective, the patient flow team achieved a 26% improvement in discharge times and 10% improvement in pediatric ICU encounters. Multiple finance-based initiatives followed implementation of the BSC, resulting in an increase in the variable contribution margin by 240%. In the patient experience perspective, patient satisfaction scores have exceeded the set targets over the last fiscal year (Press Ganey overall mean score of 84). In the work culture perspective, independent observations of teamwork increased by 72% ($P < .001$) and overall perception of teamwork increased by 75% ($P < .001$). Surveys also demonstrated that 95% of participants believed that team training would improve the way they did business, and 100% of participants would recommend team training to coworkers.

The BSC is one methodology to ensure that strategy turns into action. Because of the wide variety of options available and the hospital staff's lack of experience, many providers find implementing clinical improvement programs in health care to be challenging.[12-14] To be successful, these programs must be supported by senior management, physicians, and caregivers. Physicians, as a group, often are difficult to engage. Improvement initiatives may require physicians to change their practice, yet they frequently do not include input from the physicians, resulting in a lack of physician support for improvement initiatives and placing physicians at odds with administrators.

Clinical improvement initiatives that involve a change in physician practice must engage physicians in the process. Engaging physicians is challenging because they typically lack a background in improvement science and perceive that they will have difficulty contributing to the mission. This reluctance can be overcome by developing a specific training program for physicians, identifying clear goals and areas of focus, and linking the physicians with current operational and clinical improvement teams. In this way the physicians can become an integral part of the process, and the organization can leverage their considerable influence to achieve success.

The BSC requires thoughtful, considered adjustments in goals and metrics to meet the changing strategic plan. For example, if an ICU expansion is planned, the BSC might be updated with

TABLE 2.2 Sample Balanced Scorecard

	TARGET[a]	Quarter Actual	YTD Actual
QUALITY AND PATIENT SAFETY			
Infection prevention: catheter associated bloodstream infection	0.0	0.00	0.00
Infection prevention: urinary catheter associated urinary tract infection	0.5	1.10	0.63
Infection prevention: hand hygiene	95%	100%	98%
Infection prevention: central venous line utilization ratio	80%	76.6%	79.2%
Infection prevention: urinary catheter utilization ratio	20%	18.1%	16.2%
Pressure injury: assessed patients with acquired pressure injuries	5%	7.2%	6.1%
Patient falls rate per 1000 inpatient days	0.0	0.00	0.32
Patient falls with injury per 1000 inpatient days	0.0	0.00	0.00
Preventable medication related SRS events with patient impact	0.3	1.5	0.45
Restraints: percent of patients restrained	4%	8.4%	3.6%
Transfusion deviations	0.0	0.0	0.0
FINANCE AND GROWTH			
Agency staff: percent of worked hours	0.0%	0.8%	0.6%
Flex expense percent variance	0.0%	–0.9%	0.7%
Flex FTE percent variance	0.0%	–1.3%	–0.4%
Nursing overtime: percent of paid hours	2.5%	1.1%	1.9%
Skill mix: RN nursing care hours as a percent of all nursing care hours	97.5%	98.1%	96.9%
WORK CULTURE			
Employee injury: rate of lost days of all inpatient nursing employees	0.0	0.0	0.0
Percent terminations annualized: overall	18%	23.1%	21.2%
Percent terminations annualized: RN	20%	24.5%	19.8%
RN staff: percent with BSN or above	80%	89.1%	84.7%
RN staff: percent with certification	50%	64.3%	59.6%
PATIENT EXPERIENCE			
Likelihood to recommend	90%	88%	94%
Responsiveness of hospital staff	80%	81%	84%
Acceptable noise levels at night	80%	63%	72%
Unit cleanliness	80%	82%	80%
Overall rating of unit	90%	91%	87%
Patient satisfaction: communication among team members	85%	82%	86%

[a]Note that "target" reflects an achievable metric, allowing the team to progress towards the overall goal (e.g., the overarching goal is to have zero infections and zero medication errors). Metrics highlighted in *blue* demonstrate areas where the team exceeds targets, while metrics highlighted in *orange* demonstrate performance below targets and potential focus areas for improvement efforts. *FTE,* Full-time equivalent; *SRS,* safety reporting system; *YTD,* year to date.

new goals and metrics tied to this project and reflected in the ICU scorecards. In this way the BSC functions as a living record of how performance is tracking against the strategic plan.

Benchmarking and Collaboration

Although the BSC allows for clear tracking of specific outcomes within an institution over time, it may not detail how that center's performance compares with other similar centers. Benchmarking against other centers is an important aspect of understanding the overall quality of care provided to patients. Outcomes databases like the Society of Thoracic Surgeons (STS) database allow institutions to follow their overall performance relative to peers. Beyond internally set targets, this benchmarking highlights strengths and weaknesses within a program and can help focus resources for areas needing further attention.

