Third Edition

TOTAL BURN CARE

David N. Herndon

SAUNDERS
ELSEVIER

SAUNDERS
ELSEVIER

Saunders is an affiliate of Elsevier Inc.

1996 First edition
2002 Second edition

ISBN: 978-1-4160-3274-8

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
A catalog record for this book is available from the Library of Congress

Notice

Medical knowledge is constantly changing. Standard safety precautions must be followed, but as new research and clinical experience broaden our knowledge, changes in treatment and drug therapy may become necessary or appropriate. Readers are advised to check the most current product information provided by the manufacturer of each drug to be administered to verify the recommended dose, the method and duration of administration, and contraindications. It is the responsibility of the practitioner, relying on experience and knowledge of the patient, to determine dosages and the best treatment for each individual patient. Neither the Publisher nor the author assume any liability for any injury and/or damage to persons or property arising from this publication.

The Publisher

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

Commissioning Editor: Geoff Greenwood
Development Editor: Sharon Nash
Project Manager: Alan Nicholson
Design Manager: Jayne Jones
Illustration Manager: Bruce Hogarth
Editorial Assistant: Kirsten Lowson
Marketing Manager(s) (UK/USA): John Canelon/Lisa Damico

Contributors

Asle Aarsland MD, PhD
Assistant Professor
Department of Anesthesiology
Co-Director, Metabolism Department
University of Texas Medical Branch
Shriners Hospital for Children
Galveston, TX
USA

Brett D. Arnoldo MD
Assistant Professor of Surgery
University of Texas
Southwestern Medical Center
Dallas, TX
USA

Juan P. Barret MD, PhD
Professor of Plastic Surgery
Head of Department
Department of Plastic Surgery and Burn Centre
Hospital Universitari Vall d'Hebron
Universitat Autonoma de Barcelona
Barcelona
Spain

Robert E. Barrow PhD
Professor of Surgery, Co-ordinator of Research
University of Texas Medical Branch
Shriners Burns Hospital
Galveston, TX
USA

Orlando K. Beckum MD
Research Fellow
Department of Anesthesiology
University of Texas Medical Branch
Galveston, TX
USA

Elizabeth A. Beierle MD
Associate Professor of Surgery and Pediatrics
University of Florida
Gainesville, FL
USA

Palmer Q. Bessey MD
Professor of Surgery
Associate Director
William Randolph Hearst Burn Center
Weill Cornell Medical College
New York, NY
USA

Patricia E. Blakeney PhD
Professor
University of Texas Medical Branch
Clinical Psychologist
Shriners Hospital for Children
Galveston, TX
USA

Michael C. Buffalo RN, MSN, CCRN, ACPNP
Acute Care Pediatric Nurse Practitioner
Shriners Burns Hospital
Galveston, TX
USA

Edward Y. Chan MD
Resident Surgeon
University of Texas Medical Branch
Galveston, TX
USA

Dai H. Chung MD
Associate Professor
Department of Surgery and Pediatrics
University of Texas Medical Branch
Galveston, TX
USA

Robert H. Demling MD
Professor of Surgery
Harvard Medical School
Brigham and Women's Hospital
Boston, MA
USA

Matthias B. Donelan MD
Associate Clinical Professor of Surgery
Harvard Medical School
Chief of Plastic Surgery
Shriners Burns Hospital
Boston, MA
USA

William R. Dougherty MD, FACS
Associate Professor of Surgery
Department of Plastic Surgery
Vanderbilt University Medical Center
Nashville, TN
USA

Perenlei Enkhbaatar MD, PhD
Assistant Professor
Department of Anesthesiology
University of Texas Medical Branch
Galveston, TX
USA

E. Burke Evans MD
Professor of Surgery
Department of Orthopaedics
University of Texas Medical Branch
Galveston, TX
USA

Shawn P. Fagan MD
Assistant Professor
Shriners Hospital for Children
Boston, MA
USA

Scott Farmer MPT
Rehabilitation Services OT/PT
Shriners Hospital for Children
Galveston, TX
USA

James A. Fauerbach PhD
Chief Psychologist
Johns Hopkins Burn Center
and Associate Professor
Department of Psychiatry and Behavioral Sciences
and Department of Physical Medicine and Rehabilitation
Johns Hopkins University School of Medicine
Baltimore, MD
USA

Dilip Gahankari MBBS, MS, MCh, FRCS(Edin), FRACS (Plast)
Visiting Medical Officer
Royal Brisbane and Womens Hospital
Herston, Queensland
Australia

James J. Gallagher MD
Assistant Professor and Acute Burn Surgeon
Department of Surgery
University of Texas Medical Branch
Shriners Burns Hospitals for Children
Galveston, TX
USA

Richard L. Gamelli MD, FACS
Professor and Chairman, Department of Surgery
Chief, Burn Center
and Director, Burn and Shock Trauma Institute
Professor of Pediatrics
Department of Surgery
Loyola University Medical Center
Maywood, IL
USA

Aziz Ghahary PhD
Professor
Director, BC Professional Fire-fighters Burn and
Wound Healing Research Lab
Department of Surgery
University of British Columbia
Vancouver, BC
Canada

Nicole S. Gibran MD, FACS
Professor of Surgery
Department of Surgery
Division of Trauma/Burns
Harborview Medical Center
Seattle, WA
USA

Pam Gibson CPO
Hanger Inc., Prosthetics and Orthotics
Galveston, TX
USA

Cleon W. Goodwin MD
Director, Burn Services
Western States Burn Center
North Colorado Medical Center
Greeley, CO
USA

Mary D. Gordon RN, MS, CNS
Burn Clinical Nurse Specialist
Nursing Department
Shriners Hospital at Galveston
Galveston, TX
USA

Caran Graves MS, RD, CNSD
Clinical Dietitian
Nutrition Care Department
University of Utah Hospital
Salt Lake City, UT
USA

David G. Greenhalgh MD
Professor and Chief of Burns
Department of Surgery
University of California
Davis and Shriners Hospitals for Children Northern California
Sacramento, CA
USA

C. Edward Hartford MD
Professor of Surgery
University of Colorado Health Sciences Center
Director, Burn Program
Denver Children's Hospital
Denver, CO
USA

Hal H. Hawkins MD, PhD
Professor
Departments of Pathology and Pediatrics
Shriners Burns Hospital for Children
Galveston, TX
USA

John P. Heggers PhD, FAAM, BCLD
Professor Surgery (Plastic), Microbiology and Immunology
Shriners Hospital for Children
Galveston, TX
USA

David M. Heimbach MD, FACS
Professor of Surgery
Department of Surgery, Division of Trauma/Burns
Harborview Medical Center
Seattle, WA
USA

David N. Herndon MD, FACS
Director of Burn Services
Professor of Surgery and Pediatrics
Jesse H. Jones Distinguished Chair in Surgery
University of Texas Medical Branch
Chief of Staff and Director of Research
Shriners Burns Hospital for Children
Galveston, TX
USA

Maureen Hollyoak MBBS, MMedSci, FRACS
Vascular Fellow
Wilson, Queensland
Australia

Ted Huang MD, FACS
Clinical Professor of Surgery
Shriners Burns Hospital
University of Texas Medical Branch
Galveston, TX
USA

John L. Hunt MD
Professor
Department of Surgery
University of Texas Southwestern Medical Center
Dallas, TX
USA

Mary Jaco RN, MSN, CNAA
Nursing Director
Inpatient Services
Shriners Hospital for Children
Galveston, TX
USA

Marc G. Jeschke MD, PhD, MMS
Assistant Professor
Coordinator of Research
Shriners Hospitals for Children
University of Texas Medical Branch
Department of Surgery and Department of Biochemistry and Molecular Biology
Galveston, TX
USA

Stephen B. Jones PhD
Professor of Physiology (Surgery)
Department of Physiology and the Burn and Shock Trauma Institute
Loyola University Medical Center
Maywood, IL
USA

Richard J. Kagan MD, FACS
Chief of Staff
Shriners Hospitals for Children
and Professor of Surgery
University of Cincinnati College of Medicine
And Medical Director, Skin
AlloSource, Inc.
Cincinnati, OH
USA

G. Patrick Kealy MD
Professor of Surgery
Department of Surgery
Carver College of Medicine
University of Iowa
Iowa City, IA
USA

Michael P. Kinsky MD
Assistant Professor
Department of Anesthesiology
University of Texas Medical Branch
Galveston, TX
USA

Gordon L. Klein MD, MPH
Professor of Pediatrics and Preventative
Medicine
Department of Pediatrics
University of Texas Medical Branch
Galveston, TX
USA

George C. Kramer PhD
Director, Resuscitation Research Laboratory
and Professor
Department of Anesthesiology
University of Texas Medical Branch
Galveston, TX
USA

Jong O. Lee MD
Assistant Professor of Surgery
University of Texas Medical Branch
and Staff Surgeon
Shriners Hospitals for Children
Galveston, TX
USA

Hugo A. Linares MD
Emeritus Chief of Research Pathology
Shriners Burns Institute
Galveston, TX
USA

David B. Loran MD
General Surgery Resident
Department of Surgery
University of Texas Medical Branch
Galveston, TX
USA

