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Irwin & Rippe's Ultrasonography for Management of the Critically Ill

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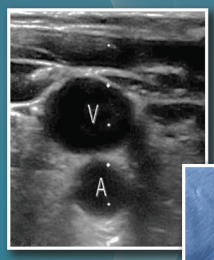

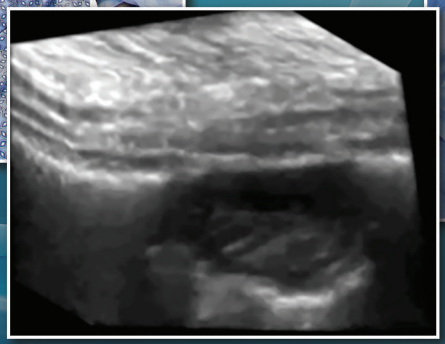

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IRWIN & RIPPE'S

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To Our Families and Patients

Preface

It is with great pleasure that we present the first edition of *Irwin & Rippe's Ultrasonography for Management of the Critically Ill*. This book contains 31 chapters in which the role of point-of-care ultrasonography (POCUS) is highlighted and emphasized. The editorial challenge that we faced in its preparation relates to changes in the available technologies and the rapid yet uneven adoption of POCUS into the practice of critical care medicine. We met these challenges by introducing techniques in the context of the topical areas that have proved popular and useful to the users of our eighth edition of *Irwin & Rippe's Intensive Care Medicine* textbook. Within the chapters of this book, we present challenging and intriguing cases with ultrasound images that provide helpful information that guides bedside management. We hope that the readers who are late adopters of using POCUS will gain some of the enthusiasm for using ultrasound at the bedside and share our excitement that has grown from our use of ultrasound to expedite critical care delivery because it allows earlier intervention that better serves our patients. We also hope that those of you who were early adopters of POCUS and are experts in its use find the content of this book a helpful educational resource for teaching others.

We present the bedside use of ultrasound as a tool that supports and enhances the experience of interprofessional and collaborative critical care teams. Our understanding of the evolution of the importance and utility of bedside ultrasound techniques has led to the development of this ultrasound-focused critical care textbook. Senior editors, Paul H. Mayo and Seth J. Koenig, were specifically recruited because they are internationally renowned for their knowledge and expertise in ultrasonography education. We also recognize the invaluable contributions of Gisela I. Banauch, another expert point-of-care ultrasonographer, who worked tirelessly to help us integrate ultrasound text and make it more accessible.

Because we believe in evidence-based medicine and a patient-focused approach, we advocate managing our ICUs according to the following guiding principles: (1) making our ICUs safer for our patients and (2) decreasing variability by following clinical practice guidelines based on the best available evidence to ensure better outcomes. We are excited about the ability of bedside ultrasound techniques to support these aims.

Our emphasis is on clinical management, early recognition of a critical illness or serious injury, and effectiveness assessment of therapeutic interventions. Discussions of basic pathophysiology are presented, guided, and supplemented by extensive references to help clinicians and researchers who wish to pursue more in-depth knowledge of these important areas. We hope and believe that the outstanding efforts of many people have resulted in an evidence-based, state-of-the-art, and comprehensive book that demonstrates the important principles of intensive care medicine and the utility of ultrasound techniques for applying them. We offer this book as a guide and support to practitioners who work for the critically ill as an aid to their efforts to diagnose and treat complicated diseases and relieve human suffering.

Craig M. Lilly
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Acknowledgments

A book of this technological sophistication required a "village" to develop and complete. In this regard, numerous outstanding individuals made significant contributions to all phases of writing and production of this book and deserve special recognition and thanks. First and foremost is our managing editor, Elizabeth Grady. Beth literally lived and breathed this book as it worked its way through its conception, development, and creation. She was the guiding and organizing spirit behind this book. It would simply not be possible without Beth's incredible organizational skills, good humor, and enormous energy.

The major innovation of the book is its focus on point-of-care ultrasonography in managing the critically ill. Assisting Paul H. Mayo and Seth J. Koenig with the tasks required to develop high-quality ultrasound videos was Yonathan Greenstein, Michael Hill, Ari Nalbandian, and Susanne Muehlschlegel who created and presented original educational videos with Eric Cucchi and Stephen Allegra, appearing as supporting actors. Assisting in preparation of the utility of ultrasonography sections in the chapters were Gisela I. Banauch, Ariel Shiloh, and Lewis Eisen. For their outstanding work, we owe them an enormous debt of gratitude. We also wish to thank the CHEST organization and their *Chest* journal and its publisher, Elsevier, for appreciating the importance of this book to the field of critical care medicine and providing us with permission to reproduce selected videos previously published in *Chest* in their Ultrasound Corner section of the journal.

Our administrative assistants, office assistants, and clinical coordinators, Sherry Jakubiak and Cynthia French, Linda Doherty, Debra Adamonis, and Carol Moreau have helped us manage our complex professional and personal lives and create room for the substantial amount of time required to organize, create, and edit this offering. We very much appreciated their deep commitment to this book and to advancing the application of point-of-care ultrasound to the field of intensive care medicine.

Our editors at Wolters Kluwer including Brian Brown, Executive Editor, have been a source of great help and encouragement. Ashley Fischer was extremely helpful and accommodating in supervising and coordinating all phases of production of the book in an outstanding way. We are grateful to Ashley Pfeiffer who handled the day-to-day details necessary with a book of this size. Lastly, we are grateful to Rajmohan Baskaran and his staff for the outstanding job they have done copyediting the manuscript for this first edition.

Our families support our efforts with unfailing encouragement and love. To them, and the many others who have helped in ways too numerous to count, we are deeply grateful.

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12 Resuscitation From Shock Following Hemorrhage

JACOB A. QUICK, DONALD H. JENKINS, JOHN B. HOLCOMB, STEPHEN L. BARNES, AND SETH J. KOENIG

Early recognition of exsanguinating hemorrhage is critical to the survivability of the acutely bleeding patient. Typical methods of in-hospital assessment, including blood pressure and hemoglobin levels, are often misleading, and reliance upon these methods frequently results in late recognition of hemorrhagic shock, giving rise to higher mortality rates. Advanced Trauma Life Support program teaches health care providers to incorporate basic physical examination skills (vital signs, pulse pressure, skin color, capillary refill, and mentation) to stratify injury severity, identify and treat immediate threats to life, and quantify blood loss.[1] Rapid, focused assessment is necessary to expeditiously identify those patients who are either in hemorrhagic shock or at risk for developing it.

Surgical patients die from shock either abruptly via inadequate oxygen delivery or subacutely through development of multisystem organ dysfunction from late recognition or inadequate resuscitation. Unlike the typical nonsurgical critically ill patient, organ dysfunction often results from the acute effects of exsanguination. Hemorrhage accounts for up to 40% of trauma deaths, second only to central nervous system injury.[2-4] Controlling hemorrhage is thus a priority for modern trauma patient care; however, the source of hemorrhage must first be identified, and identified early.

Prior to, during, and following surgical intervention, ongoing resuscitative efforts must proceed appropriately to avoid the sequelae of hypoperfusion. Although commonly utilized in nonbleeding patients, intravenous (IV) crystalloid infusion may only provide temporary volume repletion. Additionally, crystalloids increase acidosis, can contribute to coagulopathy, cause immunologic dysfunction, and impose pulmonary and renal risks, and, therefore, have limited use in the hemorrhaging patient.[5] Lost cellular components, coagulation factors, and oxygen-carrying capacity require directed replacement to achieve normal perfusion.

Trauma-induced and consumptive coagulopathy presents a unique challenge not present in other shock states. In addition to the quantitative loss of essential clotting components, hemorrhage results in hemostatic functional failure. Hyperfibrinolysis, progressive thrombocytopenia, acidosis, and hypothermia all contribute to worsening coagulopathy that mandates aggressive, early, and targeted management.

A variety of methods have been utilized to determine endpoints of resuscitation following significant hemorrhage. Failure to direct resuscitation to these specific goals may lead to over- or underresuscitation and the multitude of deleterious effects of either. No single endpoint has proven adequate, further elucidating the importance of a keen understanding of the physiologic consequences of bleeding.

Following initial resuscitation, ongoing need for blood products and hemostatic adjuncts suggests the presence of a missed injury or ongoing surgical bleeding not yet controlled. Although not always clear, failing to recognize the need to return to the operating theater or endoscopy or interventional suite will result in worsened physiology, often beyond recovery and repair.

The myriad of issues encompassing shock following hemorrhage require diligence, foresight, and intuition in order to orchestrate a successful resuscitative strategy, while minimizing the complications associated with the disease state, as well as complications of the resuscitation.