Even with comparative data, defining best practices within a single center can often be difficult, given small numbers of patients with heterogeneous disease processes and the lack of feasibility to try many different care strategies. Multi-institution quality improvement collaborations are a strategy to allow centers to learn from the experience of others, through shared evaluation of practice variability and the individual strengths of each institution. Several such collective efforts have led to improved care for children, including delivery of surfactant for preterm infants,[15] reductions of catheter-associated bloodstream infections through the National Association of Children's Hospitals and Related Institutions (NACHRI) collaborative,[16] and reductions of medical errors and other hospital-acquired conditions through the Solutions for Patient Safety collaborative.[17]

Within the congenital heart disease community, the National Pediatric Cardiology Quality Improvement Collaborative has successfully leveraged data from several large pediatric cardiac centers to highlight key areas of variability and identify best practices that may not have been successfully elucidated in prior smaller studies. With distribution of these best practices and increased focus on quality improvement at each individual site, the collaborative has seen a 40% decrease in mortality during the interstage period for hypoplastic left heart syndrome following the Norwood procedure among the participating institutions.[18] Similarly, the Pediatric Cardiac Critical Care Consortium (PC^4) is a large multicenter registry with robust data from 30 of the largest US children's hospitals.[19] PC^4 has delineated areas of substantial variability in care and outcomes[20-22] and provides participants benchmarking data and opportunities for collaborative quality improvement efforts.

Hallmarks of these collaborative efforts include transparency among center practices and the willingness to forego competition for the purposes of driving quality care. Centers must dedicate local resources not only to process improvement but also to data collection and validation. With these combined efforts, institutions can achieve better outcomes than any one center could achieve on its own, and for a larger number of patients.

Conclusion

Our primary goal as health care providers is to ensure that our patients get the best possible care. Quality improvement is the path by which we can achieve that promise in a consistent and reliable manner. Development of a robust quality framework for patient care will require:

- Validated and detailed data streams to effectively monitor processes and outcomes
- Application of proven quality improvement methodologies with dedicated resources that emphasize preserving progress in one process as new targets are identified
- Focus on safety and teamwork culture within units, including attention to human factors that affect execution of health care delivery
- Balancing priorities and strategic initiatives with careful consideration given to financial stability, growth, and sustainability
- Collaborative efforts between institutions to define and share best practices

Strong unit leadership will be needed to maintain the vision of the six domains of quality and to uphold patient-centered care and outcomes. With such leadership and combined with thoughtful application of improvement methodologies, it is possible to truly elevate the care we provide to our most vulnerable patients.

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3

Streaming Analytics in Pediatric Cardiac Care

MELVIN C. ALMODOVAR, MD

Current-state computer and information technology allows extraction and aggregation of large volumes of diverse data types to support medical decision making in hospitalized patients.[1-3] With abundant and readily available data there has been growing interest and accumulating experience with advanced data analytics techniques such that there now exists both the demand *and* an opportunity for intensivists, among other clinicians, to pursue innovative information technology applications to benefit our fragile patients. But will we soon reach the "peak of inflated expectations" followed by a rapid descent to the "trough of disillusionment" before realizing the promises of precision medicine, big data analytics, and machine learning applications as some have suggested?[4] It is the author's belief that leveraging information technology and blending expertise from multiple disciplines such as medicine, engineering, mathematics, computer science, and even behavioral science will drive greater medical intelligence and more accurate and efficient health care across the range of clinical and nonclinical scenarios. The formal establishment of the field of biomedical informatics and growing experience with data science applications to support medical decision making and patient care delivery processes support this perspective.[5-7]

The purpose of this chapter is to describe basic principles of high-frequency data analytics and, specifically, how the streaming analytics approach may be applied in the pediatric cardiac intensive care unit (CICU) to enhance our understanding and management of the critically ill patient with cardiac disease.