Tjøstolv Lund MD, PhD
Professor of Medicine and Staff Physician
Intensive Care and Burns
Haukeland University Hospital
Bergen
Norway

James E. Lynch BS, RRT
ECMO Coordinator
University of Texas Medical Branch
Galveston, TX
USA

Robert L. McCauley MD
Professor, Departments of Surgery and Pediatrics, University of Texas Medical Branch
and Chief, Plastic and Reconstructive Surgery
Shriners Burns Hospital
Galveston, TX
USA

K. A. Kelly McQueen MD, MPH
Staff Anesthesiologist
and Public Health Consultant in Humanitarian Aid and Disaster Management
Anesthesiologist
Valley Anesthesiology Consultants, Ltd.
Pheonix, AZ
USA

Janet Marvin RN, MN
Director of Patient Care Services
Shriners Hospitals for Children
Galveston, TX
USA

Arthur D. Mason Jr MD
Emeritus Chief
Laboratory Division
Brooke Army Medical Center
San Antonio, TX
USA

Dirk M. Maybauer MD, PhD
Department of Anesthesiology
University of Texas Medical Branch
Shriners Burns Hospital
Galveston, TX
USA

Marc O. Maybauer MD, PhD
Department of Anesthesiology
University of Texas Medical Branch
Shriners Burns Hospital
Galveston, TX
USA

Walter J. Meyer III MD
Pediatrician and Child Psychiatrist
Pediatric Endocrinologist
Gladys Kempner and RL Kempner Professor in Child Psychiatry
University of Texas Medical Branch
and Head, Department of Psychiatric and Psychological Services
Shriners Burns Hospital
Galveston, TX
USA

Stephen M. Milner MD
Professor of Plastic Surgery
Chief, Division of Burns
Johns Hopkins University School of Medicine
Surgical Director, Johns Hopkins Wound Healing Center
Baltimore, MD
USA

Joseph M. Mlakar MD FACS
Private Practice,
and formerly, Director
St Joseph's Burn Center
Fort Wayne, IN
USA

Ronald P. Mlcak PhD, RRT, FAARC
Director, Respiratory Care
Shriners Hospitals for Children
and Associate Professor, Respiratory Care
University of Texas Medical Branch
Galveston, TX
USA

Dan Morgan BS
Certified Prosthetist-Orthotist
Hanger Inc., Prosthetics and Orthotics
Galveston, TX
USA

Stephen E. Morris MD, FACS
Associate Professor of Surgery
Director of Trauma
University of Utah
Salt Lake City, UT
USA

Elise M. Morvant MD
Staff Anesthesiologist
East Tennessee Children's Hospital
Knoxville, TN
USA

David W. Mozingo MD
Professor of Surgery and Anesthesiology
University of Florida Health Science Center
Gainesville, FL
USA

Thomas Muehlberger MD, PhD, FRCS
Attending Plastic Surgeon
Department of Plastic and Reconstructive Surgery
Hannover Medical School
Hannover
Germany

Michael Muller MBBS, MMedSci, FRACS
Associate Professor in Surgery, University of Queensland
Senior Staff General and Burns Surgeon
Royal Brisbane and Women's Hospital
Division of Surgery
Brisbane, Queensland
Australia

Erle D. Murphey DVM, PhD, Dip ACVS
Assistant Professor
Department of Anesthesiology
University of Texas Medical Branch
Galveston, TX
USA

Kuzhali Muthu PhD
Research Assistant Professor
Department of Surgery
Member, Burn and Shock Trauma Institute
Maywood, IL
USA

Andreas D. Niederbichler Dr Med
Staff Surgeon
Hannover Medical School
Department of Plastic, Hand and Reconstructive Surgery
Burn Center
Hannover
Germany

William B. Norbury MD, MRCS
Research Burn Fellow
University of Texas Medical Branch
Shriners Hospitals for Children
Galveston, TX
USA

Nora Nugent MBBCh, BAO
Specialist Registrar in Plastic Surgery
Department of Plastic Surgery
St James's Hospital
Dublin
Ireland

Sheila Ott OTR
Occupational Therapist
Department of Occupational Therapy
University of Texas Medical Branch
Galveston, TX
USA

David R. Patterson PhD
Professor of Rehabilitation Medicine
School of Medicine
University of Washington
Seattle, WA
USA

Clifford T. Pereira MD, FRCS(Eng)
Resident Physician
Department of Surgery
County of Los Angeles Harbor-UCLA Medical Center
Torrance, CA
USA

Tam N. Pham MD
Clinical Fellow
Department of Surgery
University of Washington
Harborview Medical Center
Seattle, WA
USA

Ronald T. Plessinger MS
Medical Records Manager
AlloSource–Cincinnati
Cincinnati, OH
USA

Basil A. Pruitt Jr MD
Clinical Professor of Surgery
Department of Surgery
University of Texas Health Science Center at San Antonio
San Antonio, TX
USA

Rene Przkora MD, PhD
Anesthesiology Resident
University of Florida
Gainesville, FL
USA

Gary F. Purdue MD
Professor
Department of Surgery
University of Texas
Southwestern Medical Center
Dallas, TX
USA

Edward C. Robb AA, BS, BA, MBA
Resource Management Consultant
RMC, Inc.
Oxford, OH
USA

Rhonda Robert PhD
Associate Professor of Clinical Psychology
Division of Pediatrics
University of Texas M.D. Anderson Cancer Center
Houston, TX
USA

Laura Rosenberg PhD
Chief Clinical Psychologist
Department of Psychological and Psychiatric Services
Shriners Hospitals for Children
and Clinical Assistant Professor
Department of Psychiatry and Behavioral Sciences
University of Texas Medical Branch
Galveston, TX
USA

Marta Rosenberg PhD
Clinical Psychologist
Department of Psychological and Psychiatric Services
Shriners Hospitals for Children
and Clinical Assistant Professor
Department of Psychiatry and Behavioural Sciences
University of Texas Medical Branch
Galveston, TX
USA

Jeffrey R. Saffle MD, FACS
Professor
Burn Center
University of Utah School of Medicine
Salt Lake City, UT
USA

Arthur P. Sanford MD
Assistant Professor, Department of Surgery
University of Texas Medical Branch
Assistant Chief of Staff
Shriners Burns Hospital
Galveston, TX
USA

Paul G. Scott PhD
Professor of Biochemistry
and Adjunct Professor of Surgery
Department of Biochemistry
University of Alberta
Edmonton, AB
Canada

Michael A. Serghiou LOT
Director
Rehabilitation and Outpatient Services
Shriners Hospitals for Children
Galveston, TX
USA

Ravi Shankar PhD
Associate Professor
Department of Surgery
Loyola University Medical Center
Maywood, IL
USA

Robert L. Sheridan MD
Assistant Chief of Staff
Shriners Burns Institute
Boston, MA
USA

Edward R. Sherwood MD, PhD
Professor, James F. Arens Endowed Chair
Departments of Anesthesiology, Microbiology and Immunology
University of Texas Medical Branch
Galveston, TX
USA

Jason W. Smith MD
Resident
Loyola University Medical Center
Burn, Shock Trauma Institute
Maywood, IL
USA

Marcus Spies MD, PhD
Attending Surgeon
Assistant Chief of Staff
General Surgery, Plastic Surgery and Hand Surgery
Department of Plastic, Hand and Reconstructive Surgery
Regional Burn Center
Hannover Medical School
Hannover
Germany

Oscar E. Suman-Vejas PhD, FACSM
Assistant Professor, Department of Surgery
University of Texas Medical Branch
and Director, Children's Wellness and Exercise Center
Shriners Hospitals for Children
Galveston, TX
USA

Mark Talon MSN, CRNA
Certified Nurse Anesthetist
Department of Anesthesia
University of Texas Medical Branch
Galveston, TX
USA

Christopher R. Thomas MD, BA, FAACAP, DFAPA
Robert L. Stubblefield Professor of Child Psychiatry
Department of Psychiatry and Behavioral Sciences
University of Texas Medical Branch
Galveston, TX
USA

Tracy Toliver-Kinsky PhD
Assistant Professor
Anesthesiology
University of Texas Medical Branch
Galveston, TX
USA

Ronald G. Tompkins MD, ScD
John F. Burke Professor of Surgery
Harvard Medical School
Chief of Staff
Shriners Hospitals for Children
Boston, MA
USA

Daniel L. Traber PhD, FCCM
Charles Robert Allen Professor of Anesthesiology
Professor of Neuroscience and Cell Biology
Director, Investigative Intensive Care Unit
Department of Anesthesiology
University of Texas Medical Branch
and Shriners Hospitals for Children
Galveston, TX
USA

Edward E. Tredget MD, MSc, FRCSC
Professor
Department of Surgery
University of Alberta Hospital
Edmonton, AB
Canada

Cynthia Villarreal RPh, BSPharm
Director of Pharmacy
Department of Pharmacy
Shriners Burns Hospital
Galveston, TX
USA

Peter M. Vogt MD, PhD
Professor and Chief
Department of Plastic and Reconstructive Surgery
Burn Center
Hannover Medical School
Hannover
Germany

Thomas L. Wachtel MD, MMM, CPE
Clinical Professor of Surgery
General and Trauma Surgery/Burns
Shriners Hospitals for Children
Paradise Valley, AZ
USA

