REVIEW ARTICLE

Edward W. Campion, M.D., *Editor*

Initial Care of the Severely Injured Patient

David R. King, M.D.

From the Department of Surgery, Division of Trauma, Emergency Surgery, and Surgical Critical Care, Massachusetts General Hospital, and the Department of Surgery, Harvard Medical School — both in Boston; and the U.S. Army Special Operations Command, Ft. Bragg, NC. Address reprint requests to Dr. King at Massachusetts General Hospital, Division of Trauma, Emergency Surgery, and Surgical Critical Care, 165 Cambridge St., Suite 810, Boston, MA 02114, or at dking3@mgh.harvard.edu.

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Hippocrates wrote, "he who would become a surgeon should join an army and follow it."[1] The rapid advancement of trauma care is often, sadly, firmly linked to warfare. William Mayo, many centuries later, aptly stated, "Medicine is the only victor in war." The crisis of injury created by war has often led to innovation in trauma care and surgical creativity, and many of our best practices were forced by war into widespread adoption.[2] Others simply evolved into practice through a natural pathway of peer review, publication, and acceptance by the trauma community. Research on the management of severe injury is extremely challenging to conduct, and innovation is often driven by necessity rather than by the scientific method. Nevertheless, survival rates after severe injury are higher now than at any point in recorded history, and recent improvements in care are attributable, in part, to the nearly two decades of war on terrorism. In the United States, injury remains the leading cause of death among persons between the ages of 1 and 44 years, underscoring the fact that trauma is not only a wartime affliction.

This article reviews major advances in the care of severely injured patients. Some interventions are mechanical (tourniquets), some are pharmacologic (antifibrinolytic therapy), and others are philosophical and require a new way of thinking (early damage-control surgery). Trauma care has changed substantially in the past 20 years, as summarized in Table 1. Practicing the best evidenced-based medicine in trauma care often requires imperfect decisions based on incomplete and evolving information. An aggressive and forward-leaning posture regarding emergency surgery remains the guiding principle.

Tourniquets

At the beginning of the global war on terror, the death rate from limb exsanguination and junctional wounds was extraordinarily high,[3] despite a 1996 report on military medicine in which the authors recognized the need to use field tourniquets for life-threatening extremity hemorrhage.[4] Improvised tourniquets became commonplace, though largely ineffective. Warfighters (i.e., members of the military who fight in wars) recognized the need for better control of limb hemorrhage at the point of injury, and commercial devices to control limb exsanguination became standard on the battlefield, along with universal training in how to use them. These changes resulted in a demonstrable reduction in deaths from extremity exsanguination.[5] Prior wars saw tourniquets fall out of favor because of delayed evacuation and subsequent limb loss due to ischemia. In the current conflicts, however, evacuation times have been dramatically shortened, and limb loss due to ischemia is now rare. Advanced topical hemostatic dressings were also introduced to control limb and junctional exsanguination.[6] This advance, among others, has been codified in the Tactical Combat Casualty Care guidelines,[6] which have con-

Table 1. Approaches to the Care of Severely Injured Patients.

Approach	Purpose	Outcome
Tourniquet	Control of limb exsanguination	Temporary cessation of bleeding limb injuries
Tranexamic acid (antifibrinolysis)	Early treatment and prevention of trauma-related hyperfibrinolysis	Improved intrinsic coagulation, elimination of hyperfibrinolysis, prevention of trauma-related coagulopathy
Permissive hypotension	Limitation of ongoing blood loss, prevention of trauma-related coagulopathy	Lower-volume resuscitation, limitation of presurgical blood loss
The golden hour	Rapid institution of measures to manage traumatic injury	Early, definitive surgical control of hemorrhage
High-ratio massive transfusion	Prevention and treatment of trauma-related coagulopathy, volume expansion without hemodilution (damage-control resuscitation)	Restoration of normal hemodynamics after hemorrhage control
Ultrasonography	Noninvasive test for detection of internal hemorrhage and pneumothorax	Intracavitary bleeding identified in bilateral pleural spaces, pericardium, or intraabdominal compartment
REBOA*	Early, temporary control of noncompressible hemorrhage	Limitation of presurgical blood loss, temporary improvement in hemodynamics, minimally invasive alternative to thoracotomy and aortic cross-clamping