Overview of Real-Time Data Analytics

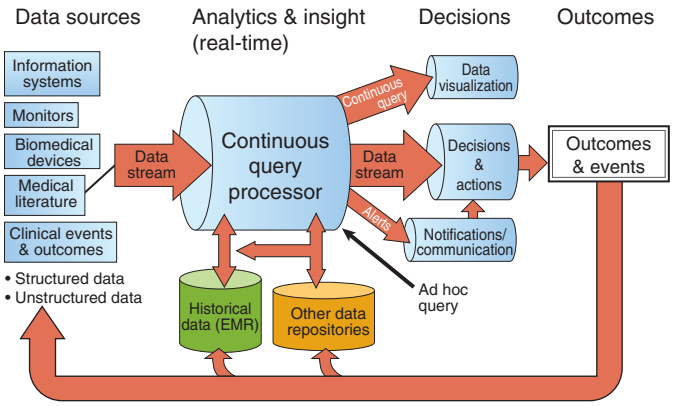
Real-time data analytics involves the capture, processing, and analysis of data as data is entering the system. In the data-rich intensive care unit (ICU) environment, information and networking technology, the ready access to clinical information, and the application of mathematical modeling methods are beginning to support our ability to better manage multiparameter data streams in our assessment and treatment of patients.[8,9] Depending on the analytics platform and database structure, stored genetic and other patient-specific, structured, and unstructured historical data may also be included, thereby adding context for the population or circumstance of interest. At the same time, this would allow for growth of captured volumes of information for later use in research, quality, and outcomes analysis. Currently there is enthusiasm that robust data management capabilities will foster the development of predictive algorithms that may eventually support enhanced real-time decision making.[10,11] For example, in patients with borderline left heart structures being considered for or undergoing biventricular repair, preoperative and postoperative hemodynamic, imaging, laboratory, and historical data may be incorporated in a real-time analytics approach to support such decisions as (1) determining whether or not biventricular repair is feasible, (2) which targeted interventions may improve likelihood of success in attaining biventricular physiology, and (3) whether the intraoperative and postoperative data indicate a successful physiology or predict successful short- and long-term outcomes in this patient population. Population-based and patient-specific historical and real-time data are available in such scenarios and, ideally, would inform the decision-making approach during each management step over time. As one can see, such a scenario exemplifies a range of data analytics approaches that may be described to include the following major categories: descriptive analytics, predictive analytics, and prescriptive analytics. These categories may be viewed along a continuum that considers what *has happened,* what *could happen,* and what *should be done,* respectively. Descriptive analytics are familiar to all of us and involve the use of summary statistics that give insight into the past and are common in health care and non–health care industries. Predictive analytics employ the use of mathematical models to forecast the future or estimate data that are not yet in existence. Accurate prediction requires that certain conditions remain constant over time and that the correct or relevant data elements are included in the models.[12] There are a growing number of health care applications and numerous non–health care applications that are currently in existence as examples of predictive methods. The extent to which any of these applications is successful is highly dependent on its level of validation during algorithm development and testing, as well as a robust system of application evaluation and reengineering as needed. Prescriptive analytics incorporate the features of predictive modeling derived from historical and real-time data to achieve accurate near- or real-time prediction for the expressed purpose of driving actions. At this time, practical applications using this type of analytics in health care are relatively rare, at least in the live clinical setting because of limitations in extracting real-time data and a paucity of successfully validated predictive models. On the other hand, there are numerous non–health care applications that are successfully driven by prescriptive analytics methodology. Some examples of these include credit card fraud protection, cyber security monitoring, GPS location and guidance, and market data management to name a few.[13,14] Finally, from the capabilities afforded by predictive and prescriptive methods

comes streaming analytics, or event stream processing, the basic foundation of which will be reviewed in the next section.

Streaming Analytics

Optimal care of critically ill cardiac patients requires thoughtful and accurate assessment of their physiologic state using a variety of data elements not just at a single point in time, but repetitively and in response to expected and unexpected events. Hence any care strategy must seek to achieve accurate diagnoses and to discern the patient's overall trajectory pattern with the paradigm that deviations from expected patterns or valid early warnings will be heeded and appropriate adjustments in care will be made.