JianFei Wang PhD
Post-Doctoral Fellow
Department of Surgery
University of Alberta
Edmonton, AB
Canada

Glenn D. Warden MD
Emeritus Chief of Staff
Professor of Surgery
Shriners Hospital for Children
Cincinnati, OH
USA

Petra M. Warner MD
Assistant Professor
University of Cincinnati College of Medicine and Shriners Hospital for Children
Cincinnati, OH
USA

Natalie Williams-Bouyer PhD
Assistant Professor, Department of Pathology
University of Texas Medical Branch
and Director, Clinical Laboratory Services
Shriners Hospitals for Children
Galveston, TX
USA

Steven E. Wolf MD
Betty and Bob Kelso Distinguished Professor
Department of Surgery
University of Texas Health Science Center
Director, Burn Center
US Army Institute of Surgical Research
Fort Sam Houston, TX
USA

Lee C. Woodson MD
Chief of Anesthesiology
Department of Anesthesiology
Shriners Hospitals for Children
Galveston, TX
USA

Joseph B. Zwischenberger MD
Professor Surgery, Medicine and Radiology
Le Roy Hillyer Endowed Chair in Surgery
Director, General Thoracic Surgery and ECMO Programs
Cardiothoracic Surgery
University of Texas Medical Branch
Galveston, TX
USA

Preface

With each subsequent edition of *Total Burn Care*, my objective has remained the same: *Total Burn Care* is designed as a text on the management of burned patients, not only for surgeons, anesthesiologists, and residents but also nurses and allied health professionals. This book has served as a sophisticated instruction manual to guide those with less experience through difficult experiences in burn care. Our hope for the future is that through multidisciplinary collaboration, scientists and clinicians will pursue solutions to the perplexing problems that burn survivors must encounter.

Contributions have been selected from a small number of institutions in order to provide a unified approach. We have allowed some repetition of concepts and techniques throughout the text so that each chapter can be self-contained in its discussion of its main topic. Themes covered elsewhere in the literature have been condensed and the bibliographies selected to assure the reader ready access to the expanded literature on current burn care.

New material is added to this book, as with every edition, reflecting the varied physiological, psychological and emotional care of acutely injured burn patients evolving through recovery, rehabilitation, and reintegration back into society and daily life activities. Almost all chapters have been totally rewritten and updated. There are many new chapters and sections in this edition, along with demonstrative color illustrations throughout the book.

The scope of burn treatment extends beyond the preservation of life and function; and the ultimate goal is the return of burn survivors, as full participants, back into their communities.

I would like to express my deep appreciation to many respected colleagues and friends for their contributions to the third edition of *Total Burn Care*. Grateful acknowledgment is given to the many authors whose time and expertise made this book possible, especially to the Shriners Hospitals for Children staff.

Sincere appreciation goes to Tiaá Bourgeois, for her excellent secretarial assistance.

I am grateful to the Elsevier publishing staff for their support and cooperation in maintaining a high standard in the development and preparation of the third edition. I wish to recognize Ms. Sharon Nash, Senior Development Editor who guided this book throughout the development process.

Finally, I would like to thank my wife, Rose, for her invaluable support.

A special thank you to Lewis Milutin, whose photographic skills produced countless of the priceless pictures presented in the book, and to Dr. Juan P. Barret, first Editor of the *Color Atlas of Burn Care*, for allowing us to reprint photos from the Atlas. The following figures were reproduced. (Plates 2.1, 3.8, 3.7, 3.9, 5.7, 5.8, 5.9, 5.10, 7.25, 7.22, 7.21, 6.26, 7.26, 7.20, 7.17, 7.30, 7.31, 7.32, 7.33, 5.38, 7.8, 7.9, 7.10, 7.11, 7.12, 7.13, 7.14, 7.15, 7.16, 7.28, 7.29, 7.27, 7.23, 7.24, 8.10, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 7.44, 7.45, 7.35, 7.38, 7.34, 7.37, 7.42, 7.43, 7.41, 8.27, 4.41, 1.2.1.4, 6.13, 4.21, 6.14, 4.30, 4.19, 4.35, 3.8, 4.59, 8.31, 7.35, 4.57, 4.63, 8.39, 9.48, 8.39, 8.42, 6.95, 6.89, 5.39, 5.31, 9.45, 9.46, 1.1.2.2, 1.1.3.3, 1.3.3.1, 1.4.1.4, 1.4.1.5, 1.3.3.2, 1.3.4.4, 1.3.4.4, 1.4.1.6, 1.4.1.7, 3.13a, 3.13b, 3.12, 6.64, 10.12, 10.13, 9.11, 9.10, 10.44, 10.46, 10.28)

David N. Herndon
2006

Contents

Immediate Care

The Burn Wound

Inhalation Injury

Response to Injury

Nonthermal Injuries

Pathophysiology

Rehabilitation

Reconstruction

Social Issues

Psychological Issues

Index

Chapter 1

History of treatments of burns

Robert E. Barrow and David N. Herndon

Chapter contents

The treatment of burns is over 3500 years old with the first direct evidence found in the cave paintings of Neanderthal man. Documentation in the Egyptian Smith papyrus of 1500 BC advocated a salve of resin and honey.[1] In 600 BC, the Chinese used tinctures and extracts from tea leaves. Nearly two hundred years later Hippocrates described the use of rendered pig fat and resin which was impregnated in bulky dressings. This was alternated with warm vinegar soaks augmented with tanning solutions made from oak bark. Celsus, in the first century AD, mentioned the use of wine and myrrh, a lotion probably used for its bacteriostatic properties. Galen, who lived from AD 130–210, used a vinegar and open wound exposure technique.[1] The Arabian physician Rhases recommended the use of cold water for the alleviation of pain associated with burns. Ambroise Paré (AD 1510–1590), who advocated a variety of ointments and poultices from medieval excremental alchemy, effectively treated burns with onions, and described a procedure for early burn wound excision. Guilhelmus Fabricius Hildanus, a German surgeon, published De Combustionibus in 1607 in which he discussed the pathophysiology of burns and made unique contributions to the treatment of contractures. In 1797, Edward Kentish published an essay describing pressure dressings as a means to relieve burn pain and blisters. Around this same period of time, Marjolin identified squamous cell carcinomas that developed in chronic open burn wounds. In the early 19th century, Dupuytren[2] reviewed the care of 50 burn patients treated with occlusive dressings and developed a classification of burn depth that remains in use today (Figure 1.1). He was perhaps the first to recognize gastric and duodenal ulceration as a complication of severe burns, a problem that was discussed in more detail by Curling of London in 1842.[3]

Dr Truman G Blocker Jr demonstrated the value of a multidisciplinary team approach to burn care and used this team approach on April 16, 1947 when two freighters loaded with ammonium nitrate fertilizer exploded at a dock in Texas City, killing 560 people and injuring more than 3000 (Figure 1.2). Dr Blocker mobilized the University of Texas Medical Branch in Galveston and soon truckloads of casualties began arriving. This 'Texas City Disaster' is still known as the deadliest industrial accident in American history. For 9 years, Drs Truman and Virginia Blocker followed more than 800 of these burn patients and published a number of papers and government reports. The Blockers became renowned for their work on burns with both receiving the Harvey Allen Distinguished Service Award from the American Burn Association. He was also recognized for his pioneering research in burns and treating children 'by cleansing, exposing the burn wounds to air, and feeding them as much as they could tolerate.' In 1962, his dedication to treating burned children convinced the Shriners of North America to build their first burn institute for children in Galveston, Texas.[4]

Most of the major advances in burn care have occurred within the last six decades. Between 1942 and 1952, shock, sepsis, and multi-organ failure caused a 50% mortality rate in children with burns covering 50% of their total body surface area.[5] Recently, burn care in children has improved survival such that a greater than 95% total body surface area burn can be survived over 50% of the time.[6] Improvements have been made in resuscitation, control of infection, support of the hypermetabolic response, nutritional support, prevention of stress ulcers, treatment of major inhalation injuries, early closure and coverage of the burn wound, effective use of anabolic agents, and the multidisciplinary team approach to burn care and rehabilitation.

Andrew M Munster became interested in measuring the quality of life after a severe burn in the 1970s, when excisional surgery and other improvements had led to a dramatic decrease in mortality (Figure 1.3). First published in 1979, his Burn Specific Health Scale became the foundation for most modern studies in burn outcome. The scale has since been improved, updated, and the scales, originally designed for adults, extended to children.

Fluid resuscitation

The foundation leading to our current fluid and electrolyte management began with the studies of Frank P Underhill who, as Professor of Pharmacology and Toxicology at Yale, studied

Fig. 1.1 Dupuytren.

Fig. 1.2 Truman G Blocker Jr.

Fig. 1.3 Andrew M Munster.

