

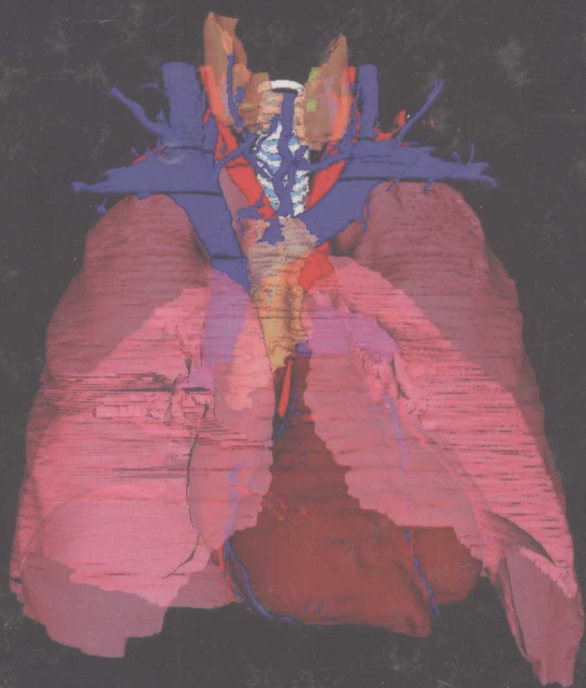
COMPLICATIONS IN CARDIOTHORACIC SURGERY

AVOIDANCE AND TREATMENT

2nd edition

Edited by

Alex G. Little and Walter H. Merrill



 WILEY-BLACKWELL

COMPLICATIONS IN CARDIOTHORACIC SURGERY

AVOIDANCE AND TREATMENT

2nd edition

EDITED BY

David G. Coombs and David H. Martin



WILEY-BLACKWELL

Complications in Cardiothoracic Surgery

AVOIDANCE AND TREATMENT
Second Edition

EDITED BY

Alex G Little, MD

Elizabeth Berry Gray Chair & Professor
Department of Surgery
Wright State University Boonshoft School of Medicine
Dayton, OH
USA

Walter H Merrill, MD

Chief, Division of Cardiothoracic Surgery
University of Mississippi Medical Center
Jackson, MS
USA

 **WILEY-BLACKWELL**

A John Wiley & Sons, Ltd., Publication

This edition first published 2010, © 2010 by Blackwell Publishing Ltd

Blackwell Publishing was acquired by John Wiley & Sons in February 2007. Blackwell's publishing program has been merged with Wiley's global Scientific, Technical and Medical business to form Wiley-Blackwell.

Registered office

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial offices

9600 Garsington Road, Oxford, OX4 2DQ, UK

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

111 River Street, Hoboken, NJ 07030-5774, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

The contents of this work are intended to further general scientific research, understanding, and discussion only and are not intended and should not be relied upon as recommending or promoting a specific method, diagnosis, or treatment by physicians for any particular patient. The publisher and the author make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of fitness for a particular purpose. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of medicines, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each medicine, equipment, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. Readers should consult with a specialist where appropriate. The fact that an organization or Website is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or Website may provide or recommendations it may make. Further, readers should be aware that Internet Websites listed in this work may have changed or disappeared between when this work was written and when it is read. No warranty may be created or extended by any promotional statements for this work. Neither the publisher nor the author shall be liable for any damages arising herefrom.

Library of Congress Cataloging-in-Publication Data

Complications in cardiothoracic surgery : avoidance and treatment / [edited by] Alex G. Little, Walter H. Merrill. – 2nd ed.

p. ; cm.

Includes bibliographical references and index.

ISBN 978-1-4051-8103-7

1. Heart—Surgery—Complications. 2. Chest—Surgery—Complications. I. Little, Alex G.

II. Merrill, Walter H.

[DNLM: 1. Thoracic Surgical Procedures—adverse effects. 2. Intraoperative Complications—prevention & control. 3. Postoperative Complications—prevention & control. WF 980 C73683 2009]

RD597.C645 2009

617.4'1201—dc22

2009013400

ISBN 9781405181037

A catalogue record for this book is available from the British Library.