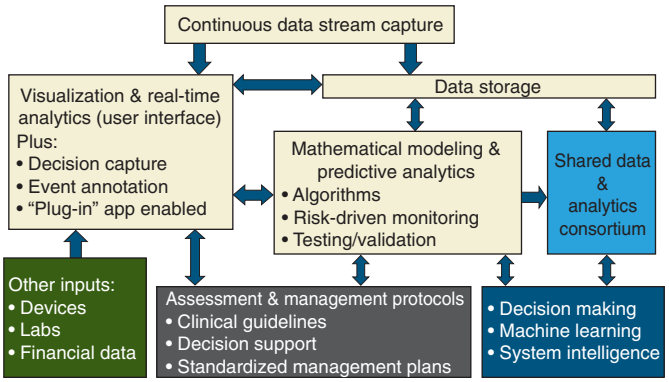
Digital data stream analysis is not new, and, historically, high-frequency, high-volume data have been processed in batches and at periodic intervals (daily, weekly, or at longer intervals). Much of the impact of this work has been realized through automation of clerical tasks and standardization of routine decisions and actions. In commercial industries, stream analytics has resulted in improved business efficiency and customer satisfaction owing to data access, the Internet, and ubiquity of personal computers and mobile devices.[13,15,16] Unfortunately, many data management systems remain fragmented and struggle with the management of large volumes of high-variety data that may present rapidly, a major consequence of which is long latency periods for access to the right data to make timely and correct decisions. In contrast to batch processing, event stream processing involves the continuous analysis of flowing time series data with the primary goals of providing real-time insight about a situation and to allow early detection of anomalies. Importantly, there is an inverse relationship between response time latency (i.e., the time from event or data element capture to delivery of action) and tactical value, thus emphasizing the importance of timely data capture, analysis, and action within the streaming analytics process.[16] For such a system to be functional, it requires a complex architecture (Fig. 3.1) with the capability to support the swift collection and aggregation of highly variable data types, the ability to analyze that data in real time, and the ability to directly influence end users (or even automated computerized systems) to make and execute appropriate decisions and actions. Ideally, such a system would include measurable outcomes and similar events as input data elements from the data stream feedback loop. This enables a rapid-cycle process to assess system performance and to support system learning and refinement as needed, as would occur in a machine learning paradigm. An additional feature worth noting is the integration of historical data or low-frequency data elements that support this approach for patient-specific or population-based applications.



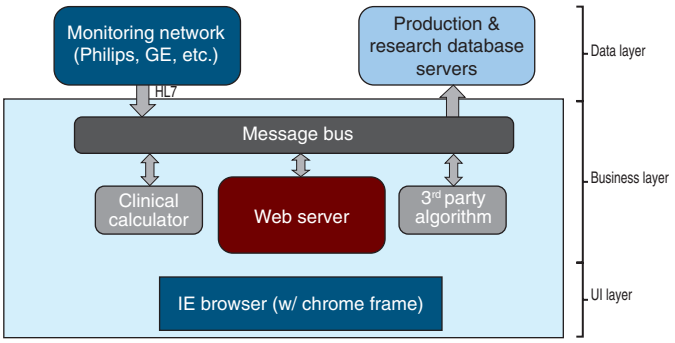
• **Figure 3.1** Stream processing architecture. *EMR,* Electronic medical record.

Development of a Real-Time Analytics Platform in the Cardiac Intensive Care Unit

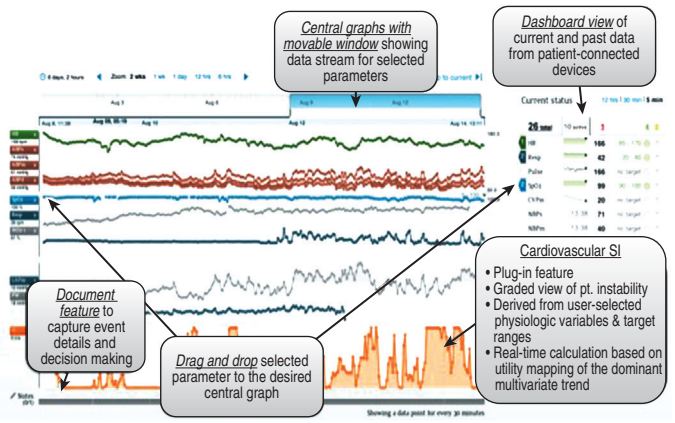
In 2010 a team from the CICU at Boston Children's Hospital, led by P. Laussen and M. Almodovar began development of the T3 system to capture, display, store, and analyze physiologic data streams from bedside monitoring devices. The term "T3" arose from the primary functional elements of the system as initially conceived to include the ability to *track* relevant physiologic data, enable assessment of a patient's *trajectory* throughout the patient's course in the CICU, and to support the ability to *trigger* appropriate responses or actions. The T3 data collection and analytics platform was designed as a Web-based, vendor agnostic, and scalable software system with three main features: an interactive data visualization user interface, a robust data analytics engine, and high-volume data storage capability. Fig. 3.2 describes an overview of the T3 platform beginning with data stream capture and ending with the multiple interfaces between its main features and data use applications. Fig. 3.3 shows a simplified version of the system architecture, noting its relatively simple structure and the ability to add third-party algorithms plus access to cumulatively stored data. The primary goals of the technology were to improve visualization of data trends for CICU patients, to develop algorithms and predictive models driven by the real-time physiologic data to guide decision making, and to create a hosting platform for the development and testing of algorithms using large volumes of stored data.