PHYSIOLOGIC RESPONSES TO HEMORRHAGE

Coagulopathy

Acute coagulopathy resulting from hemorrhage is not a new concept, but recent work has further elucidated causes and potential treatments for coagulation disturbances associated with acute, large-volume blood loss. When present, coagulopathy is associated with higher mortality, up to four times that of patients with normal coagulation profiles.[6]

Dilutional coagulation dysfunction has long been at the forefront of arguments against the use of large-volume prehospital or in-hospital resuscitation with crystalloid solutions. With continued hemorrhage, plasma constituents necessary for hemostasis are not replete and diluted. Replacing only the lost *volume* with crystalloid not only fails to replenish plasma constituents but also dilutes those remaining coagulation elements, thereby worsening hemorrhage. Additionally, crystalloid dilutional resuscitation has also been linked with increased hyperfibrinolysis—a deadly combination. However, multiple studies have shown this to be only one component of coagulation disruption, because coagulopathy in the absence of crystalloid resuscitation remains a significant problem, most notably following injury.[7]

Consumptive coagulopathy, originally thought to be the primary cause of clotting dysfunction seen in patients sustaining significant hemorrhage, is rooted in the concept of localized exhaustion of clotting factors, platelets, thrombin, and other hemostatic activators. In severe multisystem tissue damage, such as massive crush injury, this likely plays a key role in the basic view of hemorrhagic coagulation dysfunction. However, coagulopathy is often associated with major, single-site hemorrhage where direct tissue damage is limited, such as intraoperative vascular injury or isolated organ trauma from a single gunshot wound, suggesting that systemic effects are at work.[8]

Approximately 25% of traumatized patients will present with coagulopathy that differs from these classic interpretations of causative mechanisms.[9] Although dilutional and consumptive causes certainly play a role in the acute coagulopathy of hemorrhage, dysregulated systemic activation and deactivation of key hemostatic mediators, as well as hypoperfusion, significantly contribute to systemic hemostatic failure. This is evidenced by those patients who present with normal perfusion; and, despite massive tissue injury, some patients do not show signs of coagulopathy.[10] Direct tissue injury exposes tissue factor and type III collagen within the subendothelium of damaged vessels. Binding of von Willebrand factor, platelets, and factor VIIa leads to thrombin and fibrin formation. This process is then amplified by factor IX, propagating initial hemostatic response to hemorrhage. Because hemostasis is part of a coagulation continuum, whereby clot formation and lysis are principal components, the release of hemostatic factors is accompanied by concomitant increases in lytic factors. Endothelial exposure from injury and thrombin formation also result in release of tissue plasminogen activator (tPA). Additionally, plasminogen activator inhibitor 1 (PAI-1) is inhibited, leading to increased plasticity of forming clots.[8,11]

These local responses to tissue damage do not, however, fully elucidate the widespread clotting malfunction seen with large-volume hemorrhage. Systemic activation in response to hypoperfusion and shock has been implicated as a fundamentally necessary component of the acute coagulopathy of hemorrhage. This is seen with the thrombin-thrombomodulin-protein C complex. Hemorrhagic shock leads to increased circulating thrombomodulin, resulting in whole-body activation of protein C. Activated protein C then exudes its anticoagulant effects through degradation of clotting factors, specifically factors V and VIII. Studies have shown those patients in shock, regardless of degree of tissue injury, and have universally demonstrated deficiency in factor V.[7] PAI-1 is consumed, and thrombin generation subsequently downregulated on a systemic level as a result of increased protein C and glycocalyx shedding. The endothelial glycocalyx is a key regulator of vascular permeability, cell adhesion, and inflammation. At least one of four key components, syndecan-1, is shed during hemorrhagic shock exposing the membrane to inflammatory molecule adhesion, increasing permeability, and hyperfibrinolysis. The glycocalyx has been shown, at least in an animal model, to be replenished in plasma-based resuscitation and not with crystalloids.[12,13]

The presence of shock is associated with hyperfibrinolysis and worsened outcomes. When percentage of lysis at 30 minutes (LY30), as defined by thromboelastography (TEG), exceeded 3%, the associated mortality risk increased 10-fold.[6] Although fibrinolysis is a normal physiologic process, hypoperfusion-related dysregulation of mediating factors results in overactivation of the fibrinolytic process. Plasminogen activators (tPA) cleave plasminogen to plasmin and are systemically upregulated in response to hemorrhagic shock. Additionally, the downregulatory activities of PAI-1 are inhibited through depletion.[11] This sets the stage for unrestricted lysis, diffuse hemorrhage, and uncontrolled coagulopathy.

Often revered by clinicians as a key marker of a patient's hemostatic ability, thrombocytopenia is associated with worsened outcomes. However, a normal platelet count does not ameliorate the risk of mortality related to functional platelet abnormalities, especially when considering that thrombocytopenia on admission is a rare event. In a study examining 101 severely injured trauma patients with normal platelet counts, over 40% demonstrated a defect in platelet function on admission to the emergency department.[14] Again, the presence of shock is to be blamed. Hypoperfusion leading to organ dysfunction, specifically hepatic perturbations, leads to the release of substances, causing calcium channel disruption and platelet inhibition.[15] Impaired fibrinogen-platelet interactions, decreased platelet responsiveness to arachidonic acid, adenosine diphosphate, and thrombin receptor–activating peptide as well as the classic inhibitors of hemostasis—acidosis and hypothermia—resulting from hypoperfusion also contribute to decreased platelet function.[16]

Hemodynamics

Hemodynamic physiologic changes occur as a result of the need to ensure adequate tissue perfusion to vital organs. This is accomplished at the outset of severe hemorrhage through a multitude of cardiovascular mechanisms, led by sympathetic upregulation. Sympathetic outflow, resulting from atrial and carotid body baroreceptors and loss of vagal tonic inhibition as a function of hypovolemia, causes cardiac chronotropic and inotropic responses. Epinephrine increases heart rate, which in turn maintains cardiac output, despite falling stroke volume. This is first recognized clinically by an increase in diastolic pressure, and consequent narrowed pulse pressure. With worsening hypovolemia, respiratory variations in pulse pressure may develop, worsening mean perfusion pressures significantly. Sympathetic activation also increases contractility through cardiac β-receptor stimulation.

Decreased arterial and venous compliance secondary to epinephrine release improves venous return in the face of hypovolemia. Peripheral vasoconstriction is clinically identified by the presence of cool extremities. Blood is shunted away from the periphery to vital organs, such as the heart and brain. Splanchnic perfusion is compromised because endogenous vasopressin and other sympathetic substances, such as endothelin and angiotensin II, stimulate vasoconstrictive receptor systems. Consequently, renal blood flow is decreased to only a fraction of normal levels, leading to acute kidney injury and oliguria. Celiac vasoconstriction decreases hepatic and portal flow, resulting in release of proinflammatory mediators, such as interleukin 6 (IL-6).[15,17]

On a microvascular level, increases in cellular adhesion molecules cause neutrophils to adhere to the endothelial cells in the microcirculation, limiting the physical ability of red cells to navigate capillary beds. Inflammatory mediators induce endothelial cell swelling, further limiting the passage of blood constituents. Decreases of capillary flow provoke cellular ischemia and anaerobic metabolism with ensuing acidosis.[18]

As hypovolemia progresses, hemodynamic compensation fails. Cardiac output falls despite increases in contractility and heart rate. Vasoconstriction is maximized through exponential quantities of endogenous catecholamines; however, without volume, it is to no avail. Acidosis rapidly follows, heart rate variability declines, and bradycardia emerges signifying irreversible shock.

Metabolic

In 1872, Gross called shock a "rude unhinging of the machinery of life." The machinery of cellular metabolism undergoes fundamental changes in the setting of hemorrhagic shock. Hypovolemic-induced depressions of cardiac output result in diminished perfusion to end organs. The remaining intravascular volume is depleted of hemoglobin *mass*, although *concentrations* may remain relatively stable in the initial phases. Limited hemoglobin mass correlates with decreasing levels of available oxygen. To counteract this, oxygen extraction increases, measured by declining mixed venous oxygen saturation, and the patient becomes dependent upon oxygen delivery to maintain aerobic metabolic pathways and stave off impending acidosis. As hemorrhage continues and the previously described hemodynamic changes occur, anaerobic metabolism begins to materialize. The resultant acidosis shifts the oxygen dissociation curve to the right, favoring oxygen offloading at the cellular level. Mild acidosis, therefore, executes a beneficial effect, curbing progressive anaerobic transformation temporarily. If hemorrhage control is not accomplished, the availability of cellular oxygen fades, and mitochondrial energy production is halted with accumulation of pyruvate. Reduction of the efficiency of the electron transport chain causes diversion of NADH that donates a proton to pyruvate with formation of lactate. Lactic acidosis then ensues until oxygen delivery restores the electron transport chain, at which time pyruvate may reenter the citric acid cycle and lactate production decreases.

Lactate clearance has been studied extensively as a marker of resuscitation effectiveness based on these basic physiologic mechanisms. For lactate formation rates to normalize, orderly aerobic cellular metabolism must be restored. This is evidenced through an understanding of the Cori cycle, which begins with glycolysis. Yielding two adenosine triphosphates (ATPs), glycolysis also produces two lactates, which are then transported to the liver. Lactate is then converted back to glucose through hepatic gluconeogenesis at the cost of six ATPs, resulting in a net negative energy balance. Glucose then participates in glycolysis again at the cellular level, and the process repeats itself. This large energy gap cannot be replenished without resumption of normal physiologic metabolism, which requires restoration of oxygen delivery through hemorrhage control and resuscitative efforts. Therefore, normalization of lactate levels signifies success from a resuscitation viewpoint.

Blood glucose and glucose utilization is intimately linked to the production of lactate and energy. In response to hypovolemia and acidosis, adrenal medullary and cortical hormones are released. Cortisol not only aids in vasoconstriction but also promotes glucose release in large quantities to combat essential cellular starvation as a result of hypoperfusion. Insulin is suppressed, favoring glucose utilization as opposed to storage. Insulin-independent GLUT membrane proteins allow for transport of glucose to vital organs such as the heart, kidneys, brain, and others and thus provide an increased energy source. However, lactic acidosis will continue in the absence of adequate oxygen delivery. Hyperglycemic deleterious effects are far reaching and include increased infection and elevated intracranial pressure. Regarding direct correlation to hemorrhagic shock, however, hyperglycemia may result in osmotic diuresis despite decreased renal blood flow and glomerular filtration rate augmented by renin-angiotensin-aldosterone system activation, thereby worsening the already depleted intravascular volume. Growth hormone and glucagon add to this process because they promote lipolysis and glycogenolysis.