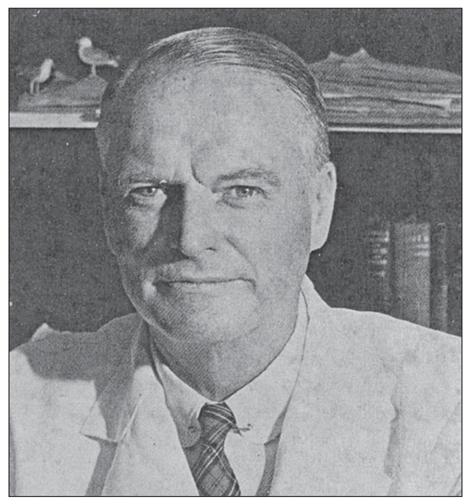

Fig. 1.4 Oliver Cope.

20 individuals burned in a 1921 fire at the Rialto Theater.[7] Underhill found that blister fluid had a composition similar to plasma and could be replicated by a salt solution containing protein. He suggested that burn patient mortality was due to loss of fluid and not, as previously thought, from toxins. In 1944, Lund and Browder estimated burn surface areas and developed diagrams by which physicians could easily draw the burned areas and derive a quantifiable percent describing the surface area burned.[8] This led to fluid replacement strategies based on surface area burned. Knaysi et al.[9] proposed a simple 'rule of nines' for evaluating the percentage of body surface area burned. In 1946, Drs Oliver Cope and Francis Moore were able to quantify the amount of fluid required for adequate resuscitation by analyzing young adults who were trapped inside the burning Coconut Grove Nightclub in Boston (Figure 1.4 and Figure 1.5). They postulated that the space between cells was a major recipient of plasma loss, causing swelling in both injured and uninjured tissues in proportion to the burn size.[10] Moore concluded that additional fluid, over that collected from the sheets and measured as evaporative water loss, was needed in the first 8 hours after burn to replace 'third space' loss. He then developed a formula for replacement of fluid based on the percent of the body surface area burned.[11] Kyle and Wallace showed the heads of children were relatively larger and the legs relatively shorter than adults and modified the fluid replacement formulas for use in

Fig. 1.5 Francis Moore.

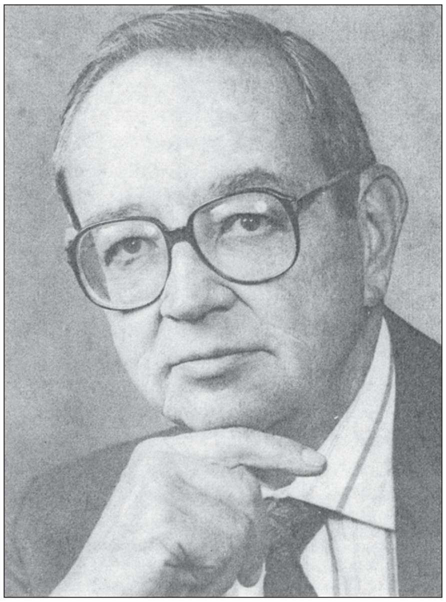

Fig. 1.6 Baxter.

TABLE 1.1

Formula	Crystalloid volume	Colloid volume	Free water
Evans	mL/kg/% burn normal saline	1.0 mL/kg/% burn	2.0 liters
Brooke	1.5 ml/kg/% TBSA lactated Ringer's	0.5 mL/kg/% TBSA burn	2.0 liters
Parkland	4 mL/kg/% TBSA	None	None
Modified Brooke	2 mL/kg/% burn first 24 hours		
Hypertonic (Monafo)	250 mEq/L Na^+ in volume to maintain urine output @ 30 mL/hour		
Warden	Lactated Ringer's + 50 mEq $NaHCO_3$ (180 mEq Na^+/L for 8 hours)		
SBH-Galveston	5000 mL/m^2 burned + 1500 mL/m^2 total	None	None

children.[12] Evans and his colleagues made recommendations relating fluid requirements to body weight and surface area burned.[13] From their recommendations, normal saline (1.0 mL/kg/% burn) plus colloid (1.0 mL/kg/% burn) along with 2000 mL D5W to cover insensible water losses was infused over the first 24 hours after burn. One year later, Reiss et al presented the Brooke formula[14] which modified the Evans formula by substituting lactated Ringer's for normal saline and decreasing the amount of colloid given. Baxter and Shires developed a formula without colloid, which is now referred to as the Parkland formula (Figure 1.6).[15] This is perhaps the most widely used formula today and recommends; 4 mL of Ringer's lactate/kg/% TBSA (total body surface area) burned/24 hours after burn. All of these formulas advocate giving half of the fluid in the first 8 hours and the other half in the subsequent 16 hours after burn (Table 1.1). The greatest quantity of solute is given in the first 24 hours after burn. After that, more hypotonic solutions are given to replace evaporative water loss. Baxter and Shires discovered that after cutaneous burn, fluid is not only deposited in the interstitial space but marked intracellular edema also develops. The excess disruption of the sodium–potassium pump activity results in the inability of cells to remove excess fluid. They also showed that protein, given in the first 24 hours after injury, was not necessary and postulated that, if used, it would leak out of the vessels and cause edema to exacerbate. This was later substantiated in studies of burn patients with toxic inhalation injuries.[16]

After a severe thermal injury, fluid accumulates in the wound. Unless there is an adequate and early fluid replacement hypovolemic shock will develop. A prolonged systemic inflammatory response to severe burns can lead to multi-organ dysfunction, sepsis, and even mortality. It has been suggested that for maximum benefit, fluid resuscitation should begin as early as 2 hours after burn.[17,18] Fluid requirements in children are greater with a concomitant inhalation injury, delayed fluid resuscitation, and larger burns.

Control of infection

Another major advancement in burn care that has decreased mortality is the control of infection. Between 1966–1975, 60–80% of patients with burns over 50% of their total body surface died of bacterial sepsis. With the introduction of efficacious silver-containing topical antimicrobials, burn wound sepsis rapidly decreased. Early excision and coverage further decreased morbidity and mortality from burn wound sepsis. In 1965, Carl Moyer[19] initially used 0.5% silver nitrate soaks as a potent topical antibacterial agent for burn wounds.

Mafenide acetate (Sulfamylon), a drug used by the Germans for treatment of open wounds in World War II, was adapted for treating burns at the Institute of Surgical Research in San Antonio by microbiologist Robert Lindberg and surgeon John Moncrief.[20] This antibiotic would penetrate third-degree eschar and was extremely effective against a wide spectrum of pathogens. Simultaneously, Charles Fox[21] in New York, developed silver sulfadiazine cream (Silvadene), which was almost as efficacious as mafenide acetate cream. While mafenide penetrates the burn eschar quickly, it is a carbonic anhydrase inhibitor which can cause systemic acidosis and compensatory hyperventilation and may lead to pulmonary edema. Because of its success in controlling infection in burns combined with minimal side effects, silver sulfadiazine has become the mainstay of topical antimicrobial therapy. Nystatin in combination with silver sulfadiazine has been used to control *Candida*[22] at Shriners Burns Hospital for Children in Galveston, Texas. Mafenide acetate, however, remains useful in treating invasive wound infections.[23]

Hypermetabolic response to trauma

Major decreases in mortality have resulted from a better understanding of how to support the hypermetabolic response to severe burns. This response is characterized by an increase in the metabolic rate and peripheral catabolism. The catabolic response was described by Sneve[24] as exhaustion and emaciation and he recommended a nourishing diet and exercise. Cope et al.[25] quantified the metabolic rate in patients with moderate burns, and Francis Moore[26] advocated the maintenance of cell mass by continuous feeding to prevent catabolism after trauma and injury. Over the last 20 years the hypermetabolic response to burn has been shown to cause increased metabolism, negative nitrogen balance, glucose intolerance, and insulin resistance. In 1974, Douglas Wilmore and colleagues[27] defined catecholamines as the primary mediator of this response. He showed that catecholamines were 5 to 6-fold elevated after major burns, causing an increase in peripheral lipolysis and catabolism of peripheral protein. Hart et al.[28] further showed that the metabolic response rose with increasing burn size, reaching a plateau at a 40% TBSA burn. Bessey, in 1984, demonstrated that the stress response required not only catecholamines but also cortisol and glucagon. Wilmore et al.[29] examined the effect of ambient temperature on the hypermetabolic response to burns and found that burn patients desired an environmental temperature of 33°C and were striving for a core temperature of 38.5°C. Thus, warming the environment from 28° to 33°C decreased the hypermetabolic response substantially, but did not abolish it. Wilmore suggested that the wound itself served as the afferent arm of the hypermetabolic response and its consuming greed for glucose and other nutrients, at the expense of the rest of the body, stimulated the stress response.[30] He felt that heat was produced by biochemical inefficiency, later defined by Robert Wolfe,[31] as futile substrate cycling. Wolfe et al. also demonstrated that burned patients were glucose-intolerant and insulin-resistant[32] with an increase in glucose transport to the periphery but a decrease in glucose uptake into the cells.[33]

Nutritional support

Shaffer and Coleman advocated high caloric feedings to burn patients as early as 1909 while Wilmore in 1971 supported supranormal feeding with a caloric intake as high as 8000 kcal/day. P William Curreri[34] retrospectively looked at a number of burned patients to quantify the amount of calories required to maintain body weight over a period of time (Figure 1.7). In a study of nine adults with 40% TBSA, he found when given a maintenance feeding at 25 kcal/kg plus an additional 40 kcal/% TBSA burned per day, their body weight could be maintained during acute hospitalization. Sutherland[35] proposed that children should receive 60 kcal/kg body weight plus 35 kcal/% TBSA burned per day. Herndon et al.[36] subsequently showed that supplemental parenteral nutrition increased both

Fig. 1.7 P William Curreri.

immune deficiency and mortality, and recommended continuous enteral feeding as a standard treatment for burns.