Set in 9.5/12pt Palatino by Aptara® Inc., New Delhi, India
Printed and bound in Malaysia by Vivar Printing Sdn Bhd

**Complications in
Cardiothoracic
Surgery**

List of Contributors

Sanjeev Aggarwal, MD

Assistant Professor
Department of Surgery
Division of Thoracic and Cardiovascular Surgery
University of Louisville
Louisville, KY, USA

Gorav Ailawadi, MD

Assistant Professor
Department of Surgery
Division of Thoracic and Cardiovascular Surgery
University of Virginia
Charlottesville, VA, USA

Mark S Allen, MD

Professor of Surgery
Mayo Clinic
Rochester, MN, USA

Nasser K Altorki, MD

Professor of Cardiothoracic Surgery
Chief, Division of Thoracic Surgery
New York Presbyterian Hospital
Weill Cornell Medical Center
New York, NY, USA

Constantine L Athanasuleas, MD

Professor of Surgery
Division of Cardiothoracic Surgery
University of Alabama,
Birmingham, AL, USA

Mark F Berry, MD

Resident, Cardiothoracic Surgery
Department of Surgery
Duke University Medical Center
Durham, NC, USA

William R Berry, MD

Research Associate
Department of Health Policy and Management
Harvard School of Public Health
Boston, MA, USA

Jain Bhaskara Pillai,**FRCS(CTh)UK, FRCS**

Super-Fellow in Cardiac Surgery
Division of Cardiac Surgery
Emory Crawford Long Hospital
Atlanta, GA, USA

William M Boedefeld, MD

University of Virginia
Charlottesville, VA, USA

Jeffrey Brown, MEd

Principal Scientist
Skilled Performance and Expertise
Klein Associates Division
Applied Research Associates
Fairborn, OH, USA

Gerald D Buckberg, MD

David Geffen School of Medicine
University of California
Los Angeles, CA, USA

Frederick Y Chen, MD, PhD

Assistant Professor of Surgery
Harvard Medical School
Director, Cardiac Surgery Research
Laboratory
Division of Cardiac Surgery
Brigham and Women's Hospital
Boston, MA, USA

Michael C Coello, MD

Resident, Cardiothoracic Surgery
Massachusetts General Hospital
Boston, MA, USA

Lawrence H Cohn, MD

Hubbard Professor of Cardiac Surgery
Harvard Medical School
Brigham and Women's Hospital
Boston, MA, USA

Lawrence L Creswell, MD

Associate Professor of Surgery
University of Mississippi Medical Center
Jackson, MS, USA

Ralph J Damiano, MD

John M Schoenberg Professor of Surgery
Chief of Cardiac Surgery
Washington University School
of Medicine
Barnes-Jewish Hospital
St. Louis, MO, USA

Thomas A D'Amico, MD

Professor of Surgery and Program Director
Division of Thoracic Surgery
Duke University Medical Center
Durham, NC, USA

Alberto de Hoyos, MD

Professor of Surgery
Assistant Professor of Surgery
Feinberg School of Medicine
Northwestern University
Chicago, IL, USA

Joel T Erskin, ScD, PA-C

Senior Instructor Pilot/Aerospace Physiologist
184MDG
184IW
United States Air Force/Kansas Air National
Guard
McConnell AFB, KS, USA

Michael P Fischbein, MD, PhD

Assistant Professor of Cardiothoracic Surgery
Department of Cardiothoracic Surgery
Stanford University School of Medicine
Stanford, CA, USA

William A Gay, Jr, MD

Professor of Surgery
Division of Cardiothoracic Surgery
Washington University School of Medicine
St. Louis, MO, USA

Ann Hendrich, RN, MSN, FAAN

Vice President, System Office
Clinical Excellence Operations
Ascension Health
St. Louis, MO, USA

Nicholas J Karis, MD

Instructor, Division of Cardiothoracic Surgery
University of Mississippi Medical Center
Jackson, MS, USA

John A Kern, MD

Associate Professor of Surgery
Department of Surgery
Division of Thoracic and Cardiovascular Surgery
University of Virginia
Charlottesville, VA, USA

Irving L Kron, MD

Professor and Chair of Surgery
University of Virginia Medical Center
Charlottesville, VA, USA