* REBOA denotes resuscitative endovascular balloon occlusion of the aorta.

tinued to evolve and guide warfighters to this day. As warfighters returned home, commercial tourniquets, along with appropriate training in their use, became popularized for everyday injury, stimulated in part by mass-casualty incidents.[7] Those awful events created an acute awareness of the need for early, aggressive control of extremity hemorrhage and led to the Hartford Consensus and the Stop the Bleed campaign.[8] These efforts were facilitated by a presidential endorsement, along with the endorsements of multiple law enforcement officials, medical stakeholders, and policymakers. The universal use of commercial tourniquets designed to control limb exsanguination has not yet been phased into every first responder's protocol. However, the data indicate that all first responders should adopt this aggressive strategy for controlling point-of-injury hemorrhage.[9] Once a tourniquet is applied in the prehospital civilian environment, it should remain tightened until it can be safely taken off for assessment at a hospital with surgical capability.

ANTIFIBRINOLYTIC THERAPY

Although the coagulopathy of trauma is not completely understood, we know that one component is malignant hyperfibrinolysis. Fibrinolysis is a normal intravascular process that maintains an appropriate balance with thrombosis. After severe injury, a hyperfibrinolytic state develops in some patients, in which thrombus is endogenously lysed faster than it can be synthesized. This alteration may exacerbate blood loss and contribute to death.[10] Tranexamic acid, a pharmacologic antifibrinolytic agent, has been used for decades to mitigate postpartum hemorrhage.[11] However, its usefulness for the treatment or prevention of hyperfibrinolysis in patients with trauma was not recognized until several years ago.[12]

Treatment with tranexamic acid (1 g administered as an intravenous bolus over a period of 10 minutes, followed by a 1-g intravenous infusion over a period of 8 hours, with the first dose given within 3 hours after injury) is simple, and its effect, if given within 3 hours after injury in the most severely injured patients, is substantial. For these reasons, treatment with tranexamic acid has been adopted as routine care on the battlefield and is gaining acceptance in the United States and elsewhere.[2] In the European Union, tranexamic acid is generally accepted as routine standard of care, and its cost, as compared with the costs of most other trauma interventions, is minimal. Administration is time-sensitive, and the greatest benefit with respect to mortality rates occurs when treatment is administered as early as possible after injury.[13] Caution should

be exercised, however, since the administration of tranexamic acid more than 3 hours after injury may increase the risk of death.

The use of this agent should also be incorporated into massive-transfusion programs. Not all patients with trauma will benefit from this intervention; in particular, there is no benefit for patients who are initially thought to have massive bleeding but who, after careful triage, are found not to have massive bleeding. However, no substantial harm has been attributed to the universal adoption of this treatment as an initial intervention for patients with suspected severe hemorrhage.[12,13] Although not directly an antifibrinolytic intervention, the administration of plasma during transport to the hospital improves coagulation status and reduces overall mortality.[14]

PERMISSIVE HYPOTENSION

A century ago, Walter Cannon stated that "inaccessible or uncontrolled sources of blood loss should not be treated with intravenous fluids until the time of surgical control." It took another 76 years to scientifically validate this dictum in a carefully executed study.[15] Unfortunately, the strategy of withholding fluid resuscitation until vascular control is achieved was slow to diffuse into routine care; for most of the 20th century, allowing trauma patients to remain hypotensive until surgical intervention violated a major principle of fluid resuscitation with crystalloid solutions. The common practice of administering 2 liters of crystalloid fluid in hypotensive trauma patients worsens coagulopathy and acidosis and should be abandoned. Normotensive patients should receive no fluid resuscitation, whereas hypotensive patients should have fluid resuscitation withheld until systolic blood pressure approaches 80 mm Hg systolic, at which point careful, small-volume boluses of blood or plasma (250 to 500 ml) should be given to maintain systolic blood pressure between 80 and 90 mm Hg. The wars in the Middle East created an environment, whether by necessity, scientific principle, or command directive, that favored widespread use and acceptance of permissive hypotension.[16] This approach not only is safe but also may provide a substantial survival benefit for patients with penetrating or blunt trauma.[17] The safe limits of permissive hypotension are unknown, but the administration of large-volume intravenous fluids before surgical control of hemorrhage is dangerous and should not be performed unless circumstances, such as a coexisting traumatic brain injury, dictate otherwise.[17-19]