Immunologic

Hemorrhagic shock results in a multitude of immune responses related to the upregulation of cellular signaling designed to protect, but often result in harm. Extensive research in the last decade has shown that hemorrhagic shock activates inflammatory cascades, resulting in profound abnormalities. The effect of immunologic dysregulation is often manifested by a spectrum of clinical problems, including acute respiratory distress syndrome (ARDS), systemic inflammatory response syndrome, coagulation abnormalities, and multiple organ dysfunction syndrome (MODS). Cytokines such as IL-1, IL-6, tumor necrosis factor α, cellular signaling pathways involving toll-like receptors, and microRNA have all been implicated.[19] However, there have been no clear data regarding which of the many involved substances plays the key role in development and propagation of the overactive inflammatory response. One of the major areas of study involves the activated immune response that results in enhanced activation and adhesion of leukocytes. During this activated stage, neutrophils can release harmful reactive oxygen species, which are thought to play a major role in loss of capillary integrity. This leads to edema and the sequestration of fluid in the tissues and the interstitial space. Additionally, immunologic responses to therapy, specifically large-volume crystalloid infusion, may trigger the altered immune response to hemorrhage and has been a growing area of research.[20]

SHOCK RECOGNITION

Early recognition of hemorrhagic shock is essential to prevent mortality. Aside from blatant exsanguination, hemorrhagic shock can be difficult to define in its early stages. A high index of suspicion is necessary for prompt, accurate diagnosis. Probable mechanisms of hemorrhagic shock must be thoroughly and rapidly examined and treated.

Every patient who is at risk for hemorrhage should be evaluated through methods delineated in the Advanced Trauma Life Support program. By quickly proceeding through the primary survey (evaluation), immediate life threats are recognized and can be treated.[1] This presents a departure from traditional methods of initial patient evaluation of taking a long, thorough history from the patient, discussing options, and planning a workup. A hemorrhaging patient does not have the luxury of time, and delayed recognition of shock often results in death. Immediate threats to life must be identified early, and minor injuries or findings must not derail the primary goal of addressing potentially lethal matters.

No one feature results in the diagnosis of hemorrhagic shock. Basic physical examination skills utilized in context often form a clinical impression that leads to the diagnosis. Heart rate and blood pressure, which are often used in the incorrect definition of shock, may be normal. β-Blockers, untreated

hypertension, and physical fitness may confound interpretation of hemodynamic normalcy. A narrowed pulse pressure, however, is typically present, and often missed owing to a normal systolic value. Anxiety or belligerence may be a sign of shock and can easily be confused for intoxication or isolated brain injury. Decreased mental status should be considered an ominous sign of impending decompensation. Cool, clammy extremities in a patient at risk for shock are clinical markers for peripheral vasoconstrictive compensation. Pallor may also be present and, in an otherwise healthy patient, should invoke a sense of urgency. Hypothermia, a key component of the lethal triad (hypothermia, coagulopathy, acidosis) is an independent predictor of mortality in hemorrhaging patients.

Exhaustive laboratory studies are often unhelpful, especially in the early stages of shock. For example, hemoglobin and hematocrit levels are frequently normal, because the laboratory result is a measure of concentration—which remains unchanged until compensatory mechanisms and interstitial to intravascular fluid shifts have occurred. However, when a hemoglobin level of less than 11 g/dL is present, it is associated with a mortality rate of nearly 40%.[21] Most patients with hemorrhagic shock were physiologically normal prior to the offending insult. This makes the arterial blood gas quite useful, because any acid-base abnormality can be presumed to be caused by the event that brought the patient to the hospital, and not underlying medical conditions. Patients with a base deficit (BD) greater than 6 are at higher risk of mortality and the need for massive transfusion. Severity of injury and mortality is linearly associated with the degree of the initial coagulopathy, and an international normalized ratio (INR) of greater than 1.5 reliably predicts the need for massive transfusion.[10,22] Tissue oxygen saturation continues to be investigated as a simple, reliable, and early marker of the presence of hemorrhagic shock.[23]

Adjuncts to the clinical examination include very few imaging studies. For the injured patient, chest and pelvic radiographs may be of great utility because they can help identify major hemorrhage in two of the five key locations where deadly hemorrhage may occur. The Focused Assessment with Sonography for Trauma (FAST) is utilized to identify tamponade, hemothorax, pneumothorax, and intraperitoneal hemorrhage. Long-bone fractures are often readily identified. In nontrauma cases, a nasogastric tube may be inserted for suspected gastrointestinal hemorrhage to aid in localization. Endoscopy and interventional radiologic methods may also be employed emergently as conditions warrant.

Those patients who transiently respond to volume administration should undergo expeditious reevaluation to localize the cause of hemorrhage. Transient response conveys ongoing hemorrhage and beseeches health care providers to act quickly to obtain hemorrhage control.

Shock scoring systems may aid in the clinical diagnosis of hemorrhagic shock when uncertainty exists. Many studies of hemorrhagic shock identification scoring systems use the necessity for transfusion as the outcome of interest. The Emergency Transfusion Score involves the use of nine markers, with a weighted coefficient assigned to each marker. For example, a systolic pressure of <90 mm Hg carries the most weight, at 2.5 times higher than mechanism of injury. The Trauma-Associated Severe Hemorrhage (TASH) system was developed in Germany and incorporates many of the clinical features described earlier, in addition to BD and hemoglobin. The TASH has been shown to reliably predict the need for massive transfusion.[24] A simplified method of identifying the probability of life-threatening hemorrhage was developed from military experience. Tachycardia, hypotension, acidosis, and acute anemia are all independent risk factors for the need of massive transfusion. When all four are present, approximately 80% of patients will require massive transfusion. The validity of this model, however, rests on a weighted evaluation, with pH carrying the most value, and thus is difficult to rapidly calculate.[25] The ABC score was developed to eliminate the need for laboratory results to rapidly determine the presence of hemorrhagic shock and to predict the need for massive transfusion. Four components (penetrating mechanism, systolic pressure <90 mm Hg, heart rate >120 beats per minute, and positive FAST), each with equal weight make up the ABC score. Patients with all four variables present have a near 100% need for massive transfusion.[26]

Utility of Ultrasonography for Diagnosis of Hemorrhagic Shock

As discussed earlier, early control of the site of bleeding is an essential part of the management of hemorrhagic shock. Source control requires identification of the source of bleeding. Ultrasonography has utility for this purpose, because it can be deployed at the point of care for urgent evaluation of the critically ill patient. Ultrasonography has the advantage of immediate application by the frontline clinical team who can integrate the results of the examination into the other key elements of emergency evaluation: the history, physical examination, and initial laboratory results. This is not to discount the importance of advanced imaging techniques, such as computed tomography (CT) or

angiography; yet, these suffer the disadvantage of some inevitable delay in their performance and require patient transport to areas where resuscitation techniques are limited, further adding risk to the patient.

The ultrasonography examination is performed by a member of the trauma team while other key elements of initial resuscitation are ongoing. Modern bedside ultrasonography machines are small enough that they can be brought to the bedside without blocking access to the patient by other members of the trauma team. The machine has multiple uses beyond examination for life-threatening hemorrhage, such as vascular access, airway management, and assessment for alternative causes for shock.

EXAMINATION FOR INTRA-ABDOMINAL HEMORRHAGE

The FAST examination utilizes ultrasonography to rapidly identify an intra-abdominal source of bleeding. It has replaced diagnostic peritoneal lavage as the technique of choice for management of abdominal trauma and is standard practice for evaluation for intra-abdominal bleeding in trauma.[27]

SCANNING TECHNIQUE

A phased array cardiac probe on abdominal preset gives serviceable images. If available, a curvilinear abdominal probe is used. The hepatorenal and splenorenal spaces are imaged in longitudinal axis to look for fluid collecting along the retroperitoneal surface, between the intra-abdominal viscera. On the right side, the probe is placed in the midaxillary line on the lower chest wall in order to obtain a transcostal view of the liver in a coronal imaging plane. Once the appropriate intercostal space is found, the probe is angled and tilted to achieve a clear image of the hepatorenal space. The presence of fluid is taken as an indication of intra-abdominal bleeding (Video 12.1). The examiner also checks for prehepatic fluid and, using the liver as an acoustic window, examines the subdiaphragmatic space for fluid. Video 12.1 describes and illustrates the components of the FAST examination with examples of fluid found in each of the areas in a routine study. The scan is repeated on the left with examination of the splenorenal, presplenic, and subdiaphragmatic spaces (Video 12.1). The operator then checks for pelvic fluid. The probe is placed just above the level of the iliac crest in the midline using a transverse scanning plane and angled downward through the bladder to search for fluid in the pelvis (Video 12.1). Pelvic fluid indicates an intra-abdominal source of bleeding in the patient with hemorrhagic shock. Some examiners include examination of the right and left lower lateral abdominal quadrants to the FAST examination. The FAST examination includes the subxiphoid view of the heart (subcostal long-axis view) in order to exclude hemopericardium and pericardial tamponade. Intravascular volume status may also be assessed by examining both the IVC respirophasic changes, and cardiac filling. Hypovolemia is suggested when the left ventricle appears hyperdynamic. Additionally, decreased filling pressures may result in relatively small atria and increased ejection fraction (Video 12.1). The subxiphoid view of the inferior vena cava (IVC) is included to examine for IVC size and respiratory variation. The presence of a small diameter IVC or respirophasic variation of IVC size suggests hypovolemia.

Case 1

An elderly woman acutely develops severe respiratory distress and is brought to the emergency department.[28] She has a history of diabetes, hypertension, and cirrhosis but was feeling well until today. On physical examination, she has a distended abdomen and after endotracheal intubation she develops shock. Because of her hypotension, the clinicians feel that she is too unstable for transport for CT of her chest and abdomen. POCUS is performed to determine the etiology of her sudden cardiopulmonary failure. ***Based on her clinical history and the findings presented in Videos 12.2 and 12.3,[28] what is the likely etiology of this patient's cardiopulmonary failure?*** *Video 12.4 describes the findings and discusses their clinical relevance.[28]*

The FAST examination can be performed rapidly. If initially negative, it can be repeated as clinically indicated. In the presence of hemorrhagic shock, a positive examination indicates intra-abdominal bleeding and the need for urgent source control.