Stress ulcers

Nearly 150 years ago, Dupuytren and Curling defined acute gastrointestinal ulcers as major problems after burn. Czaja, McAlhany, and Pruitt[37] at the Institute of Surgical Research in San Antonio studied burn patients and found gastric erosions in 86% of all burns over 40% TBSA (Figure 1.8). The incidence of gastric erosion was reduced by scheduling antacids to treat the low pH. This led to the now traditional protocol of measuring gastric pH on an hourly basis and alternating Maalox and/or Amphogel to adjust the gastric pH. This has virtually eliminated gastric ulcers as a problem in patients with a major burn. Continuous enteral feeding also helps maintain the integrity of gut mucosa, decreases bacterial translocation, and minimizes the need for antacids.

Early excision

One of the most effective therapies in decreasing mortality from major thermal injuries has been the early excision of the burn wound and its coverage.[38] Jackson and colleagues[39] pioneered excision and grafting, beginning in 1954, with burns of 3% TBSA gradually increasing up to burns covering 30% TBSA. Janzekovic,[40] working alone in Yugoslavia in the 1960s, developed the concept of removing deep second-degree burns by tangential excision with a simple uncalibrated knife (Figure 1.9). She treated 2615 patients with deep second-degree burns by tangential excision of eschars between the third and fifth day after burn and covered the excised wound with autografts which allowed patients to return to work within 2 weeks or so from the time of injury. William Monafo[41] was one of the first Americans to advocate the use of excision and grafting techniques of larger burns (Figure 1.10). Dr John Burke,[42] while at Massachusetts General Hospital in Boston, reported an unprecedented survival after massive excision to the level of fascia in children with burns over 80% TBSA and practiced early burn excision throughout the early 1970s and 1980s using a combination of tangential excision for the smaller

Fig. 1.9 Janzekovic.

Fig. 1.8 Pruitt.

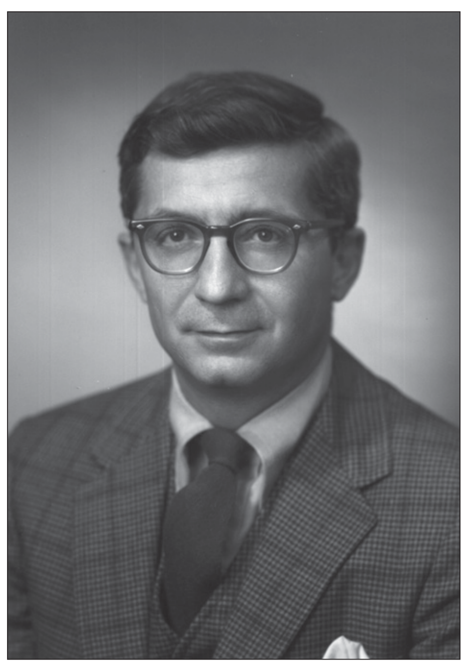

Fig. 1.10 William Monafo.

burns (Janzekovic's technique) and excision to the level of fascia for the larger burns (Figure 1.11). He showed a decrease both in length of hospital stay and mortality in massively burned patients. Lauren Engrav et al.[43] compared tangential excision versus non-operative treatment in burns of indeterminate depth. Their randomized prospective study, conducted in 1983, showed that deep second-degree burns of <20% TBSA when grafted early, allowed patients to return to work earlier, reduced hospital time, and showed less hypertrophic scarring. Herndon et al.,[44] in a randomized prospective study, showed a decrease in mortality in massively burned adults with third-degree burns when treated with early excision of the total burn wound as opposed to conservative treatment. He also reported that these massively burned children with 98% TBSA burns have a 50% survival rate.[45,46]

Skin grafting

Progress in skin grafting techniques has paralleled the developments in wound excision. A Swiss medical student, JI Reverdin, performed reproducible skin grafts[47] in 1869. The method gained widespread attention throughout Europe, but since the results were extremely variable the method quickly fell into disrepute. JS Davis[48] resurrected this technique in the United States during the 1930s and reported the use of 'small deep grafts' later known as pinch grafts. Split-thickness skin grafts were accepted during the 1930s due in part to improved and reliable instruments. The Humby knife, developed in 1936, was the first reliable dermatome, but was cumbersome. Padgett and Hood developed an adjustable dermatome which had cosmetic advantages. Padgett[49] also developed a system for categorizing skin grafts into four types based upon thickness. Tanner and colleagues,[50] in 1964, revolutionized burn wound grafting with the development of the meshed skin graft and J Wesley Alexander[51] gave us a simple method of widely expanding autograft skin and then covering it with cadaver skin (Figure 1.12). This has since been the mainstay in the treatment of massively burned individuals. Jack Burke[52] developed an artificial skin in 1981, which is marketed today as Integra™. He first used this artificial skin on very large burns which covered over 80% of the TBSA. David Heimbach led one of the early multicenter randomized clinical trials using Integra™.[53] The development of tissue cultured grown skin by Bell et al.,[54] in combination with an artificial dermis, perhaps offers the best opportunity for better outcomes.

Inhalation injury

During the 1950s and 1960s burn wound sepsis, nutrition, kidney dysfunction, wound coverage, and shock were the main focus of burn care specialists.[55] Over the last 25 years these problems have been clinically treated with more and more success; thus, a greater interest in inhalation injury evolved. A simple classification of inhalation injury separates problems occurring in the first 24 hours after injury, which include upper airway obstruction and edema, from those which manifest after 24 hours. These include pulmonary edema and tracheobronchitis, which can progress to pneumonia, mucosal edema, and airway occlusion due to the formation of airway plugs from mucosal sloughing.[55,56] The extent of damage from the larynx to tracheobronchial tree depends upon the solubility of the toxic substance and duration of exposure. Nearly 45% of inhalation injuries are limited to the upper airways above the vocal cords while 50% have an injury to the major airways. Less than 5% have a direct parenchymal injury that results in early acute respiratory death.[55]

With the development of objective diagnostic methods the incidence of an inhalation injury in burned patients can now be

Fig. 1.11 John Burke.

Fig. 1.12 J Wesley Alexander.

identified and its complications identified. Xenon-133, scanning was first used in 1972 in the diagnosis of inhalation injury.[57,58] When this radioisotope method is used in conjunction with a medical history the identification of inhalation injury is quite reliable. The fiberoptic bronchoscope is another diagnostic tool which under topical anesthesia can be used for early diagnosis of inhalation injury.[59] It also is capable of pulmonary lavage to remove airway plugs and particulate matter.

Shirani, Pruitt, and Mason[60] reported that smoke inhalation injury and pneumonia, in addition to age and burn size, greatly increased burn mortality. The realization that the physician should not under-resuscitate burn patients with an inhalation injury was emphasized by Navar et al.[61] and Herndon et al.[62] A major inhalation injury requires 2 mL/kg/% TBSA burn more fluid in the first 24 hours postburn to maintain adequate urine output and organ perfusion. Multicenter studies looking at patients with adult respiratory distress have advocated respiratory support at low peak pressures to reduce the incidence of barotrauma.

The high-frequency oscillating ventilator, advocated by Cioffi[63] and Cortiella et al.,[64] has added the benefit of pressure ventilation at low tidal volumes with rapid inspiratory minute volume which provides a vibration to encourage inspissated sputum to travel up the airways. The use of heparin, N-acetylcysteine, nitric oxide inhalation, and bronchodilator aerosols have been used with some apparent benefit at least in pediatric populations.[23,65,66]

Inhalation injury still remains one of the most prominent causes of death in thermally injured patients. In children the lethal burn area for a 10% mortality without a concomitant inhalation injury is a 73% total body surface area burn, but with an inhalation injury, the lethal burn size for a 10% mortality rate is a 50% body surface area burn.[46]

Summary

The evolution of burn treatments has been extremely exciting over the last 40 years. It is our hope that the next 10 years will witness the development of an artificial skin which combines the concepts of Burke et al.[67] with the tissue culture technology described by Bell.[54] Inhalation injury, however, remains one of the major determinants of mortality in severely burned children and adults. Further improvements in several of smoke inhalation injuries are expected through the development of arterial venous CO_2 removal and extracorporeal membrane oxygenation devices.[68] Perhaps even lung transplants will fit into the treatment regimen for end-stage pulmonary failure. Our goals continue to strive for a better understanding of the pathophysiology of contractures and hypertrophic scar formation in order to effectively treat scar formation and how to modulate it in a positive manner. Further decreases in burn mortality can be expected; however, continued advances are necessary to understand how to rehabilitate patients and return them to a productive life.