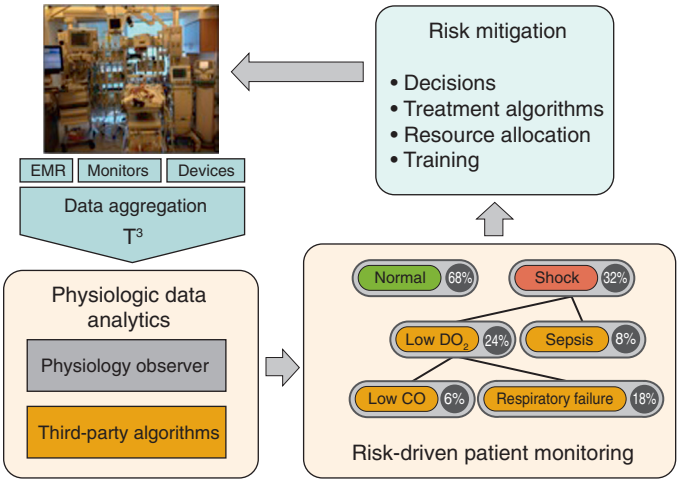
• **Figure 3.2** Overview of the T3 data collection and analytics platform.



• **Figure 3.3** T3 software system architecture. *IE,* Internet Explorer; *UI,* user interface.



• **Figure 3.4** T3 user interface showing trend patterns for multiple physiologic parameters, including the cardiovascular stability index *(SI)*. Each data point represents 5-second averages of the continuously streamed data.

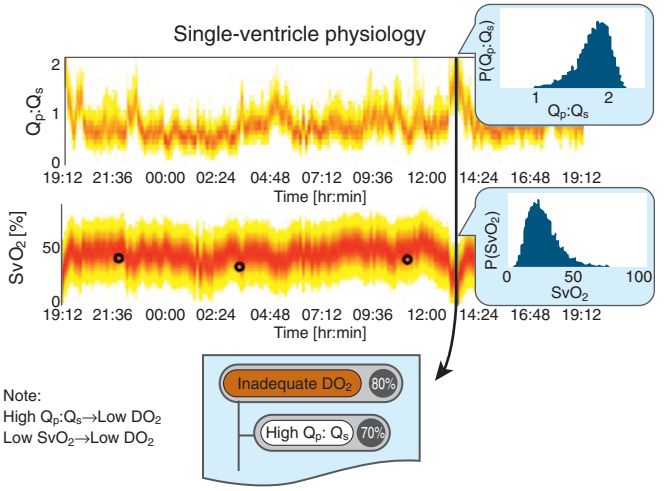


• **Figure 3.5** Risk-based monitoring process. *EMR,* Electronic medical record.

The T3 visualization user interface, as originally designed, is shown in Fig. 3.4 and demonstrates how multiple data streams are viewed simultaneously with trend patterns easily viewed in context with one another. The interactive interface allows selected parameters to be placed on the screen where desired and the ability to zoom in for higher resolution (down to 5-second interval averages between data points). The trend pattern can be examined along the timeline using a sliding, zoomable window for as long as the patient has been connected to a bedside monitor. The dashboard view in the upper right shows a sparkline summary of the recent data trends, the current parameter value, and user-determined boundary limits for each parameter. The user interface also allows for note entry or event annotation on the timeline (bottom) using free text entry or menu-driven options. This allows for decisions or other entries to be captured for easy querying and reporting at a later time.

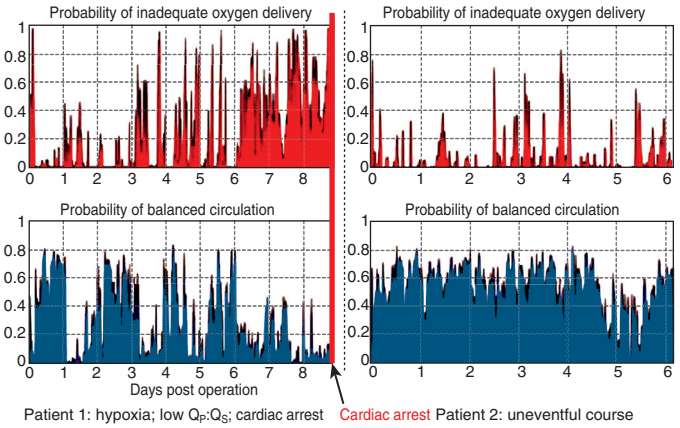
Among the analytics features of the system is the ability to select a sample of multiparameter data from the live interface and display summary statistics in tabular form for each parameter. In addition, the first plug-in algorithm, the cardiovascular stability index (SI), was designed to represent a graded view of patient instability and is displayed along with the other parameters from which it is derived (see Fig. 3.4). The SI is generated from user-selected physiologic variables (for instance, oxygen saturation as measured by pulse oximetry [SpO_2], mean blood pressure [BP], and heart rate [HR]) and requires customized upper and lower target ranges for each included variable. The SI is a real-time calculation based on utility mapping of the dominant multivariate trend calculated from the streaming data; in essence the value is influenced by the rate of change and the extent to which the measured value deviates from the ideal range parameter for the selected variables. In the early experience with the algorithm, the predictive ability of the SI was evaluated in 28 neonates with hypoplastic left heart syndrome following stage I palliation. Using the variables SpO_2, HR, and mean arterial BP, the maximum SI within the first 6 to 48 hours postoperatively (SI >0.11) predicted an ICU length of stay greater than 12 days. All patients with SI less than 0.11 (n = 13) were discharged from the ICU within 12 days.