EXAMINATION FOR HEMOTHORAX

The extended FAST examination uses elements of thoracic ultrasonography to evaluate the patient with hemorrhagic shock for hemothorax. In addition, the examination has utility to examine for pneumothorax, pericardial effusion, and pericardial tamponade on an emergency basis.

SCANNING TECHNIQUE

With the patient in supine position, fluid will distribute in the dependent thorax owing to gravitational effect. On both the right and left sides, the probe is placed in the midaxillary to posterior axillary line on the chest in a coronal imaging plane and moved over adjacent interspaces to examine for fluid. The examination for pleural fluid may be performed by extending the scan performed for intra-abdominal fluid to the area above the diaphragm. The finding of significant pleural fluid in a patient with hemorrhagic shock indicates hemothorax and the need for consideration of urgent source control (▶ Video 12.1).

Case 2

A young man was diagnosed with bilateral pulmonary emboli, a right lower lobe pulmonary infarct, likely secondary to a new diagnosis of acute myeloblastic leukemia.[29] He was started on induction chemotherapy. On day 3 of chemotherapy, he developed acute onset of right-sided chest pain, hypoxemia, and a drop in his hemoglobin level. POCUS is performed. ***Based on your interpretation of the ultrasound images presented in ▶ Video 12.5,[29] what is the likely diagnosis?*** *▶ Video 12.6 presents description of the findings and their clinical interpretation.[29]*

EXAMINATION FOR RETROPERITONEAL BLEED

Retroperitoneal bleeding is a potential cause of hemorrhagic shock that may be difficult to identify by physical examination. Ultrasound examination of the retroperitoneum is also limited and has a high false-negative rate. For this reason, in patients who present in hemorrhagic shock with no identifiable cause, a retroperitoneal source should be considered, and expedient CT or angiographic evaluation or an operative intervention should proceed in instances where a high index of suspicion exists.

SCANNING TECHNIQUE

The probe is used to examine the flank area bilaterally. Using a coronal scanning plane, the probe is moved over the flank. Identification of retroperitoneal fluid collection indicates retroperitoneal bleeding and the urgent need for consideration of source control (▶ Video 12.1).

Case 3

An elderly man with a recent history of a left middle cerebral artery stroke secondary to an aortic fibroelastoma was admitted to the hospital for progressive left lower extremity weakness and aphasia.[30] Reimaging of the brain revealed multiple new territorial infarcts thought to be cardioembolic from the fibroelastoma. He was started on anticoagulation. He subsequently developed shock, respiratory failure, and declining hemoglobin level from 13.2 to 6.0 g/dL. ***Esophagogastroduodenoscopy was normal and a POCUS examination was performed. ▶ Videos 12.7 and 12.8[30] present images obtained from his right and left flank areas, respectively. Based on your review of these images, what is the likely diagnosis?*** *A discussion of their findings and their clinical implications is presented in ▶ Video 12.9.[30]*

LIMITATIONS OF ULTRASONOGRAPHY

Ultrasonography readily identifies fluid collections. In hemorrhagic shock, the trauma team may reasonably assume that the fluid represents hemorrhage and take action based upon this supposition. If the patient is unstable, this may result in early surgical intervention. If time permits, the finding may lead to further imaging with CT scan or angiography; if an interventional radiology approach seems appropriate.

Patient-specific characteristics such as obesity and edema may degrade the ultrasonography image. This is most likely to occur when imaging the retroperitoneum. Competence in scanning during emergency situations, such as for the evaluation of hemorrhagic shock, requires effective training for competence[31] because inaccurate results may have severe consequence in the unstable patient.

Perhaps the greatest limitation of using ultrasonography to identify sources of hemorrhagic shock is misinterpretation of a negative result. Patients who exhibit signs of hemodynamic compromise related to hemorrhage may have a completely normal ultrasound examination.[32] When this occurs, providers should resist being lulled into complacency based upon the negative imaging examination and must remain vigilant to ensure rapid hemorrhage control is obtained.

Despite these limitations, ultrasonography is an effective tool for the initial and ongoing evaluation of the patient with hemorrhagic shock. It can be fully integrated into the team effort at the bedside, and it gives immediate and valuable clinical information. As such, it is an essential component of the imaging strategy for the evaluation and management of hemorrhagic shock.

Case 4

A middle-aged man with cirrhosis was admitted with hepatic encephalopathy and treated with lactulose with resolution of delirium.[33] His hospital course was complicated by recurrent encephalopathy. He developed shock and had worsening abdominal distention. There were no overt signs of gastrointestinal bleeding. His hematocrit had decreased from 37.2% to 26.3% and he had a markedly elevated lactate level. POCUS was performed to try and identify the etiology of the acute anemia. In anticipation of endotracheal intubation left upper quadrant ultrasound was performed. ***Based on our interpretation of the ultrasound images presented in Videos 12.10-12.12,[33] what is the likely etiology of this patient's acute anemia?*** *Their findings and clinical implications are presented in Video 12.13.[33]*

HEMORRHAGE CONTROL

Obvious external hemorrhage is controlled first by manual pressure. Pressure is the force applied per unit area. To effectively control hemorrhage with direct pressure, one must limit the area over which it is applied. For example, a finger placed deliberately is often more efficacious than two hands placed over a large surface.

Tourniquets have seen increasing use in both civilian and military populations in recent years. Commercially available tourniquets are simple to apply with minimal training, are lightweight, and effective at controlling extremity hemorrhage. Tourniquets should be utilized in the way they were designed, to occlude arterial hemorrhage. Isolated venous occlusion, without arterial cessation of hemorrhage, will worsen blood loss.[34] Junctional hemorrhage, occurring high in the groin, for example, is often difficult to control with pressure or tourniquets alone and, typically, requires emergent surgical intervention. However, adjuncts such as the junctional emergency tourniquet system may be useful for some patients.[35]

Local hemostatic agents are widely available and have shown promise in controlling both external hemorrhage, and organ bleeding encountered in the operating suite. Topical hemostats are typically constructed of bioabsorbable material with the addition of thrombin and/or fibrin and are available in a variety of application constructs. Polymerized sprays, injectable foam, and biologic sheets are among the many methods available. Cost and local availability often dictate which product may be utilized. It is important to avoid intravascular injection or placement of these products, because embolization is a risk.

Noncompressible torso hemorrhage has been identified as a major cause of death both in military and civilian studies.[36] Few techniques other than surgery are available to address noncompressible hemorrhage, such as bleeding in the abdomen, retroperitoneum, or chest. It is important to recognize that these techniques are temporizing measures in lieu of definitive hemorrhage control. Resuscitative thoracotomy, although effective for ceasing torso hemorrhage, is associated with high mortality rates and is frequently impractical for the general physician to successfully accomplish. Resuscitative endovascular balloon occlusion of the aorta was first described over 50 years ago and has seen increased use recently. It involves advancing and inflating an endovascular balloon into the aorta via percutaneous femoral artery access. This can be accomplished in the emergency department with minimal equipment and has been shown to be effective at controlling torso hemorrhage.[37] Self-expanding polyurethane foam, injected through percutaneous techniques intraperitoneally, has shown promise and efficacy. The liquid polymer rapidly expands, conforming to intra-abdominal anatomy and stopping hemorrhage. The foam is then removed at the time of surgery. Studies are currently underway to further characterize this technique.[38]

Surgical control of hemorrhage is beyond the scope of this chapter; however, it warrants mention. Once hemorrhagic shock is identified, immediate control of hemorrhage must be undertaken. Delaying definitive care with exhaustive radiologic or laboratory studies is unwise. At centers without surgical capabilities, rapid transport to a tertiary facility, when hemorrhage is suspected, is safer than definitively identifying the source of that hemorrhage. Control in the operating room or angiography suite is crucial to avoid death, and initial evaluation and management should effectively move toward that goal.

Systemic adjuncts for controlling hemorrhage in the presence of coagulopathy may be utilized to help normalize coagulation disturbances and avoid ongoing bleeding. Many of these pharmacologic adjuncts are utilized off-label; however, significant data exist to support their use in certain situations. Prothrombin complex concentrates, initially developed to treat isolated congenital factor deficiencies, provide rapid, effective correction of factor-based coagulation disruptions. Three-factor (factors II, IX, and X) and four-factor (factors II, IX, X, and VII) varieties are available and are associated with minimal adverse events.[39] Recombinant factor VIIa has been associated with normalization of conventional coagulation tests, and decreased transfusion requirements.[40] Anti-inhibitor binders have also been utilized in specific circumstances, such as coagulopathy in the presence of novel anticoagulants. Recently, a dabigatran-specific antibody fragment has been released. Prior to the inception of idarucizumab, no method of therapeutic reversal was available for patients anticoagulated with dabigatran.[41] Currently, several agents are being developed to target coagulopathy resultant from factor Xa inhibitors, direct thrombin inhibitors, and other novel mechanistic medications.

Tranexamic acid, an antifibrinolytic, arose to the forefront of pharmaceutic hemorrhage control after the release of the CRASH-2 trial.[42] This study showed significant reductions in mortality. Subsequent studies confirmed its efficacy, and it is now frequently utilized as an adjunct during resuscitation of hemorrhagic shock.[43-45] Its efficacy, low cost, and wide availability make tranexamic acid an attractive adjunct to hemostatic control.

HISTORY OF HEMORRHAGIC SHOCK RESUSCITATION

The modern-day trauma system owes a large debt to combat casualty care. Techniques from system development to operating room procedures have their roots in battlefield medicine. Resuscitation is no stranger to advancement during wartime as well. To understand the advancements made and differences that exist with modern combat resuscitation strategies, it is important to understand the history of combat resuscitation.