References

1. Majo G. The healing hand. Harvard: Harvard University Press; 1973.
2. Dupuytren G. Lecons orales de clinque chirorjica faites a ‘l’Hotel-Dieu de Paris. Paris: Baillière; 1832: Vol. 1: pp 413–516, Vol 2: pp 1–80.
3. Curling TB. On acute ulceration of the duodenum in cases of burn. Med Chir Trans London 1842; 25:260–281.
4. Blocker TG Jr. Talk given to plastic surgery residents. Galveston, Texas, October 1, 1981, unpublished.
5. Bull JP, Fischer AJ. A study of mortality in a burns unit: a revised estimate. Ann Surg 1954; 139(95):269–274.
6. Wolf SE, Rose JK, Desai MH, et al. Mortality determinants in massive pediatric burns. Ann Surg 1997; 225(5):554–569.
7. Underhill FP. The significance of anhydremia in extensive surface burns. JAMA 1930; 95:852.
8. Lund CC, Browder NC. The estimation of areas of burns. Surg Gyn Obstet 1944; 79:352–358.
9. Knaysi GA, Crikelair GF, Cosman B. The rule of nines: it’s history and accuracy. Presented to the Am Soc Plast & Reconstruct, New York City, November 6, 1967.
10. Cope O, Moore FD. The redistribution of body water. Ann Surg 1947; 126:1016.
11. Moore FD. The body-weight burn budget. Basic fluid therapy for the early burn. Surg Clin North Am 1970; 50(6):1249–1265.
12. Kyle MJ, Wallace AB. Fluid replacement in burnt children. Br J Plast Surg 1951; 194–204.
13. Evans EI, Purnell OJ, Robinett PW, et al. Fluid and electrolyte requirements in severe burns. Ann Surg 1952; 135:804.
14. Reiss E, Stirmann JA, Artz CP, et al. Fluid and electrolyte balance in burns. JAMA 1953; 152:1309.
15. Baxter CR, Shires T. Physiological response to crystalloid resuscitation of severe burns. Ann NY Acad Sci 1968; 150:874.
16. Tasaki O, Goodwin C, Saitoh D, et al. Effects of burns on inhalation injury. J Trauma 1997; 43(4):603–607.
17. Barrow RE, Jeschke MG, Herndon DN. Early fluid resuscitation improves extended outcomes in thermally injured children. Resuscitation 2000; 45:91–96.
18. Wolf SE, Rose JK, Desai MH, et al. Mortality determinants in massive pediatric burns. Ann Surg 1997; 5:554–569.
19. Moyer CA, Brentano L, Gravens DL, et al. Treatment of large human burns with 0.5 per cent silver nitrate solution. Arch Surg 1965; 90:812–867.
20. Lindberg RB, Moncreif JA, Switzer WE, et al. The successful control of burn wound sepsis. J Trauma 1965; 5(5):601–616.
21. Fox CL Jr, Ruppole B, Stanford W. The control of Pseudomonas infection in burns with silver sulfadiazine. Surg Gynecol Obstet 1969; 128:1021.
22. Heggers JP, Robson MC, Herndon DN, et al. The efficacy of nystatin combined with topical microbial agents. J Burn Care Rehabil 1989; 10(6):508–511.
23. Monafo WW, West MA. Current treatment recommendations for topical burn therapy. Drugs 1990; 40:364–373.
24. Sneve H. The treatment of burns and skin grafting. JAMA 1905; 45:1–8.
25. Cope O, Nardi GL, Quijano M, et al. Metabolic rate and thyroid function following acute thermal trauma in man. Ann Surg 1953; 137:165–174.
26. Moore FD. Burns in metabolic care of the surgical patient. Philadelphia: WB Saunders; 1959.
27. Wilmore DW, Long JM, Mason AD, et al. Catecholamines: mediators of hypermetabolic response to thermal injury. Ann Surg 1974; 180:653–669.
28. Hart DW, Wolf SE, Chinkes DL, et al. Determinants of skeletal muscle catabolism after severe burn. Ann Surg 2000; 232(4):455–465.
29. Wilmore DW, Mason AD, Johnson DW, et al. Effect of ambient temperature on heat production and heat loss in burn. J Appl Physiol 1975; 38:593–597.

30. Wilmore DW, Aulick LH, Mason AD, et al. Influence of the burn wound on local and systemic responses to injury. Ann Surg 1977; 186:444–445.
31. Wolfe RR, Durkot MJ, Wolfe MH. Effect of thermal injury on energy metabolism, substrate kinetics and hormonal concentration. Cric Shock 1982; 9:383–394.
32. Wolfe RR, Durkot MJ, Allsop JR, Burke JF. Glucose metabolism in severely burned patients. Metabolism 1979; 28(10):1031–1039.
33. Wilmore DW, Smith RJ, O'Dwyer ST. The gut: a central organ after surgical stress. Surgery 1988; 104:917–923.
34. Curreri PW, Richmond D, Marvin J, Baxter CR. Dietary requirements of patients with major burns. J Am Diet Assn 1974; 65:415–417.
35. Sutherland AB. Nitrogen requirements in the burn patient: a reappraisal. Burns 1977; 2:238–244.
36. Herndon DN, Barrow RE, Stein M, et al. Increased mortality with intravenous supplemental feeding in severely burned patients. J Burn Care Rehabil 1989; 10(4):309–313.
37. Czaja AJ, McAlhany JC, Pruitt BA. Acute gastroduodenal disease after thermal injury. An endoscopic evaluation of incidence and natural history. N Engl J Med 1974; 291(18):925–929.
38. Tompkins RG, Remensnyder JP, Burke JF, et al. Significant reductions in mortality for children with burn injuries through the use of prompt eschar excision. Ann Surg 1988; 208(5):577–585.
39. Jackson D, Topley E, Cason JS, et al. Primary excision and grafting of large burns. Ann Surg 1960; 152:167–189.
40. Janzekovic Z. A new concept in the early excision and immediate grafting of burns. J Trauma 1970; 10:1103–1108.
41. Monafo WW. Tangential excision. Clin Plast Surg 1974; 1:591–601.
42. Burke JF, Bondoc CC, Quinby WC. Primary burn excision and immediate grafting: a method of shortening illness. J Trauma 1974; 14:389–395.
43. Engrav LH, Heimbach DM, Reus JL, et al. Early excision and grafting versus non-operative treatment of burns of indeterminate depth. A randomized prospective study. J Trauma 1983; 23:1001–1004.
44. Herndon DN, Barrow RE, Rutan RL, et al. A comparison of conservative versus early excision. Ann Surg 1989; 209:547–553.
45. Herndon DN, Gore DC, Cole M, et al. Determinants of mortality on pediatric patients with greater than 70% full-thickness total body surface area thermal injury treated by early total excision and grafting. J Trauma 1987; 27:208–212.
46. Barrow RE, Spies M, Barrow LN, et al. Influence of demographics and inhalation injury on burn mortality in children. Burns 2004; 30:72–77.
47. Reverdin JL. Greffe epidermique. Bulletin de la Societe' Imperiale de Chirurgie de Paris 1869; 101:511–515.
48. Davis JS. The use of small deep skin grafts. JAMA 1914; 63:985–989.
49. Padgett FC. Indications for determination of the thickness for split skin grafts. Am J Surg 1946; 72:683–693.
50. Tanner JC, Vandeput J, Olley JF. The mesh skin graft. Plast Reconst Surg 1965; 34:287–292.
51. Alexander JW, MacMillan BG, Law E, et al. Treatment of severe burns with widely meshed skin autograft and meshed skin allograft overlay. J Trauma 1981; 21(6):433–438.
52. Burke JF, Yannas IV, Quimby WC, et al. Successful use of a physiologically acceptable artificial skin in the treatment of extensive burn injury. Ann Surg 1981; 194:413–428.
53. Heimbach D, Luterman A, Burke J, et al. Artificial dermis for major burns. A multi-center randomized clinical trial. Ann Surg 1988; 208(3):313–320.
54. Bell E, Ehrlich HP, Buttle DJ, et al. Living tissue formed in vitro and accepted as skin-equivalent tissue of full-thickness. Science 1981; 211:1052.
55. Moylan JA. Inhalation injury – a primary determinant of survival following major burns. J Burn Care Rehabil 1981; 1: 78–84.
56. Foley FD, Moncrief JA, Mason AD. Pathology of the lung in fatally burned patients. Ann Surg 1968; 167:251.
57. Moylan JA, Wilmore DW, Mouton DE, et al. Early diagnosis of inhalation injury using 133xenon lung scan. Ann Surg 1972; 176:477.
58. Agee RN, Long JM, Hunt JL, et al. Use of 133xenon in early diagnosis of inhalation injury. J Trauma 1976; 16:218.
59. Moylan JA, Adib K, Birnhaum M. Fiberoptic bronchoscopy following thermal injury. Surg Gynecol Obstet 1975; 140:541.
60. Shirani KZ, Pruitt BA, Mason AD. The influence of inhalation injury and pneumonia on burn mortality. Ann Surg 1987; 205:82.
61. Navar PD, Saffle JR, Warden GD. Effect of inhalation injury on fluid resuscitation requirements after thermal injury. Am J Surg 1985; 150(6):716–720.
62. Herndon DN, Barrow RE, Traber DL, et al. Extravascular lung water changes following smoke inhalation and massive burn injury. Surgery 1987; 102(2):324–349.
63. Fitzpatrick JC, Cioffi WG Jr. Ventilatory support following burns and smoke-inhalation injury. Resp Care Clin N Am 1997; 3(1):21–49.
64. Cortiella J, Mlcak R, Herndon DN. High frequency percussive ventilation in pediatric patients with inhalation injury. J Burn Care Rehabil 1999; 20(3):232–235.
65. Herndon DN, Traber DL, Pollard P. Pathophysiology of inhalation injury. In: Herndon DN, ed. Total burn care. London: WB Saunders; 1996:175–183.
66. Desai MH, Mlcak R, Richardson J, et al. Reduction in mortality in pediatric patients with inhalation injuries with aerosolized Heparin/N-acetylcysteine. J Burn Care Rehabil 1998; 19(3): 210–212.
67. Burke JF, Yannas IV, Quinby WC, et al. Successful use of a physiologically viable artificial skin in the treatment of extensive burn injury. Ann Surg 1981; 194:413–428.
68. Zwischenberger JB, Cardenas VJ, Tao W, et al. Intravascular membrane oxygenation and carbon dioxide removal with IVOX: can improved design and permissive hypercapnia achieve adequate respiratory support during severe respiratory failure? Artif Organs 1994; 18:833–839.