Jennifer S Lawton, MD

Associate Professor of Surgery
Department of Surgery
Division of Cardiothoracic Surgery
Washington University and Barnes Jewish
Hospital
St. Louis, MO, USA

Anson M Lee, MD

Research Fellow
Division of Cardiothoracic Surgery
Washington University School of Medicine
St. Louis, MO, USA

Lawrence S Lee, MD

Division of Cardiac Surgery
Department of Surgery
Brigham and Women's Hospital
Harvard Medical School
Boston, MA, USA

Joseph LoCicero, III, MD

Professor of Surgery
SUNY Downstate
Director of Surgical Oncology
Chief of General Thoracic Surgery
Maimonides Medical Center
Brooklyn, NY, USA

James D Luketich, MD

Henry T Bahnson Professor of Cardiothoracic
Surgery
Chief, Heart, Lung, and Esophageal Surgery
Institute
University of Pittsburgh School of Medicine
Pittsburgh, PA, USA

Hari R Mallidi, MD, FRCS

Instructor, Department of
Cardiothoracic Surgery
Stanford University School
of Medicine
Stanford, CA, USA

Douglas J Mathisen, MD

Chief, Cardiothoracic Surgery
Hermes C Grillo Professor of Surgery
Visiting Surgeon
Massachusetts General Hospital
Boston, MA, USA

Bryan F Meyers, MD, MPH

Professor of Surgery
Division of Cardiothoracic Surgery
Washington University School
of Medicine
St. Louis, MO, USA

Keith S Naunheim, MD

The Vallee and Melba Willman Professor
of Surgery
Chief, Division of Thoracic Surgery
St. Louis University Medical Center
St. Louis, MO, USA

Francis D Pagani, MD, PhD

Professor, Department of Surgery
Section of Cardiac Surgery
University of Michigan
Ann Arbor, MI, USA

Subroto Paul, MD

Assistant Professor of Cardiothoracic Surgery
New York Presbyterian Hospital
Weill Cornell Medical Center
New York, NY, USA

Arjun Pennathur, MD

Assistant Professor of Surgery
Heart, Lung, and Esophageal Surgery Institute
University of Pittsburgh School of Medicine
Pittsburgh, PA, USA

John D Puskas, MD, MSc, FACS

Professor of Surgery and Chief of Cardiac
Surgery
Division of Cardiac Surgery
Emory Crawford Long Hospital
Atlanta, GA, USA

Ellen W Raboin, MBA, MSOD, MAHOS

Consultant
Human and Organization Systems
CareQuest Consulting
Danville, CA, USA

Daniel B Raemer, PhD

Associate Professor
Department of Anesthesia and Critical Care
Massachusetts General Hospital
Harvard University
Boston, MA, USA

Michael F Reed, MD

Associate Professor of Surgery
Division of Thoracic Surgery
University of Cincinnati College of Medicine
Cincinnati, OH, USA

Robert C Robbins, MD

Chairman and Professor of Cardiothoracic
Surgery
Department of Cardiothoracic Surgery
Stanford University School of Medicine
Stanford, CA, USA

William Stein, IV, MD

Postdoctoral Research Fellow
Department of Cardiothoracic Surgery
Stanford University School of Medicine
Stanford, CA, USA

Paul N Uhlig, MD, MPA

Associate Professor
Department of Preventive Medicine
and Public Health
University of Kansas School of Medicine-Wichita
Wichita, KS, USA

Nirmal K Veeramachaneni, MD

Assistant Professor of Surgery
Division of Cardiothoracic Surgery
University of North Carolina at Chapel Hill
Chapel Hill, NC, USA

Jeffrey B Velotta, MD

Postdoctoral Research Fellow
Department of Cardiothoracic Surgery
Stanford University School of Medicine
Stanford, CA, USA

Paul F Waters, MD

Professor of Surgery
Yale School of Medicine
New Haven, CT, USA

Cameron D Wright, MD

Professor of Surgery
Harvard Medical School
Attending Surgeon
Massachusetts General Hospital
Boston, MA, USA

Acknowledgements

I would like to extend my thanks, gratitude, and appreciation to both the faculty and colleagues at the University of Chicago who trained and molded me, and to the high quality and enthusiastic residents whom I have had the good fortune to work with and train over the years. The community of thoracic surgeons is very special and it is an honor to be a part of it.