Empiric crystalloid administration owes its roots to strategies developed in the Vietnam War. Based on research by Shires,[46,47] Dillon,[48] and others, the need for volume resuscitation was brought to the forefront to replace an interstitial volume debt, secondary to intravascular movement in hemorrhagic shock. High-volume crystalloid resuscitation strategies were used to replace volume loss encountered by the bleeding soldier in ratios of 3:1 to as high as 8:1. The physiology was sound, but outcomes were disappointing, as survival rates did not improve. In fact, the adopted strategy of large-volume IV fluid administration spawned its own set of complications, most notably the emergence of Da Nang lung, known now as ARDS. Reports linking ARDS to crystalloid resuscitation and subsequent immunologic effects appeared as early as 1967.[49]

Despite this, massive volume resuscitation strategies prevailed for more than 30 years. In the early 1990s, Rotondo and colleagues published the first major data on damage control surgery, employing early, rapid hemorrhage control, and temporizing measures to avoid the effects of ongoing massive resuscitation related to prolonged operative escapades.[50] This sparked a fury among traditionalists, but led to a series of manuscripts debunking the idea of benefit associated with large-volume resuscitation.

A report by the Institute of Medicine in 1999, as well as two consensus conferences held by Office of Naval Research, the US Army Medical Research and Material Command and the Uniformed Services University of Health Sciences, in 2001 and 2002, addressed concerns of resuscitation techniques, further delineating the adverse effects of large-volume resuscitation and giving recommendations for alternative strategies. First noted was the paucity of level I and II data to support the then standard of care. Second, the immunologic activity of common IV fluids and deleterious effects of high-volume resuscitation were best defined by complications related to their use. Third, the reports supported the initial battlefield use of low-volume hypertonic saline (HTS) resuscitation.[51] A 250-mL bolus of HTS was chosen based on research showing decreased neutrophil activation as well as increased oncotic properties. Fourth, triggers for fluid resuscitation were defined as systolic blood pressure <80 mm Hg or the absence of palpable radial pulse, decreasing blood pressure, or altered mental status with no confounding brain injury.[52] This protocol allowed for "permissive hypotension" during resuscitation until definitive hemorrhage control. The goal was not to return blood pressure to normal, but rather to target clinical goals of mentation and palpable pulse. These protocols were developed with several civilian trauma studies in mind, showing survival benefit to limited initial resuscitation.[53] The combination of a large number of studies near the turn of the millennium ultimately culminated in a complete 180° shift from the high-volume crystalloid resuscitation seen in the Vietnam War. Currently, an injured soldier with a palpable pulse and is awake and alert will have an IV placed, but no volume will be infused. Oral hydration is encouraged, and rapid evacuation is undertaken. If fluids are given, they are in low volume and hypertonic in nature.

The concept is simple—without effective hemostasis, no amount of resuscitation will affect a mortality benefit. In the Iraq and Afghanistan Wars, the goal of resuscitation changed—from early volume resuscitation to early hemorrhage control. With this objective highlighted, tourniquets were reintroduced, and pharmaceutic adjuncts like recombinant factor VIIa and tranexamic acid were added to the armamentarium to aid cessation of hemorrhage.[44]

Rural, marine, or mountainous areas typically require longer transport times and represent some of the civilian austere environments. In these scenarios, much of the same wisdom gained from combat research should be utilized, with minimal prehospital resuscitation prior to arrival at definitive care. Once arriving at the tertiary facility, however, resuscitation may begin with the same tenant—crystalloid resuscitation is a thing of the past. Blood component therapy is now utilized early, rather than after several liters of lactated Ringers or saline. Higher ratios of plasma to red blood cells (RBCs) have been a point of study in recent years, with ratio of 1:1 showing improved outcomes.[54] The evidence supporting the value of replenishing specific blood components early in hemorrhagic shock resuscitation is convincing.

INITIAL RESUSCITATION

Previously, initial resuscitation of hemorrhagic shock involved large-volume fluid resuscitation and maintenance of normothermia. Although these methods aimed to address two of the three components of the lethal triad, coagulopathy was largely ignored. Today's resuscitation techniques specifically target the coagulopathy of hemorrhage through the concept of damage control resuscitation.

Damage control resuscitation focuses on several key goals and begins immediately upon arrival to the emergency department. The first of which is to maintain a slightly lower-than-normal systolic blood pressure of approximately 90 mm Hg. This serves to limit clot disruption by allowing some degree of stasis to occur, increasing the chance for clot development, and strengthening. Peripheral vasoconstriction is preserved, and perfusion to vital organs is increased with permissive hypotension. Conversely, large amounts of IV fluids will reverse peripheral vasoconstriction and, without hemorrhage control, will ultimately worsen blood loss. Excessive or misdirected fluid resuscitation to achieve normal hemodynamics will lead to dilution of existing clotting factors, aggravating coagulopathy and exacerbating hemorrhage. The benefits of permissive hypotension were first recognized, and eloquently described, over 100 years ago by W.B. Cannon. His observations of the deleterious effects of copious volume

resuscitation prior to hemorrhage control persist today. The current evolving hypotensive resuscitation literature continues to show improved mortality and morbidity in both traumatic and nontraumatic bleeding events.[55]

Second, damage control resuscitation directly addresses the coagulopathy of hemorrhage. Fluid resuscitation commences with blood component therapy. As described earlier, crystalloids lack the essential elements necessary to combat the coagulopathy of hemorrhage and are evidenced to exacerbate inflammatory dysregulation. Coagulopathy and inflammation are suppressed through administration of early plasma and platelets. These components also provide volume resuscitation, thus achieving both the first and second goals of the initial resuscitation. For patients in hemorrhagic shock, directly addressing hyperfibrinolysis is accomplished with tranexamic acid, which is most efficacious within 3 hours of injury. It acts to compete with plasmin, blocking fibrinolysis. Other antifibrinolytic pharmaceuticals are available, such as ε-aminocaproic acid. Concentrated clotting factors, such as prothrombin complex concentrates and recombinant factor VIIa, have the benefit of rapid repletion of essential clotting elements, with the effects within minutes of infusion, and should be considered in severely injured or hemorrhaging patients.

Third, blood component therapy serves not only to maintain the above state of permissive hypotension while replenishing the stores of circulating procoagulants but also to optimize oxygen delivery in the interlude prior to, and during surgical, endoscopic or interventional hemorrhage control. Increasing oxygen delivery through augmentation of the blood's oxygen-carrying capacity with red cells minimizes tissue oxygen debt in the setting of compromised circulation more so than crystalloid preparations. By relieving oxygen debt through increased oxygen delivery, acidosis is quelled because aerobic metabolism is supported, and lactate production is limited. Decreased acidosis is crucial for normal global cellular and enzyme function.

Although there are clear benefits to blood component resuscitation, the optimal ratio of blood component therapy continues to be studied. A variety of ratios (fresh frozen plasma [FFP]:PLT:RBC) exist to closely mimic the constituents of whole blood transfusion, which, in civilian centers, is rarely available. Early platelet and plasma administration have been associated with decreased mortality. In the PROMMTT study, investigators noted a three- to fourfold increase in mortality in patients who received a 1:2 (FFP:RBC) transfusion ratio in the first 6 hours, as compared to those who received a 1:1 transfusion ratio.[56] This large, multicenter study showed clear benefit of early plasma initiation in the setting of hemorrhagic shock. More recently, Holcomb and colleagues tested the differences between 1:1:1 and 1:1:2 (FFP:PLT:RBC) ratios, and found equivocal mortality rates at both 24 hours and 30 days between the two. However, fewer deaths from exsanguination were noted in the 1:1:1 group.[54] Early, high-ratio transfusion of plasma and platelets not only aids in correction of coagulation dysfunction but also restores volume with necessary coagulation components shed during hemorrhagic shock.

Massive transfusion protocols have been widely adopted at both major centers and smaller hospitals. Development of these protocols has been associated with lower mortality rates. Although the term "massive" implies a greater volume of products, multiple studies have shown decreased overall product usage when these protocols are effectively utilized early in the resuscitation. Several reasons exist to explain this somewhat paradoxical finding. First, by limiting crystalloid resuscitation, blood loss is lessened and dilutional coagulopathy is curbed, which ultimately will result in less product transfusion. Second, early activation allows for efficient optimization of the tenets of damage control resuscitation, resulting in less acidosis, improved organ function, and less blood loss while hemorrhage is controlled. Third, for a patient presenting with hemorrhagic shock, predetermined massive transfusion protocols offer a streamlined method of delivering product to the patient while assuring that appropriate component ratios are maintained. Some published indicators for massive transfusion include[57] (1) INR >1.5, (2) BD >6, (3) systolic blood pressure <90 mm Hg, (4) hemoglobin <11 g/dL, (5) heart rate >120, and (6) positive FAST scan. The more of these factors that are present, the more likely the patient should undergo massive transfusion, with early plasma administration in a fixed-ratio paradigm.

Damage control resuscitation strives to reach a balance between achieving optimal physiologic function, while limiting the unwanted effects of the resuscitation itself, and is most useful from the time of presentation through the period of definitive surgical, endoscopic, or interventional hemorrhage control. It must expeditiously be initiated upon arrival in the emergency department, often with limited information. Prolonged resuscitation should not delay definitive hemorrhage control in order to achieve distant hemodynamic or physiologic goals. Time spent in the emergency department equates

to lost time in the operating room, endoscopy, or interventional suites where damage control resuscitation may be continued, and decisive hemorrhage control obtained. The initial phase continues through the operative intervention, and damage control principles are upheld by targeting the above physiologic goals. To this end, damage control *surgery* is often performed, which consists of surgical hemorrhage control, limitation of contamination, and temporary closure, deferring definitive repair of non–life-threatening injuries until physiologic correction is achieved in the intensive care unit (ICU) in the second resuscitative phase.