Chapter 2

Teamwork for total burn care: achievements, directions, and hopes

David N. Herndon and Patricia E. Blakeney

Chapter contents

Major burn injury evokes strong emotional responses in most lay persons and health professionals who are confronted by the spectre of pain, deformity, and potential death associated with significant burns. Severe pain and repeated episodes of sepsis followed by predictable outcomes of either death or a survival encumbered by pronounced disfigurement and disability has been the expected pattern of sequelae to serious burn injury for most of mankind's history.[1] However, these dire consequences have, over time, been ameliorated so that, while burn injury is still intensely painful and sad, the probability of resultant death has been significantly diminished. As illustrated in Table 2.1, during the decade prior to 1951, a 49% mortality rate occurred in young adults (15–43 years of age) with total body surface area (TBSA) burns of 45% or greater.[2] Forty years later, statistics from the pediatric and adult burn units in Galveston, Texas indicated that the 49% mortality rate accompanied a 70% or greater TBSA for the same age group. In 2006, those mortality figures have improved even more dramatically, so that almost all infants and children, when resuscitated adequately and quickly, can be expected to survive.[3] Although improved survival was the primary focus of burn treatment advancement for many decades, that goal has now virtually been accomplished.

Such improvement in forestalling death is a direct result of the maturation of the science of burn care. Scientifically sound analyses of patient data have led to the development of formulas for fluid resuscitation[4–7] and nutritional support.[8,9] Clinical research has demonstrated the utility of topical antimicrobials in delaying onset of sepsis, thereby contributing to decreased mortality of burn patients.[10] Prospective randomized clinical trials have determined the efficacy of early surgical therapy in improving survival for many burned patients by decreasing blood loss and by diminishing the occurrence of sepsis.[11–16] Basic science and clinical research have contributed to decreased mortality by describing pathophysiology related to inhalation injury and suggesting treatment methods which have decreased the incidence of pulmonary edema and pneumonia.[17–20] Scientific investigations of the hypermetabolic response to major burn injury have led to improved management of this life-threatening phenomenon, resulting not only in diminished loss of life but also promising improved quality of life.[21–35]

Melding scientific research with clinical care has been promoted throughout the recent history of burn care, in large part because of the aggregation of burned patients into single purpose units staffed by dedicated healthcare personnel. Dedicated burn units were first established in Great Britain in order to facilitate nursing care.[36] The first US burn center was established at the Medical College of Virginia in 1946 followed that same year by the US Army Surgical Research Unit, later renamed the US Army Institute of Surgical Research.[36] Directors of both of these centers and later the founders of the Burn Hospitals of Shriners Hospitals for Children emphasized the importance of collaboration between clinical care and basic scientific disciplines.[1] The organizational design of these centers stimulated the formation of a self-perpetuating feedback loop of clinical and basic scientific inquiry.[36] Scientists in such a system receive first-hand information about clinical problems while clinicians receive provocative ideas about patient responses to injury from experts of other disciplines. Advances in burn care attest to the value of a dedicated burn unit organized around the concept of a collegial group of basic scientists, clinical researchers, and clinical care givers, all asking questions of each other, sharing observations and information, and together seeking solutions to improve the welfare of their patients (Figure 2.1).

Findings of the group at the Army Surgical Research Institute pointed out the necessity of involving many disciplines in the treatment of patients with major burn injuries and stressed the utility of a team concept.[1] The International Society of Burn Injuries and its journal, Burns, and the American Burn Association with its publication, Journal of Burn Care and Research, have publicized to widespread audiences the notion of successful multidisciplinary work by burn teams.

Members of a burn team

As illustrated by a perusal of the contents of either of the aforementioned journals and by the contents of this volume, the burn team can include epidemiologists, molecular biolo-

TABLE 2.1 PERCENT TOTAL BODY SURFACE AREA (TBSA) BURN FOR AN EXPECTED MORTALITY OF 50% IN 1952, 1993, AND 2006

Age (years)	1953† (% TBSA)	1993* (% TBSA)	2006° (% TBSA)
0–14	49	98	99
15–44	46	72	88
45–65	27	51	75
>65	10	25	33

†Bull, JP, Fisher, AJ. Annals of Surgery 1954;139.
*Shriners Hospital for Children and University of Texas Medical Branch, Galveston, Texas.
°Pereira CT et al. J Am Coll Surg 2006; 202(3): 536–548 and unpublished data. PP. 1138–1140 (PC65)

Fig. 2.1 Different experts from diverse disciplines gather together with common goals and tasks, sharing overlapping values to achieve their objectives. (Reprinted with permission from: Barret JP, Herndon DN, eds. Color atlas of burn care. London: WB Saunders; 2001.)

gists, microbiologists, physiologists, biochemists, pharmacists, pathologists, endocrinologists, nutritionists, and numerous other scientific and medical specialists. Burn injury is a complex systemic injury, and the search for improved methods of treatment leads to inquiry from many approaches. Each scientific finding stimulates new questions and potential involvement of additional specialists.

At times, the burn team can be thought of as including the environmental service workers responsible for cleaning the unit, the volunteers who may assist in a variety of ways to provide comfort for patients and families, the hospital administrator, and many others who support the day-to-day operations of a burn center and significantly impact the well-being of patients and staff. The traditional concept of the burn team, however, connotes the multidisciplinary group of direct-care providers. Burn surgeons, nurses, dietitians, and physical and occupational therapists are the skeletal core; most burn units include anesthesiologists, respiratory therapists, pharmacists, and social workers. In recent years, as mortality rates have decreased, interest has intensified in the quality of life for burn survivors, both acutely in the hospital and for the long term. Consequently, more burn units have added psychologists, psychiatrists, and, more recently, exercise physiologists to their burn-team membership. In pediatric units, child life specialists and school teachers are significant members of the team of care takers as well.

Infrequently mentioned as members of the team, but obviously important in influencing the outcome of treatment, are the patient and the family of the patient. Persons with major burn injuries contribute actively to their own recovery, and each brings individual needs and agendas into the hospital setting which influence the ways in which treatment is provided by the professional care team.[37] The patient's family members often become active participants; obviously so in the case of children, but also in the case of adult patients. Family members become conduits of information from the professional staff to the patient; they act, at times, as spokespersons for the patient, and at other times, they become advocates for the staff in encouraging the patient to cooperate with dreaded procedures.

With so many diverse personalities and specialists potentially involved, it may appear absurd to purport to know what or who constitutes a burn team. Yet references to the 'burn team' are plentiful, and there is common agreement on some specialists whose expertise is required for excellent care of significant burn injury.

Surgeons

A burn surgeon is the key figure of the burn team. Either a general surgeon or a plastic surgeon or, perhaps, both with expertise in providing emergency and critical care, as well as the techniques of skin grafting and amputations, provides leadership and guidance for the rest of the team which may include several surgeons. The surgeon's leadership is particularly important during the early phase of patient care when moment-to-moment decisions must be made based on the surgeon's knowledge of the physiologic responses to the injury, the current scientific evidence, and the appropriate medical/surgical treatment. The surgeon must not only possess knowledge and skill in medicine but must also be able to communicate clearly, both receiving and giving information, with a diverse staff of experts in other disciplines. The surgeon cannot alone provide comprehensive care but must be wise enough to know when and how to seek counsel as well as how to give directions clearly and firmly to direct activities surrounding patient care. The senior surgeon of the team is accorded the most authority and control of any member of the team and, thus, bears the responsibility and receives the accolades for the success of the team as a whole.[37]

Nurses

The nurses of the burn team represent the largest single disciplinary segment of the burn team, providing continuous coordinated care to a patient.[36] The nursing staff is responsible for technical management of the 24-hour physical treatment of the patient. As well, they provide emotional support to the patient and patient's family and control the therapeutic milieu that allows the patient to recover. The nursing staff is often the first to identify changes in the patient's condition and initiate therapeutic interventions.[36] Because recovery from a major burn is a rather slow process, burn nurses combine the qualities of sophisticated intensive care nursing with the challenging aspects of psychiatric nursing. Nursing case management can play an important role in burn treatment, extending the coordination of care beyond the hospitalization through the lengthy period of outpatient rehabilitation.