Alex G Little, MD

Likewise, I am grateful for the many teachers, mentors, and colleagues who have instructed, guided, and supported me during the course of my journey in cardiothoracic surgery. Working with students and residents has been a particular joy and privilege. Finally, I wish to acknowledge my indebtedness to the many patients who have taught me so much.

Walter H Merrill, MD

Preface

The reception of the first edition of this book has encouraged us to proceed with the development of this second edition. As before, we think of our book as a complement to the standard cardiothoracic surgery textbooks that address operative techniques and postoperative care. Acquisition of the information gained from the careful study of these books helps to establish the basic fund of knowledge that the thoracic surgery trainee and practitioner builds upon to establish final surgical competence. This knowledge foundation is supplemented by the real world experience with patients in the operating room, hospital, and clinic. It is this combination of knowledge and experience that leads to the development of the fully mature and capable thoracic surgeon.

We all are aware that this real world learning process involves the recognition of complications and the ability to learn from them. This is expressed in the common observation that good results come from experience and experience is acquired by making mistakes and learning from them. As before, the goal of our book is to minimize the frequency of surgical complications and maximize the patients' outcome when they do occur by allowing the reader to learn from the operative and clinical experience of those who have gone before. This means that each generation can learn and benefit from the experience already gained by others. There is no need for each of us to make our own mistakes or have our own complications if we can benefit from the experience and accumulated wisdom of others.

Therefore, this book and its chapters are focused on the issue of complication prevention and/or recognition and treatment. While the chapter authors have been asked to address the correct or standard way to perform operations and care for patients afterward, they have also been challenged to address and emphasize specific issues related to both intraoperative techniques and postoperative care that will reduce the incidence of complications. This is a slightly but importantly different focus from standard textbooks. As some complications are essentially inevitable, also addressed by the authors are the issues of timely recognition and appropriate treatment of complications when they do occur, despite best efforts to prevent them.

In summary, we hope that this book will serve as a useful supplement to, and not a replacement for, standard textbooks and operative atlases. We are confident that the readers will be representative of the proud tradition of a constant commitment to excellence in cardiothoracic surgery.

Alex G Little and Walter H Merrill

Contents

List of Contributors, vii

Acknowledgements, x

Preface, xi

- 1 Preventing Complications: New Frontiers of Safety Science in Cardiothoracic Surgery, 1**
Paul N Uhlig, William R Berry, Ellen W Raboin, Jeffrey Brown, Joel T Erskin, Ann Hendrich and Daniel B Raemer
- 2 Thoracic Incisions, 22**
Michael F Reed
- 3 Arrhythmias following Cardiac and Thoracic Operations, 54**
Joseph LoCicero, III
- 4 Complications of Cardiopulmonary Bypass and Cardioplegia, 74**
Lawrence L Creswell and Nicholas J Karis
- 5 Myocardial Protection: Why and How, 143**
Constantine L Athanasuleas and Gerald D Buckberg
- 6 Complications after Pulmonary Resection: Lobectomy and Pneumonectomy, 158**
Mark F Berry and Thomas A D'Amico
- 7 Complications of Tracheobronchial Resection, 182**
Michael C Coello and Douglas J Mathisen
- 8 Complications of Lung Volume Reduction Surgery, 202**
Nirmal K Veeramachaneni and Bryan Meyers
- 9 Complications of Lung Transplantation, 219**
Paul F Waters
- 10 Complications of Esophageal Resection, 228**
Subroto Paul and Nasser K Altorki
- 11 Complications of Minimally Invasive Esophagectomy, 247**
Arjun Pennathur and James D Luketich