ONGOING RESUSCITATION

While initial resuscitation of hemorrhagic shock is to serve as a bridge to operative, interventional, or endoscopic hemorrhage control, ongoing resuscitation following hemorrhage aims to restore normal physiologic parameters to ensure adequate oxygen delivery to resume normal bodily functions once hemorrhage has ceased. Despite effective damage control resuscitative measures, patients often exhibit varying degrees of physiologic instability in the ICU. Similar principles exist in the ongoing resuscitative phase, which is typically undertaken in the ICU. Patients arriving from the operating theater may remain hypovolemic, coagulopathic, hypothermic, and acidotic, necessitating further intensive management to achieve a successful resuscitation. Endpoints of resuscitation should be aggressively targeted in this phase to ensure rapid resolution of metabolic derangements that may have occurred during the preceding interventions.

Endpoints of Resuscitation

Traditional endpoints of resuscitation, such as heart rate, blood pressure, and urine output, are grossly inadequate as sole markers of physiologic normalization. Although these common methods provide insights into the overall clinical picture, they fail to accurately demonstrate resuscitation success. Confounding variables abound when considering these easily attainable, yet simplistic determinations. For example, heart rate is altered by a variety of mechanisms that may be unrelated to the adequacy of resuscitation. Pain and anxiety commonly cause tachycardia, whereas the widespread use of β-blockers and other cardiac medications may prevent it—rendering heart rate less useful. Urine output has long been utilized as an endpoint signifying the adequate restoration of perfusion to an end organ. However, oliguria may be present despite completion of resuscitation. CT evaluation is ubiquitous and often utilizes IV contrast, which commonly results in acute tubular necrosis despite aggressive resuscitation. Medications, specifically antibiotics, are known to cause acute interstitial nephritis. Additionally, the initial hypoperfusion event may have caused direct tubular injury resulting in oliguria, despite adequate resuscitation. Managing oliguria with large volumes of resuscitation fluid will inevitably result in the undesirable consequences of over resuscitation. Conversely, entities such as diabetes insipidus and cerebral salt wasting cause polyuria and may falsely reassure the clinician.

Hemorrhagic shock occurs as the result of hypoperfusion, and thus markers of hypoperfusion should be sought as valid endpoints. An arterial blood gas is commonly touted as the most beneficial laboratory test in the resuscitation of a patient in hemorrhagic shock because of the rapid, comprehensive information gained, including BD. The BD assumes a normal pCO_2, which is a crucial point to consider, because it allows for the true metabolic derangement to be elucidated. Clinicians typically examine the pH and may miss significant acidosis, especially if the patient is compensating with tachypnea. For this reason, the BD is a test that requires virtually no analysis, and provides a simple number that, in hemorrhagic shock, is an accurate marker of perfusion. Through the mechanisms described earlier in this chapter, acidosis results as a function of hypoperfusion and anaerobic metabolism at the cellular level. As this acidosis worsens, BD becomes more negative. An initial BD less than 6 is associated with the need for massive transfusion and damage control resuscitation practice implementation. Similarly, a persistent BD following hemorrhage control suggests the need for further resuscitation. Multiple studies have shown benefits of using the BD as an endpoint of resuscitation.[58,59] The goal should be a rapid normalization of the BD. Decreased mortality is associated with normalization of the BD within the first 24 hours of hospitalization. Some issues with BD warrant mention, however. If sodium bicarbonate is employed in the initial resuscitation phase, the BD becomes useless, secondary to the addition of exogenous base to the equation. Only in the most severe acidosis cases should bicarbonate even be considered. Another relative indication for

bicarbonate administration is to increase the effectiveness of resuscitation adjuncts, such as prothrombin complex concentrate or recombinant factor VIIa, which have decreased efficacy below a pH of 7.2. The BD may be confounded by other acidotic states, such as hyperchloremia, which is typically iatrogenic in nature. Additionally, BD often lags behind the resuscitation, and its continued pursuit may lead to overresuscitation. When the BD persists, the presence of a missed injury or ongoing causes for hypoperfusion should be reviewed.

To counter the issues associated with BD, serum lactate is employed. In the setting of acute hemorrhagic shock, increases in lactate are the result of tissue and cellular mitochondrial dysfunction, and thus lactate provides insights into tissue perfusion. Parallel physiologic hypoperfusion mechanisms will cause the level of lactate to increase, secondary to anaerobic metabolism. Similar to BD, lactate clearance within 24 hours has been shown in many studies to be associated with lower mortality rates.[60,61] Several societies have incorporated lactate into their resuscitation guidelines, including the Society of Critical Care Medicine and the Eastern Association for the Surgery of Trauma; and an internal consensus conference on hemodynamic monitoring has recommended utilization of lactate clearance as an endpoint of resuscitation. Lactate clearance is affected by hepatic function, and, for those patients with either underlying or acute hepatic insufficiency, elevated lactate concentrations may persist secondary to decreased clearance by the liver and may be misleading in these circumstances. Some have further criticized the ability of lactate levels to determine perfusion adequacy by citing the multiple *aerobic* processes, including glucose utilization in the setting of hyperglycemia, as potential nonperfusion-related causes for hyperlactatemia. However, many consider lactate one of the most useful endpoints in the resuscitation of hemorrhagic shock.

Adequate tissue perfusion depends upon both oxygen delivery and tissue oxygen demand. This supply-demand relationship can be determined by examining central venous oxygen saturation ($ScvO_2$) measurement from a central venous catheter. Normal physiologic conditions incur approximately 25% oxygen extraction at the tissue level, resulting in a $ScvO_2$ of 75%, given an arterial saturation of 100%. When tissue demand increases, or oxygen delivery decreases, as in hemorrhagic shock, more oxygen is extracted, decreasing $ScvO_2$. $ScvO_2$ has been shown to be a marker of both fluid responsiveness and reinstatement of normal perfusion.[62] By restoring normal cardiac output with volume administration, preload and afterload optimization, and inotropic support, the delivery component of $ScvO_2$ is corrected. Complexity arises, however, in addressing the demand component of $ScvO_2$. Peripheral vasoconstriction, as described earlier, is a compensatory mechanism in the face of hypovolemia. This vasoconstriction ultimately leads to decreased tissue oxygen extraction and a rising $ScvO_2$. Conversely, in hemorrhagic shock, tissue oxygen demand and concomitant extraction are typically increased secondary to tissue-level hypoxia, resulting from acute hypovolemia and hypoperfusion. Increased oxygen extraction in response to hemorrhage leads to a delivery-dependent state and declining $ScvO_2$. These two competing forces have resulted in an argument against the efficacy of $ScvO_2$ as a resuscitation marker and work to confuse the interpretation of $ScvO_2$. Despite these intricacies, $ScvO_2$ remains an endpoint of interest, and abnormal elevations or decreases in $ScvO_2$ should prompt the clinician to adjust resuscitation based on results.

In hemorrhagic shock, restoration of normal oxygen delivery (DO_2) is the ultimate goal, making this calculated value extremely useful for determining sufficiency of resuscitation. The equation is defined as the product of arterial oxygen content and blood flow and involves three main components: cardiac output, hemoglobin, and oxygen saturation (SaO_2). The contribution of partial pressure of oxygen is negligible and is often omitted in bedside calculations of DO_2. With the equation, we simplify the concept of perfusion, by separating it into two main determinants—flow and content. To address arterial oxygen content, first the SaO_2 is optimized through oxygen administration, increased FiO_2, or through ventilator methods to increase oxygenation. Hemoglobin is then optimized, keeping in mind the clear benefit of restrictive transfusion strategies shown in virtually all patient populations. Next, flow is maximized via optimization of cardiac output, which typically equates to targeting stroke volume through ongoing resuscitation or application of inotropic agents. Through these methods, normalizing oxygen delivery represents a valid and complete endpoint of resuscitation for hemorrhagic shock. Like the endpoints described earlier, DO_2 is not without limitation. In states of decreased tissue oxygen extraction, DO_2 may not coincide with cellular perfusion. Additionally, advanced monitoring is required to obtain stroke volume measurement, and depending upon the device used, significant error may be introduced into the equation.

Coagulation Endpoints

Many damage control resuscitation measures are directed at controlling the early coagulopathy of hemorrhage. The ongoing phase of resuscitation continues this focus. Conventional coagulation tests are helpful and provide insight into ongoing coagulopathy. Considering the above endpoints, the clinician should consider normalizing coagulation function with plasma, platelets, cryoprecipitate, or pharmacologic means. Understanding each of the blood components and when to utilize them is crucial in the resuscitation of hemorrhagic shock. TEG and rotational thromboelastometry (ROTEM) have gained wide acceptance over the last decade owing to the ability to help guide resuscitation and serve as a set of endpoints specifically relating to the coagulopathy associated with hemorrhage. Developed in 1948 to detect congenital factor deficiencies, this technology has broadened its use to hemorrhage of all types. TEG is a dynamic test that measures both the formation and lysis of the clot. Results are presented graphically and numerically and allow for a global assessment of clotting function, by illuminating abnormalities at specific sites in the clotting cascade and offering detailed information regarding coagulation function.