The most advanced analytics feature of the T3 platform involves a predictive analytics technique, termed *risk-based patient monitoring* or *risk analytics* (Etiometry, LLC, Brighton, Massachusetts), which involves signal processing methodology along with the application

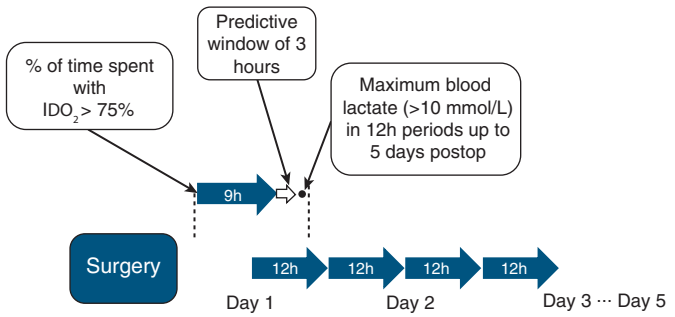


• **Figure 3.6** Panels showing probability density functions generated from streamed physiologic and intermittent laboratory data (SvO_2) for Q_p:Q_s and SvO_2. Note the trend pattern change in which a rise in Q_p:Q_s is associated with a decreased SvO_2 as would be expected in single-ventricle physiology with parallel circulations. *DO_2,* Oxygen delivery; *Q_p,* pulmonary blood flow; *Q_s,* systemic blood flow; *SvO_2,* mixed venous saturation.

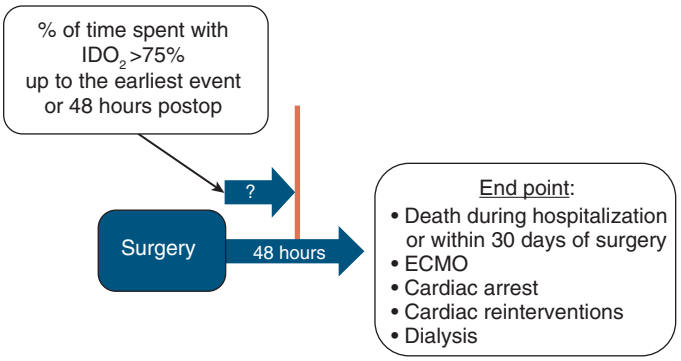
of algorithms derived from physiology-based models to estimate the probability that a certain physiologic state exists. A key goal of this approach is to assist in the management of clinician data overload by processing multiparameter data streams and to account for the inherent uncertainty that exists in any clinical assessment or treatment decision.[10,11] A flow diagram depicting the risk-based monitoring process is shown in Fig. 3.5, where, as an example, the probability of shock is estimated given the quantitative assessment of its possible attributes. By signal processing methods, quantitative estimates that a condition exists (like shock or poor oxygen delivery) are generated from probability density functions for the relevant variables derived from the continuous physiologic data stream. Fig. 3.6 shows how the probability density functions for the attributes ratio of pulmonary to systemic blood flow (Q_p:Q_s) and mixed venous saturation (SvO_2) are viewed over time and how the data can be translated into a quantifiable risk of the condition, which in this case is inadequate oxygen delivery (IDO_2), using the single-ventricle physiology model. The analysis can be



• **Figure 3.7** Risk-based analytics demonstration of the probability of inadequate oxygen delivery on two patients with single-ventricle physiology. *Q_p:Q_s,* Ratio of pulmonary to systemic blood flow.



• **Figure 3.8** Test design scheme for the evaluation of the IDO_2 algorithm as a predictor of physiologic state as defined by lactate >10. *IDO_2,* Inadequate oxygen delivery.