- 12** Operations for Benign Esophageal Disorders, 266
Keith S Naunheim
- 13** Complications of Mediastinal Procedures, 286
Cameron D Wright
- 14** Complications of Pleural Operations and Procedures, 295
Alberto de Hoyos
- 15** Complications from Chest Wall Procedures, 325
Mark S Allen
- 16** On-Pump Coronary Artery Bypass Grafting, 333
Jennifer S Lawton and William A Gay, Jr
- 17** Off-Pump Coronary Artery Surgery: A Safe Approach, 351
Jain Bhaskara Pillai and John D Puskas
- 18** Valvular Operations, 375
Frederick Y Chen, Lawrence S Lee and Lawrence H Cohn
- 19** Complications of Myocardial Reconstruction, 392
Gorav Ailawadi and Irving L Kron
- 20** Complications after Atrial Fibrillation Surgery, 404
Anson M Lee and Ralph J Damiano Jr
- 21** Heart Transplantation, 419
William Stein, IV, Jeffrey B Velotta, Hari R Mallidi, Michael P Fischbein and Robert C Robbins
- 22** Assist Devices, 436
Sanjeev Aggarwal and Francis D Pagani
- 23** Aortic and Great Vessel Operations, 456
William M Boedefeld and John A Kern
- Index, 473

Preventing Complications: New Frontiers of Safety Science in Cardiothoracic Surgery

Paul N Uhlig, William R Berry, Ellen Raboin, Jeffrey Brown, Joel T Erskin, Ann Hendrich and Daniel Raemer

This chapter is written by an interdisciplinary team of authors with experience studying and applying safety science in cardiothoracic surgery. Paul Uhlig is a cardiothoracic surgeon with special expertise in high reliability clinical teamwork. Bill Berry is a cardiothoracic surgeon whose full-time work concerns patient safety and risk management. Ellen Raboin has expertise in group processes and team interactions and special expertise in action research regarding teamwork and safety in health care environments. Jeffrey Brown is an aviation safety and human factors expert with extensive experience in implementing and studying teamwork in cardiac surgery and other health care settings. Joel Erskin is a cardiothoracic surgery physician assistant and former USAF pilot, safety educator, and hospital commander, who co-lead early efforts to improve health care outcomes on the basis of principles of aviation safety. Ann Hendrich is a nationally recognized nurse executive and health care leader with expertise in transforming clinical care processes to improve safety and reliability. Dan Raemer is a biomedical engineer and leader in the field of health care simulation with expertise in critical event simulation and team training in cardiothoracic surgery. The chapter is written jointly from all of these perspectives.

In the same way as new approaches to cardiothoracic surgical operations are reshaping and transforming the specialty, new approaches for decreasing risk and improving patient safety are transforming the way that cardiothoracic surgical care is organized and practiced. This transformation is driving significant changes in surgical practice, education, and certification. Most importantly, it is producing better and safer patient care and a better experience of care for patients and practitioners alike.

Evidence supporting the effectiveness of these new approaches comes from pioneering studies in health care and from more fully developed research in

other areas of high-risk human teamwork such as aviation, space flight, nuclear power plant operations, and similar high consequence human activities where safety has been extensively studied. For us, incorporating these new approaches into our own daily work has been a remarkable experience. As experienced clinicians and scientists familiar with previous methods for achieving quality and safety in healthcare, it seems evident to us that the new ways are significantly better than the ways in which we were trained. We believe that convincing data will follow. For us, it is impossible to go back.

Accordingly, this chapter is written somewhat differently than chapters in most surgical textbooks. It is an invitational summary of emerging concepts, intended to introduce you to new ideas and help you explore them in your own practice. We believe that as you consider these ideas and incorporate them into your work, you will find them to be as fascinating, surprising, and hopeful as they are for us.

Tuesday morning, 7:05 a.m.

Claire shoots a quick smile at Marilyn as the two women in surgical scrubs walk briskly toward the pump room between OR 29 and 30. Marilyn, the manager of OR cardiac nursing, has been here since 5:30 a.m. getting things ready for the day. As usual, Claire is running a little late, carrying her motorcycle helmet in one hand and her loupes in the other. "Good morning, Claire. You're in 29 today," says Marilyn, acknowledging Claire's smile. "The cine for your first case is up on the computer, but we're having a little trouble finding the H and P." "Thanks, Marilyn," says Claire, "I'll get it for you. The office must have forgotten to send it over last night."