TEG and ROTEM share many similarities; however, the nomenclature differs between the two. Abnormalities in clot initiation are measured by R value (time to clot initation) (TEG) or CT (Clotting Time) (ROTEM). Clot initiation is dependent upon clotting factors. Therefore, a prolonged R or CT value corresponds to a deficiency in clotting factors. Prolongations are commonly seen with anticoagulant use and in the presence of factor inhibitors. Therapies include plasma transfusion, prothrombin complex concentrates, and recombinant factor VII. As the clot develops, the tracing diverges and becomes parabolic in shape. The initial angle of this divergence is known as alpha (α). The α corresponds to the rapidity of clot development and is mainly dependent upon fibrinogen, with a minor role played by platelets. A steep angle indicates overly rapid clot development, whereas a gradual angle indicates a slowly developing clot. Hypofibrinogenemia and hyperfibrinolysis often result in a low α value. Therapies include plasma, which has the greatest *amount* of fibrinogen, and cryoprecipitate, which has the highest *concentration* of fibrinogen. As the clot strengthens, the parabolic curve peaks, resulting in the maximal amplitude (MA) (TEG) or maximum clot firmness (MCF) (ROTEM) of the clot. This is largely dependent upon platelets, with fibrinogen and platelet-fibrinogen interactions contributing to a lesser extent. Low MA/MCF values are seen with thrombocytopenia and in the presence of antiplatelet agents, such as aspirin or clopidogrel. Treating low MA/MCF values is limited to platelet transfusion only. The downsloping TEG tracing represents the time for clot lysis. Normal lysis at 30 minutes, LY30 (TEG) or CL30 (ROTEM), is 0%. Minor increases in lysis (3%-8%) are associated with increased mortality and should be rapidly addressed. Therapy includes antifibrinolytic medications, such as tranexamic acid and *ε*-aminocaproic acid. Plasma and cryoprecipitate may also be employed to replace lost fibrinogen, but the mainstay of treatment is to cease hyperfibrinolysis with pharmacologic means.[63]

Employing targeted pharmacologic and transfusion strategies based on TEG measurements allows for normalization of coagulopathy, while limiting untoward effects of overresuscitation or underresuscitation. Additionally, it may result in fewer transfusions, which in turn will decrease complications related to transfusion.

Monitoring

Today's ICUs utilize advanced technologies to determine volume status and resuscitation parameters. The Swan-Ganz pulmonary artery catheter (PAC), since its introduction in 1970, has provided a wealth of information regarding hemodynamics to a large variety of patient populations. However, multiple, large randomized trials have failed to show a mortality benefit when PAC parameters were used to guide resuscitation.[64,65] And, in some trials, higher mortality, increased morbidity, and larger volume fluid resuscitation were seen with PAC use. Additionally, with less-invasive monitors becoming more and more available, the PAC has fallen out of favor. The benefits of the PAC, however, should not be understated in certain instances. Patients with significant arrhythmias or those with pulmonary hypertension may benefit from PAC catheterization, because noninvasive methods frequently fail to demonstrate accurate hemodynamic results. Furthermore, perioperative use of PACs to guide resuscitation has shown in multiple studies to show a mortality and morbidity benefit.[66] For hemorrhagic shock, the PAC may provide information not available from noninvasive methods and, therefore, should be considered in selected patient populations.

In addition to PACs, a variety of minimally invasive and noninvasive techniques are available to rapidly determine endpoints of resuscitation. Arterial waveform analysis methodologies have seen widespread use in recent years. Continuous pulse contour cardiac output monitors (PiCCO; Phillips) utilize proprietary thermodilution arterial catheters, typically inserted in the femoral artery, to determine cardiac output through pulse contour analysis. Frequent calibration is necessary, and a learning curve exists both from a physician and nursing point of view.[67] Lithium dilution cardiac output (LiDCO; LiDCO Limited) is measured through the injection of lithium via a central venous access line. The concentration changes of lithium are then measured with a lithium-sensitive sensor attached to an existing arterial line. Again, multiple daily calibrations are necessary; however, a variety of derived variables, including cardiac output, are readily calculated and have been shown to be equivalent to thermodilutional techniques.[68] Arterial waveform monitors (Vigileo; Edwards Lifesciences) provide cardiac output measurement through existing arterial lines and do not require injection-based calibration. By measuring the pulse pressure variations, stroke volume is calculated, and cardiac output is derived. Although typically less precise than the above dilutional methods, arterial waveform monitors provide information using existing catheters with minimal training.[69]

Noninvasive methods of cardiac output determination continue to be developed. Ultrasonic cardiac output monitoring (USCOM; Uscom Ltd) utilizes an ultrasound probe placed at the sternal notch to measure beat-to-beat variability, cardiac output, and systemic vascular resistance. It requires minimal training and has been validated against thermodilution. Obesity may be a barrier to utilizing this method and may increase error rates in measurements.[70] Another noninvasive device (NICOM; Cheetah Medical) uses bioreactance to measure phase shifts and amplitude after passing a current between electrodes placed on the chest. The phase change correlates well with changes in stroke volume and aortic blood volume. This noninvasive monitor has shown good correlation and reliability both with Doppler ultrasound and thermodilution methods.[71] It is important to note that reliable monitoring is crucial to determining adequacy of resuscitation. Blind resuscitation invariably misses the mark, resulting in either overresuscitation or underresuscitation and worsened outcomes.

Fluids and Component Therapy

Historically, crystalloid solutions were almost exclusively utilized in resuscitation following hemorrhage. Traditional regimens called for infusing crystalloids while awaiting blood products from the blood bank, with repeated bolus doses as necessary. Following at least 2 L of crystalloid infusion, PRBC were considered. Unfortunately, this approach led to worsened coagulopathy, worsened organ failure, and overall outcomes. Recent evidence has shown improved mortality and morbidity with earlier use of blood products, including plasma transfusion. As stated previously, a key component to both early damage control resuscitation and ongoing resuscitation in the ICU is that crystalloids offer little benefit for hemorrhagic shock. Unlike patients in septic shock, hypotension and hemodynamic collapse are secondary to blood loss. This simple idea of *replacing what was lost* is at the cornerstone of hemorrhagic shock management. Crystalloid preparations inevitably are used to some extent, either as medication carriers or as transfusion flushes. However, their use should be limited as much as possible—especially in the early phases of resuscitation, before hemorrhage control is gained. Once in the ICU, targeted and thoughtful use of crystalloid may be employed, but again holding true to damage control tenants. Fluid shifts occurring as the result of hemorrhage are often profound and worsened by large-volume IV fluid administration. Control of coagulopathy and acidosis also falls victim to isotonic and hypotonic crystalloid volume use.

HTS is one crystalloid formula that has proven beneficial. Solutions of 3%, 5%, and 7.5% are commercially available. High concentrations of sodium chloride delivered to the vascular system favor the flux of water from the interstitial space and from the cells to augment the blood volume. This results in a rapid restoration of intravascular volume. Infusions of small amounts of these solutions lead to hemodynamic responses equivalent to much larger volumes of crystalloid solutions. This is advantageous because of both the rapidity of the response and the limited volume necessary to achieve the same goals. Recent work suggests these fluids decrease the activation of neutrophils, modulate cytokine and adhesion molecule expression, and suppress the production of reactive oxygen species. These immunomodulatory effects have been shown to decrease the risk of MODS.[72] Proponents believe that the smaller volumes lead to less tissue edema and associated potential complications. Once fluid is drawn into the vascular space, sodium chloride is diluted and equilibrates across the fluid spaces of the body. As this happens, the effect of the HTS is gradually lost. Increases in mean arterial pressure

are short-lived, with hemodynamic effects lasting only 15 to 75 minutes.[73] The largest potential danger with hypertonic solutions is hypernatremia. This may be accentuated in the previously dehydrated patient without additional extravascular fluid to donate to the vascular system. Although some rapid and transient hypernatremia seems to be tolerated, caution in administration and careful monitoring of sodium levels are important in the safe use of these solutions.

Whole blood contains all of the factors lost by the bleeding patient, including plasma proteins, clotting factors, platelets, and white blood cells, as well as erythrocytes. Although fresh whole blood is a superb resuscitation fluid, it has a short storage life and, therefore, has limited use in the typical civilian setting. Additionally, infectious disease testing and blood banking inventory management issues have made whole blood largely unavailable. However, whole blood is used in many centers, and clinical studies on whole blood are underway for civilian trauma patients. Prospective data collected in these studies may present an impetus for change in blood banking and provide access to this useful and efficacious resuscitative fluid.

RBC transfusion is common for the resuscitation from hemorrhage and should be utilized early in the process. Initial resuscitation practices often employ uncrossed blood products with O-negative; however, packed red blood cells (PRBCs) should be typed and cross-matched as early as feasible to avoid transfusion reactions. PRBCs can be stored for 42 days according to current Food and Drug Administration standards. However, detrimental effects of stored PRBCs can be related to their age. Hyperkalemia is a well-known problem with red cell storage, because potassium is lost into the PRBC supernatant over time. Increased risk of cardiac events, infection, multisystem organ failure, and mortality are also associated with older RBCs.[74,75] Despite safeguards, clerical errors lead to mismatched blood administrations, with a rate of fatal major ABO blood group reactions of between 1 in 500,000 and 1 in 2 million. Currently, the risk of infection from a transfused unit is 1 in 30,000 to 1 in 150,000 for hepatitis C, and 1 in 200,000 to 1 in 2,000,000 for human immunodeficiency virus.[76]

The benefits of early plasma administration continue to be realized through multiple randomized trials. Plasma should be considered an initial resuscitation fluid in hemorrhagic shock, along with PRBCs. Thawed plasma is plasma that is stored for up to 5 days at 1°C to 6°C. This storage timeline is based on similar RBC storage guidelines and preservation of factors V and VIII; however, clinical data are lacking.[77,78] Because more centers are using earlier and increased amounts of plasma, thawed plasma is now routinely available at many trauma centers, and increasingly stored in emergency departments. Type AB plasma, the universal donor for plasma, is chosen initially before cross-matched product is available. Group A plasma has been shown to be a safe alternative to Type AB, and empiric utilization of Group A plasma may expand the use of massive transfusion protocols and help encourage the use of early plasma transfusion where AB availability is limited.[79] Having thawed plasma available in the emergency department allows for the initiation of a protocol-driven high ratio of FFP to PRBCs. Plasma transfusion risks of TRALI, infection, and multisystem organ failure increase at the rate of approximately 2% with each unit transfused.[80] However, these observations have been made in the context of higher survival among patients who received high ratios of FFP, suggesting that those patients survived despite the potential cost of sepsis and multisystem organ failure development.