• **Figure 3.9** Test design scheme for the evaluation of the IDO_2 algorithm as a predictor of selected end point. *ECMO,* Extracorporeal membrane oxygenation; *IDO_2,* inadequate oxygen delivery.

computed at single or multiple time points or even continuously. Continuous real-time risk assessment reveals the trajectory pattern for a condition of interest that may evolve in due course or in response to therapeutic interventions. Taken further, if a given pattern can be shown to "predict" a certain outcome, then in theory the early detection of anomalies could be achieved from the data stream to alter treatment course to either achieve or avoid that outcome. Algorithm testing and proper validation is crucial for this to be adopted by clinicians and to be safely incorporated into clinical practice. In a simple but illustrative example, Fig. 3.7 shows the continuous probability assessments for IDO_2 and Q_p:Q_s equal to 1 in two patients, one who experiences cardiac arrest and other experiencing an uneventful course. One can appreciate the difference in risk analytics trend pattern between the two patients experiencing different outcomes. One can also appreciate the sustained rise in IDO_2 probability and a simultaneously low risk of "imbalanced Q_p:Q_s" that occurred in patient 1 a few days leading up to the arrest, which might be attributable to the Q_p:Q_s imbalance with low DO_2 as a cause of the event.

Since its initial creation, the IDO_2 algorithm has undergone further evaluation and testing in regard to its ability to predict a patient's physiologic state and outcomes.

In a retrospective study of a sample of 274 neonates undergoing cardiac surgery over a 4-year period, the risk analytics IDO_2 algorithm, derived from the continuous physiologic and periodic laboratory data parameters of SvO_2 value of 50% or less, SaO_2-SvO_2 difference of 50 or higher, and mean arterial blood pressure of 45 mm Hg or less, was evaluated as a predictor of blood lactate level greater than 10 mmol/L and separately as a predictor of poor outcome. Poor outcome was defined as experiencing cardiac arrest, dying by postoperative day 30, and the need for cardiac reintervention, mechanical circulatory support, or dialysis. The test design for predicting an abnormal physiologic state (lactate level greater than 10 mmol/L) involved identifying the percentage of time spent immediately postoperatively with IDO_2 probability greater than 75% over a 9-hour period leading up to a predictive window 3 hours before a maximum lactate value of greater than 10 mmol/L was measured. These 12-hour cycles occurred up to 5 days postoperatively as is shown diagrammatically in Fig. 3.8. In predicting poor outcome the test design involved identifying the percentage of time IDO_2 was greater than 75% up to the earliest event or 48 hours postoperatively. The schema for this design is shown in Fig. 3.9. Receiver operating characteristic analysis revealed an area under the curve (AUC) for elevated blood lactate level prediction of 0.84 (0.75–0.9) and an AUC of 0.84 (0.77–0.89) in predicting poor outcome.

In a separate study the IDO_2 algorithm and thus the predictive analytics approach was evaluated in its ability to predict a measured SvO_2 value less than 40%. A low measured SvO_2 in high-risk postoperative cardiac patients has been widely accepted as a proxy for low cardiac output, a condition approaching a state of anaerobic metabolism, and high risk of poor clinical outcome.[17,18] In this multi-institutional study involving over 1500 cardiac surgical and nonsurgical cardiac patients less than 12 years of age, the IDO_2 algorithm (probability of IDO_2 value greater than 75%) driven off continuous physiologic data plus periodically measured SvO_2 by venous blood gas was shown to be a good predictor of SvO_2 less than 40% (AUC of 0.84). The test design was based off IDO_2 greater than 75% between 15 and 120 minutes leading up to SvO_2 measurement. In this study the relative risk of measuring a low SvO_2 level (<40%) increased with higher IDO_2 range, with the IDO_2 range 75% to 100% associated with a relative risk of 4 to 7 in this population of neonates, infants, and children with cardiac disease.

From these studies it is apparent that the IDO_2 algorithm provides real-time quantitative information about a patient's condition, and that the rise in IDO_2 value, even to modest levels, may signify an increased risk of inadequate DO_2, thus triggering some sort of action to potentially improve the patient's immediate course and subsequent outcome. To date neither the IDO_2 algorithm nor any of the work involving the T3 predictive analytics has been evaluated in relation to specific treatment actions. However, since

its initial creation the T3 analytics platform has undergone modifications to the visualization user interface that enable its use as an always-on persistent display of the continuous data stream plus IDO_2 estimation, with the real-time incorporation of selected laboratory data in the same view. Body system and physiology-based views (i.e., respiratory and neurologic) have been developed with work on the incorporation of more diverse data elements ranging from static patient-specific information to digitally available waveform data.