An hour later, Claire has settled comfortably into her OR routine. Her iPod is docked and playing the third track of her opening playlist, a Ravel orchestration of Mussorgsky's *Pictures at an Exhibition*. The IMA is down and Claire is placing the last cannulation suture. As usual, the room is relaxed and happy. It always is for Claire's cases, Marilyn thinks to herself as she catches up on her charting in the computer.

"ACT is 300," says Dave. It has been at least 2 months since he has done an on-pump case with Claire, maybe longer, he thinks to himself. He is sure it has been at least 2 months, because that is how long the contract negotiations with the hospital have been going on. He sighs and shakes his head thinking about those negotiations. What a mess. As chief of perfusion services, the contract negotiations have occupied every nonclinical moment of his days and quite a few restless nights, too, for what seems like an eternity. Fewer on-pump cases, in fact fewer cases overall since the surgical group opened their own hospital 2 years ago. Dave is 58. He has been a perfusionist here since he finished training 30 years ago. Before that he was a respiratory therapist. So much has changed, he thinks to himself, as he sits down behind his pump.

Claire's voice interrupts his thoughts, "OK to clamp and cut?" Dave leans forward, accidentally bumping his clipboard, which falls to the floor. He reaches

down to retrieve the clipboard, turns off the arterial pump head, clamps several lines, and replies, "OK to clamp and cut." Claire watches Dave settle back into his seat. Marilyn is right, Claire reflects, remembering something Marilyn mentioned yesterday. Marilyn said that Dave didn't restock cannulas last week and seemed preoccupied. He is different somehow, Claire thinks to herself, not the same steady Dave who took me under his wing when I started here 4 years ago. Maybe I should talk to him sometime.

A few minutes later, Claire has finished cannulating. She double checks the aortic line for air and looks up at Dave. "Dave, you OK for going on?" she asks. Dave nods. Claire takes the clamp off the venous line. "On bypass please, Dave, drift to 34, keep the cardioplegia warm." Claire watches as dark red blood swirls into the venous line and drains toward the pump. She scans the field and watches the heart begin to empty. She thinks of her patient, Jim, a 40-year-old man with a bicuspid aortic valve. His LAD lesion had been a surprise. A new valve and one graft. Not a bad first case of the day.

Her mind flashes briefly to Jim's family. She said hello to them on the way to the OR. Tiffany, Jim's wife, had seemed so young. So had their four children. "Marilyn, can you let the family—," she begins, but stops in mid sentence as her eyes move across the field to the aortic line. "Dave, is everything OK? The heart's empty but I don't see any blood in the aortic line, just prime."

"I know," says Dave. "I can't flow. I don't know. . . Oh, here it is. No, that isn't it. I don't know. For some reason. . . I can't flow with the centrifugal pump. I'm changing to the backup pump head, the roller pump. It should take just a second."

Claire is aware of the clicking of clamps and a flurry of activity as Dave rapidly resets his pump. "Susan, I need that line clamp back," Claire says to her scrub nurse, "right now." Claire looks at the monitor and watches as the arterial pressure drops through 30. She scans the lines and surgical field, looking up across the drapes at John, the anesthesiologist, who is now at full attention at the head of the table. "Dave," Claire says, "I'm clamping the venous line here at the field. John, go into Trendelenberg and run whatever fluids you've got wide open. Marilyn, would you see if anyone is in the pump room? Maybe Shelly can come in and help Dave." Her heart sinks as she checks the arterial pressure again: 18 mm Hg and falling. Why didn't he flow in before draining out, she thinks to herself. We've talked about that before. She watches the lines warily for air and asks Susan for another line clamp, just in case.

"I've switched over, Claire. Coming up on flow now," says Dave. Claire feels a moment of relief as Dave opens a clamp and turns on the pump. What happens next will be etched in her mind forever. With a sudden, decompressive tearing sound a torrent of blood erupts from the pump, drenching Dave, turning the wall, the pump, and the ceiling red, and flooding the floor. Dave's face is covered with blood and he cannot see. His mask is saturated and sucks so tightly to his face that he cannot breathe. He pulls frantically at the mask and reaches blindly, desperately for his pump control. Somehow he shuts off the pump and the torrent stops.

Claire looks up at the monitor. The pressure has settled flat at 12 mm Hg. Her mind is racing to absorb the scene: blood everywhere, total confusion in the room, the empty heart still beating as if oblivious, steep Trendelenberg, John determinedly squeezing in some sort of crystalloid, her patient warm with no blood volume and no blood pressure.