Platelets are transfused in two different formulations. Pooled whole blood–derived platelets are generally transfused in 6-unit increments from five to six different blood donors. Apheresis platelet units are derived from a single donor and are transfused in volumes approximately equal to 5 to 6 units of pooled whole blood–derived platelets. Because evidence continues to emerge, it is becoming clear that platelets, once an afterthought during traditional resuscitation practices, should be transfused at higher ratios. Many massive transfusion protocols include platelets in the first or second tier of the transfusion guideline. Improved outcomes have been seen when fixed-ratio transfusion strategies include platelets early in the schema. Platelet counts of less than 20,000 per μL should always be corrected in any bleeding patient, whether or not a life-threatening injury has been identified. If the patient has a known history of antiplatelet use within the preceding 7 days, it may be necessary to transfuse platelets despite a platelet count greater than 50,000 per μL, particularly in those patients with head injury or those being managed nonoperatively for significant solid organ injury. Platelet counts of less than 100,000 per μL are a relative indication for platelet transfusion in the head-injured patient with evidence of intracranial hemorrhage, whether as a single-system injury or as part of multisystem injuries. It is possible that we have been overly restrictive in the use of platelet transfusions, because recent data suggest that increased and early use improves survival.[56] Both pooled and apheresis platelets are stored at room

temperature for up to 5 days. Bacterial contamination remains the greatest risk of platelet transfusion; however, apheresis platelet units have been shown to have lower risk of infection because they are derived from a single donor.

Cryoprecipitate is a product of FFP that contains factor VIII, von Willebrand factor, fibrinogen, fibronectin, factor XIII, and platelet microparticles. The benefits of including cryoprecipitate in massive transfusion protocols have yet to be confirmed.[81] As a product of plasma, cryoprecipitate contains many of the constituents of plasma, only in concentrated, less voluminous form. For this reason, unless a specific coagulation defect is targeted, cryoprecipitate likely offers little benefit over FFP in the early resuscitation of hemorrhagic shock. Cryoprecipitate is made after centrifuging thawed plasma and removing the supernatant. It has a shelf life of 1 year when frozen at −20°C. Cryoprecipitate is customarily transfused in 10-unit bags, although this is highly variable. As a result of this practice, patients generally receive 2.5 g of cryoprecipitate per transfusion.

Vasopressor and Inotropic Support

Despite adequate volume resuscitation, some patients require additional pharmacologic means to attain hemodynamic goals. In these patients, selective use of vasopressor agents may be necessary. A keen understanding of each agent's receptor targets and their resultant effects is required to effectively make use of vasopressors in the resuscitation of hemorrhagic shock. Norepinephrine is widely used and is at the forefront of many algorithms aimed to treat critically ill patients. Acting weakly on β_1 receptors, norepinephrine mildly increases contractility, while it acts to strongly activate α_1 receptors, affording potent vasoconstriction. Bradycardia is commonly seen and is, therefore, not recommended for those with bradyarrhythmias. Dopamine acts on multiple receptors and is strongly associated with tachycardia and the development of tachyarrhythmia. At lower doses, it acts as a dopamine (D_1) receptor agonist and may produce vasodilation through action on β_2 receptors. The so-called renal dose dopamine, at low doses, has not been shown to improve renal perfusion or treat renal insufficiency, and although theoretical advantages exist, clinically it has no benefit. At somewhat higher doses, dopamine triggers β_1 receptors and increases contractility and heart rate. With increasing doses, α_1 receptors are activated and vasoconstriction results. Dopamine is typically a second-line agent for most situations relevant to hemorrhagic shock, because the risk of tachyarrhythmia is increased in patients who are already tachycardic.

Epinephrine is a powerful agent acting strongly on both α and β receptors. In the case of cardiac arrest, 1-mg bolus doses remain a mainstay of treatment. When higher doses are used, tissue ischemia becomes more likely. High-dose epinephrine infusions worsen acidosis and ultimately may result in cardiac ischemia, and therefore are not recommended. Lower doses, however, may be beneficial as either intermittent boluses or infusions. Particular benefits may be seen prior to anesthetic induction for procedural hemorrhage control.

Phenylephrine is a pure α-agent, effecting potent vasoconstriction. Care should be taken when beginning a phenylephrine infusion in patients with hemorrhagic shock. These patients are typically maximally vasoconstricted via endogenous catecholamine release, and cardiac output is being sustained by the patient's tachycardia. Further vasoconstriction, without stimulation of β receptors, will worsen cardiac output by causing a reflex bradycardia, and reduced cardiac output. Additionally, phenylephrine infusions in elderly patients may increase afterload beyond that which the aging heart can function, causing acute heart failure and precipitous drop in cardiac output.

Vasopressin has been increasingly utilized in the resuscitation of patients following hemorrhage. Evidence suggests endogenous vasopressin stores are rapidly depleted in response to hemorrhage, and replacement with a low-dose infusion is warranted when hemodynamic profiles are not optimized. The greatest benefit appears to be when vasopressin is used in conjunction with other vasoactive medications, such as norepinephrine. When norepinephrine doses are greater than 12 μg/min, concomitant vasopressin infusion has been shown to allow norepinephrine to be titrated down, while maintaining desirable hemodynamics. High-dose infusions (>0.04 U/min) are strongly associated with coronary ischemia and are not recommended.

Dobutamine and milrinone are two inotropic agents that typically have limited use in hemorrhagic shock. Dobutamine, a pure β-agonist, has a strong effect on contractility and heart rate. It is also associated with vasodilation and may result in up to a 10% drop in systemic vascular resistance. Milrinone, a phosphodiesterase inhibitor, increases contractility by increasing cyclic adenosine monophosphate. It too, acts as a vasodilator and preferentially vasodilates the pulmonary vascular bed. Owing to their

vasodilating properties, both of these pharmaceuticals offer limited benefit in the resuscitation following hemorrhage. In selected circumstances, principally preexisting heart failure, they may be utilized, but invasive monitoring is necessary to fully appreciate these benefits.

Additional Therapies

Coagulopathy may persist despite aggressive initial treatment. It is important to reevaluate coagulopathy within the first 48 hours of the ICU stay. Preexisting conditions, such as cirrhosis, may prevent adequate coagulopathic control without repeated dosing of medications, such as vitamin K, prothrombin complex concentrates, or plasma (if volume is necessary). Similarly, hyperfibrinolysis may still be present and require dosing of tranexamic acid. If renal failure is present, the presence of uremic platelet dysfunction should be considered and treated with high-dose DDAVP.

Steroids have been studied in many shock states; however, they have shown little benefit in hemorrhagic shock. One area of interest where steroids may have benefit is in the realm of acute acquired adrenal insufficiency. In patients with persistent hypotension, despite adequate volume resuscitation, a random cortisol level and empiric dosing of either hydrocortisone or dexamethasone should be considered. Many clinicians use clinical judgment to guide administration of steroids in the face of a "relatively" low serum random cortisol. The cortisol stimulation test is controversial, but when used, the patient's cortisol level should increase a minimum of 9 μg/dL above baseline upon administration of cosyntropin.

Glycemic control should be initiated upon arrival to the ICU. Hyperglycemia encourages a proinflammatory state and results in worsened outcomes. Targets should be reasonable, because iatrogenic hypoglycemia is associated with worsened outcomes as well. Nutritional support should be initiated as early as prudent, depending upon the patient's physiologic state. Intra-abdominal hemorrhage and subsequent operations often preclude early enteral feeding, as do the necessity of vasopressor agents. Most vasoactive medications decrease splanchnic circulation, which increases the risk of tube feed necrosis and other nutritionally related enteric disasters.

Evidence continues to emerge regarding the use of thromboembolic prophylaxis in the setting of hemorrhage. As directed treatment of coagulopathy is associated with improved outcomes, so is thromboembolic prevention. Hemorrhaging patients often are in a prothrombotic and paradoxically coagulopathic state. Overactivation of the clotting cascade combined with stasis from hypotension and vascular damage from the inciting event complete Virchow's triad, and therefore put patients at increased risk for thrombotic events. Once hemorrhage control has been demonstrated, thromboembolic prophylaxis should be initiated. In most cases, waiting more than 24 hours is unnecessary and leads to higher rates of thromboembolic events.

Home medications should be reviewed and begun as necessary. Preinjury statin use is associated with increased rates of myocardial ischemia when these medications are not restarted upon admission. Withholding β-blocker medications may result in rebound tachycardia and tachyarrhythmias and increase risk of cardiac ischemia. Diuretics are typically detrimental until the patient is beyond the resuscitative phases and are generally withheld until stability is demonstrated. In those patients who take diuretics regularly, however, special attention is warranted in regard to volume overloaded states, and the development of pulmonary edema. Anticoagulants should be restarted with caution. Certain conditions, such as patients with mechanical heart valves or recent percutaneous coronary stents, may require anticoagulant or antiplatelet agents to be restarted as soon as possible. An accurate and thorough history is essential to obtain, especially in the aging population.

SUMMARY

Shock following hemorrhage represents a significant, multifaceted process impacting a significant number of patients. Early recognition is crucial to improve outcomes. Once recognized, hemorrhage control must rapidly be obtained to prevent further physiologic derangements, for without it, any resuscitation strategy is futile. Hemostatic adjuncts, both topical and IV, may be utilized to reach this goal. Damage control principles, with targeted treatment of coagulopathy, early use of plasma, and limited crystalloid volume, should be employed in patients at risk for exsanguination. Before, during, and after hemorrhage has ceased, resuscitation efforts must proceed with goals to normalize hemodynamic, coagulation, and perfusion parameters. Resuscitation endpoints should be targeted, with the combined use of advanced monitoring techniques, laboratory results, and clinical judgment.

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Critical Care

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