Visual Analytics and Data Visualization

Visual analytics represents another area of science that is inherent to the streaming analytics approach. As described in the previous section, data visualization is an important component of the T3 analytics platform because it provides a graphical representation of data that identifies and communicates important patterns and concepts about the data. According to Alberto Cairo, a renowned data visualization expert, the goal of any visualization is to "assist the eyes and brain to perceive what lies beyond their natural reach." Thus data visualization seeks to integrate our visual perception capabilities with our cognitive abilities so that we can receive and process the information effectively.[19]

Ideally, a visualization should provide an intuitive, integrated view of relevant parameters while preserving situational context, support care management, and be interactive, allowing the end user to easily navigate and manipulate the data. Visual analytics involves analytic reasoning as facilitated by visualization interfaces and is believed to play a key role in supporting the effective use of data and information derived from big data analytics techniques.[20] When designing and implementing a data visualization tool, human factors principles should be considered to enhance the user experience and thus promote a higher likelihood of user adoption.[21] However, with any novel or evolving technology application, resistance to adoption may occur for a variety of reasons. This can be addressed with attention to potential or known barriers early in the design, testing, and implementation course. From the clinical safety perspective, simulation methods may be useful for training purposes and also to identify system glitches, through usability and heuristic evaluation, before and after the system is brought into production.[22]

Final Comments

Streaming analytics has made its way into the contemporary ICU, though this is not an entirely new phenomenon given the history of intensive monitoring and use of broad, though basic, types of clinical data since the early days of critical care medicine. What is different from previous eras are a number of factors related to the evolution of standards and expectations around outcomes, the growth in knowledge and information in medicine, advances in computer and information technology that bring massive volumes of information to us, and examples outside of health care that real-time analytics can be applied in profound and beneficial ways. Though limited to a few examples, this chapter highlights some of the early experience of streaming analytics in a critical care environment, specifically in a dynamic, high-volume pediatric CICU. The impetus to pursue high-frequency data analytics in this unit arose from the desire to better understand the trajectory patterns of critically ill patients in hopes of identifying anomalies in their course, affording the opportunity to proactively manage situations and avoid catastrophic events. In addition, it was recognized that the demands of the dynamic, data-rich, and resource-intensive CICU coupled with the potential for data overload among clinicians warranted pursuit of a system with T3's capabilities. It was also recognized that the electronic medical record and existing telemetry systems were not capable of providing an intuitive and integrated view of the data elements necessary to assist in the continuous and rapid assessment of a patient's trajectory or evolving pattern of deterioration. And lastly, without ready access to stored, aggregated data, extracting meaningful insight was onerous or impossible in some cases where event review was necessary. What has been achieved by the creation and implementation of the T3 system is summarized as follows:

1. High-frequency physiologic data from multiple sources are now captured, aggregated, and stored, then accessed and distributed.
2. Captured data can be organized and presented on an intuitive visual interface for efficient and effective processing by clinicians in the live clinical setting who must make timely assessments and interventions.
3. Streamed data can be analyzed in real time to produce a variety of metrics that help to quantitatively assess a patient's condition instantaneously or over time and allow for trend pattern assessment, including judgment of the response to treatment.
4. Predictive analytics using signal processing and mathematical modeling techniques from the combination of high-frequency data and intermittent data is achievable to estimate variables or a stream of relevant data that does not yet exist. With further development, testing, and validation, these streams may reduce data overload and improve the timeliness and effectiveness of care.
5. A robust data analytics platform can support integration of data that continuously grows and integrates elements from multiple sources, thus enhancing knowledge about the individual patient or groups of patients within a database and through data sharing across institutions and databases. Depending on the platform structure, databases can be leveraged to support benchmarking, protocol integration, and quality improvement and rapid-cycle research activity. Regardless of the system architecture, it is crucial that data privacy and security be achieved and maintained.
6. At the time of this writing, other systems with similar capabilities have been or are actively being developed at institutions around the world. Laussen and others at The Hospital for Sick Children in Toronto are expanding the data science approaches upon which the T3 platform is based, which now include waveform data. His colleagues in the neonatal ICU at the same institution have been working on big data applications using high-frequency analytics to enhance the monitoring and identification of important events in at-risk neonatal patients.[23] At Texas Children's Hospital, real-time high-frequency data were being used to develop an algorithm designed to identify subtle signs of clinical deterioration that may lead to cardiopulmonary arrest in complex neonatal patients with parallel circulations.[24] Finally, a group at Emory University Hospital, like others, has been working on the optimal engineering design to achieve the "smarter ICU," an important part of which involves the application of big data analytics to improve caregiver situation awareness for early identification of anomalies and prompt intervention.[25] From work described in this chapter, it appears that further technologic advances are likely and the achievement of automated intelligent early warning and patient management technology-driven processes involving streaming analytics are now within our reach.

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