In her mind's eye, as if in slow motion, she somehow sees Tiffany and the children sitting in the waiting room. Time changes and the door from the pump room opens. "Shelly! Thank God," Claire says. "See if you can help Dave. I don't know what happened but something just blew up. We've got no pressure, no volume, and the patient's warm. John, Shelly, think with me."

Pausing the action

Pause for a moment and reflect about what you are experiencing as you read this story. If we have done our job well as authors, you have hopefully been drawn into the story. It may have become real for you. As a surgeon, you may be imagining yourself in Claire's place, experiencing her stress and picturing what she should do next. Possibly, you have faced a similar situation in your career and could offer her advice.

This story is our attempt to show you the power of simulation in health care. Simulation is like a story brought to life. Throughout history, storytelling has been the main way that information has been passed among people. Even today, telling stories remains the most powerful form of communication. A well-designed simulation, like a good story, feels authentic. People in the simulation feel and act as if they are in a real situation.

We have paused our story to emphasize some important points about simulation and its value in helping people reflect about their actions in difficult situations. When actions can be paused, people often recognize things that are not evident when they are caught up in the flow of events. Much of the information within events is perishable, lost by the time the event is over. Simulation allows actions and perishable information to be captured, so that they can be reconsidered later.

Often the most important learning opportunity in simulation occurs after the simulation, when the people involved come together to review their experience (often recorded on videotape) and share their thoughts and observations in a debriefing. It is very helpful to have a trained facilitator guiding this conversation. It is often surprising to people how much their initial impressions of what happened can change as they see events unfold again, watch their own actions, and hear the perspectives of others.

Back to our story

In fact, this is a real story. Specifics of the case and the people have been changed. But the clinical situation happened exactly as the story describes.

What was the outcome? Working together, the surgical team recognized that enough blood was still present in the venous reservoir to restore an effective

blood volume. The challenge was how to get the blood from the reservoir back into the patient in the short time that was available, without a functioning pump or arterial line.

Recalling past research training, the surgeon remembered giving volume in the laboratory by pouring saline into a funnel connected to the right atrium suspended above the heart. The venous reservoir was like the funnel; all they had to do was somehow get it above the patient. The surgeon focused the attention of the team on this goal. Improvising, the perfusionists were able to detach the venous reservoir from the pump and lift it above the level of the heart, allowing blood to drain back into the patient. The patient's blood pressure normalized. After stabilizing the patient, cleaning the room, and changing out the pump, the rest of the operation proceeded uneventfully. The patient did well. After the operation, the patient and family were informed fully about the mishap and what was done.

What was the cause? The direct cause was an unrecognized clamp on the arterial line just downstream from the centrifugal pump head. The pump could not flow because of the clamp. The perfusionist switched to a backup roller pump that overpressurized the clamped arterial line and blew it out.

A deeper cause was distraction and fatigue of the perfusionist, a result of organizational circumstances. Contributing to the accident was a communications culture that led the nursing leader to "hint and hope" about changes she had noted rather than bringing her concerns openly and comfortably to the attention of the perfusionist and other team members. The communications culture also gave members of the team limited options for eliciting and responding to concerns in an effective way.

In this case, the outcome was good. Often when things go wrong, people are able to react and save the situation. Part of safety science deals with how to optimize crisis management. Another important part of safety science studies risk preconditions that can be proactively modified, making it less likely for an adverse event to occur. Most of the opportunities for transforming care are in this area.

As a result of this experience, procedural changes were adopted including test perfusion before initiating bypass, and establishing arterial inflow before opening the venous line. If you are thinking like a safety scientist, you recognize that these changes do not address many root causes of this accident.

The system approach to safety and the safety pyramid

James Reason, one of the pioneering thought leaders of the field of safety science, emphasizes that there are two ways to understand and achieve safety: the person approach and the system approach [1, 2]. From the person approach, the primary focus of the story above would be on the actions of the perfusionist and mistakes that were made by that person. The basic assumption of the person approach is that if something goes wrong, it is obvious that someone must be responsible.