Anesthesiologists

An anesthesiologist who is an expert in the altered physiologic parameters of the burned patient is critical to the survival of the patient, who usually undergoes multiple surgical procedures acutely. Anesthesiologists on the burn team must be familiar with the phases of burn recovery and the physiologic changes to be anticipated as the burn wounds heal.[1] Anesthesiologists play significant roles in facilitating comfort for burned patients, not only in the operating room but also in the painful ordeals of dressing changes, removal of staples, and physical exercise.

Respiratory therapists

Inhalation injury, prolonged bed rest, fluid shifts, and the threat of pneumonia concomitant with burn injury render respiratory therapists essential to the patient's welfare.[36] They evaluate pulmonary mechanics, perform therapy to facilitate breathing, and closely monitor the status of the patient's respiratory functioning.

Rehabilitation therapists

Occupational and physical therapists begin at the patient's admission to plan therapeutic interventions to maximize functional recovery. Burned patients require special positioning and splinting, early mobilization, strengthening exercises, endurance activities, and pressure garments to promote healing while controlling scar formation. These therapists must be very creative in designing and applying the appropriate appliances. Knowledge of the timing of application is necessary. In addition, rehabilitation therapists must become expert behavioral managers for their necessary treatments are usually painful to the recovering patient who will resist in a variety of ways. While the patient is angry, protesting loudly, or pleading for mercy, the rehabilitation therapist must persist with aggressive treatment in order to combat quickly forming and very strong scar contractures. The same therapist, however, typically is rewarded with adoration and gratitude from an enabled burn survivor.

Nutritionists

A nutritionist or dietitian monitors daily caloric intake and weight maintenance and recommends dietary interventions to provide optimal nutritional support to combat the hypermetabolic response of burn injury. Caloric intake as well as intake of appropriate vitamins, minerals, and trace elements must be managed to promote wound healing and facilitate recovery.

Psychosocial experts

Psychiatrists, psychologists, and social workers with expertise in human behavior and psychotherapeutic interventions provide continuous sensitivity in caring for the emotional and mental well-being of patients and their families. These professionals must be knowledgeable about the process of burn recovery as well as human behavior in order to make optimal interventions. They serve as confidants and supports for the patients, families of patients, and on occasion, for other burn team members.[38] They often assist colleagues from other disciplines in developing behavioral interventions with problematic patients which allow the colleague and the patient to achieve therapeutic success.[39] During initial hospitalization, these experts attend to managing the patient's mental status, pain tolerance, and anxiety level to provide comfort to the patient and also to facilitate physical recovery. As the patient progresses toward rehabilitation, the role of the mental health team becomes more prominent in supporting optimal psychological, social, and physical rehabilitation.

Functioning of a burn team

Gathering together a group of experts from diverse disciplines will not constitute a team.[40] In fact, the diversity of the disciplines, in addition to individual differences of gender, ethnicity, values, professional experience, and professional status render such teamwork a process fraught with opportunities for disagreements, jealousies, and confusion.[41] The process of working together to accomplish the primary goal, i.e. a burn survivor who returns to a normally functional life, is further complicated by the requirement that the patient and family of the patient collaborate with the professionals. It is not unusual for the patient to attempt to diminish his immediate discomfort by pitting one team member against another or 'splitting' the team. Much as young children will try to manipulate parents by going first to one and then to the other, patients, too, will complain about one staff member to another or assert to one staff member that another staff member allows less demanding rehabilitation exercises or some special privilege.[42] Time must be devoted to a process of trust-building among the team members. It is imperative that the team communicate — openly and frequently — or the group will lose effectiveness.

The group becomes a team when they have common goals and tasks to be accomplished and when they share, as individual members, overlapping values that will be served by accomplishing their goals.[43,44] The team becomes an efficient work group through a process of establishing mechanisms of collaboration and cooperation which facilitate focusing on explicit tasks rather than on covert distractions of personal need and interpersonal conflict.[44,45] Work groups develop best in conditions which allow each individual to feel acknowledged as valuable to the team. [46,47]

A burn team has defined and shared goals with clear tasks. For the group of burn experts to become an efficient team, skillful leadership that facilitates the development of shared values among team members and ensures the validation of the members of the team as they accomplish tasks is necessary. The burn team consists of many experts from diverse professional backgrounds; and each profession has its own culture, its own problem-solving approach, and its own language.[48] For the team to benefit fully from the expertise of the members of the team, every expert voice must be heard and acknowledged. Team members must be willing to learn from each other, eventually developing their own culture and communicating in language that all can understand. Attitudes of superiority and prejudice are most disruptive to the performance of the team.

There will be disagreement and conflict, but these can be expressed and resolved in a respectful manner. Research suggests that intelligent management of emotions is linked with successful team performance in problem solving and in conflict resolution.[49] When handled well, conflicts and disagreements can result in increased understanding and new perspectives which can, in turn, enhance working relationships[50] and lead to improved care for the patient.[51]

The acknowledged formal leader of the team is the senior surgeon who may find the arduous job of medical and social leadership difficult and perplexing. Empirical studies, with remarkable consistency, indicate that the required functions for successful leadership can be grouped into two somewhat incompatible clusters:

- to direct the group toward tasks and goal attainment; and
- to facilitate the interaction of the group members, enhancing their feelings of worth.[44,47,51–54]

Task-oriented behavior by the leader may at times clash with the needs of the group for emotional support. During those times, the team may inadvertently impede the successful performance of both the leader and the team as the group seeks alternate means of establishing feelings of self-worth. When the social/emotional needs of the group are not met, the group begins to spend more time attempting to satisfy individual needs and less time pursuing task-related activity.

Studies of group behavior demonstrate that high performance teams are characterized by synergy between task accomplishment and individual need fulfillment.[44,52] Since one formal leader cannot always attend to task and interpersonal nuances, groups allocate, informally or formally, leadership activities to multiple persons.[44,45,47,53] The literature in organizational behavior indicates that the most effective leader is one who engages the talents of others and empowers them to utilize their abilities to further the work of the group.[44,45,53] Failure to empower the informal leaders limits their abilities to contribute fully.

For the identified leader of the burn team, i.e. the senior surgeon, to achieve a successful, efficient burn team, it is important that the leader be prepared to share leadership with one or more 'informal' leaders in such a way that all leadership functions are fulfilled.[44,45,47,53,55] The prominence and the identity of any one of the informal leaders will change according to situational alteration. The successful formal leader will encourage and support the leadership roles of other members of the team, developing a climate in which the team members are more likely to cooperate and collaborate toward achievement beyond individual capacity.

For many physicians, the concept of sharing leadership and power appears at first to be threatening, for it is the physician, after all, who must ultimately write the orders and be responsible for the patient's medical needs.[56] However, sharing power does not mean giving up control.[53] The physician shares leadership by seeking information and advice from other team members and empowers them by validating the importance of their expertise in the decision-making process. The physician, however, maintains control of the patient's care and medical treatment.

Summary and hopes for the future

Centralized care provided in designated burn units has promoted a team approach to both scientific investigation and clinical care which has demonstrably improved the welfare of burn patients. Multidisciplinary efforts are imperative for the continued increase in understanding of and therapeutic responses to the emotional, psychological, and physiologic recovery and rehabilitation of the burned person. Tremendous scientific and technological advances have led to dramatically increased survivability for burn victims.

Our hopes for the future are that by following the same model of collaboration, scientists and clinicians will pursue solutions to the perplexing problems which the burn survivor must encounter. Physical discomforts such as itching still interfere with rehabilitation of the patient. New techniques for controlling hypertrophic scar and for reconstructive surgeries could do much to diminish the resultant disfigurement.[57] The combined use of anabolic agents[33,34] and supervised strength and endurance training[27,28] are currently being investigated as means of enhancing the well-being of survivors of massive burn injury. Further development of psychological expertise within burn care and increased public awareness of the competence of burn survivors may ease the survivor's transition from incapacitated patient to functional member of society. We hope that burn care in the future will continue to devote the same energy and resources which have resulted in such tremendous advances in saving lives to improving the capacity for preserving optimal quality of life for survivors.

References

1. Artz CP, Moncrief JA. The burn problem. In: Artz CP, Moncrief JA, eds. The treatment of burns. 2nd edn. Philadelphia: WB Saunders; 1969:1–21.
2. Bull JP, Fisher AJ. A study of mortality in a burns unit: a revised estimate. Ann Surg 1954; 139:269–274.
3. Pereira CT, Barrow RE, Sterns AM, et al. Age-dependent differences in survival after severe burns. J Am Coll Surg 2006; 202(3):536–548.
4. Evans EI, Purnell OJ, Robinett PW, et al. Fluid and electrolyte requirements in severe burns. Ann Surg 1952; 135: 804–817.
5. Baxter CR, Marvin JA, Curreri PW. Fluid and electrolyte therapy of burn shock. Heart Lung 1973; 2:707–713.
6. Artz CR. Burns updated. J Trauma 1976; 16:2–15.
7. Carvajal HE. Fluid therapy for acutely burned child. Compr Ther 1977; 3:17–24.