DAMAGE-CONTROL SURGERY

Damage-control surgery is a technical strategy to control massive bleeding. This approach prioritizes the control of hemorrhage and contamination on initial surgical intervention and involves leaving the abdominal cavity with a temporary closure and delaying all other definitive surgical maneuvers and reconstructions for subsequent operations. Sometimes referred to as "staged" surgery, damage control promotes survival in patients with the most severe injuries and the greatest blood loss. Some patients have to undergo serial operations over a period of many days to avoid the physiological insult of one prolonged operation entailing extensive blood loss. Between surgical stages, patients are placed in the intensive care unit, where their physiological status is carefully managed, with attention to resuscitation, resolution of acidosis, maintenance of normothermia, and elimination of coagulopathy, usually with the use of sedation and mechanical ventilation. On subsequent returns to the operating room, definitive surgical reconstruction is performed as physiologically tolerated, and the abdomen is closed as soon as all reconstruction is complete.

Although this approach has roots in the early 20th century, it was resurrected and named damage-control surgery in 1993.[20] The collective surgical experience in the global war on terror solidified the practice of damage control, and it has been adopted by trauma centers in many nations, including in most developed countries with adequate medical resources.[21,22] Damage-control surgery is now recognized as the standard of care for the most severely injured patients who are undergoing surgery for massive bleeding. Its adoption directly mitigates the vicious cycle of hypothermia, acidosis, and coagulopathy. Within 24 hours after completion of the index (damage-control) operation, the next operation should be performed, and each subsequent operation should be performed within 24

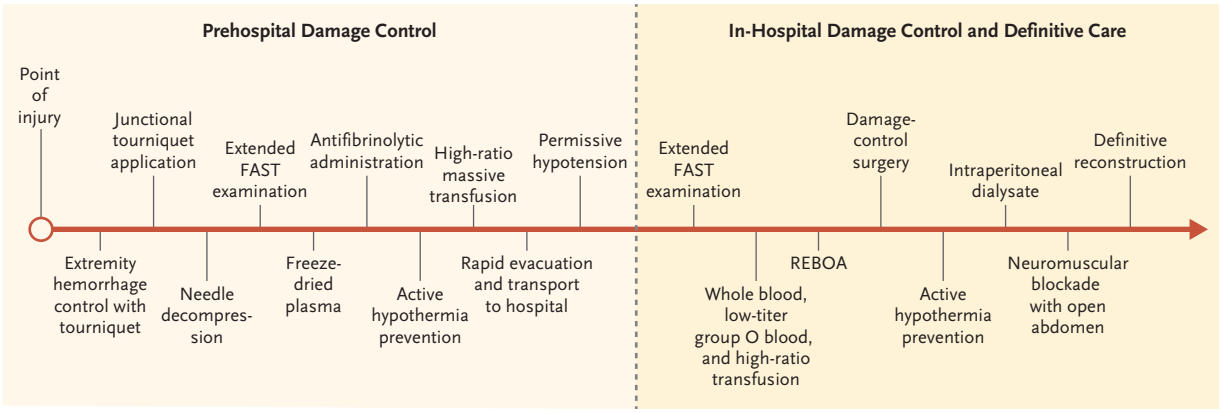

Figure 1. Possible Interventions during the Golden Hour.

The primary purpose of the golden hour concept is to achieve early hemorrhage control. Prehospital and in-hospital maneuvers toward this goal include initial care, triage, rapid evacuation, and resuscitation. FAST denotes focused abdominal sonography for trauma, and REBOA resuscitative endovascular balloon occlusion of the aorta.

hours after completion of the previous operation, in order to improve the chances of primary fascial closure.[23,24] Surgical attempts at primary fascial closure should occur every day, since bedside examination is not predictive of whether the fascia will close. In addition, the use of a vacuum device for temporary abdominal closure and the use of early, temporary neuromuscular blockade improve rates of primary fascial closure and should be considered if they are not contraindicated.[25] Caution should be exercised in selecting patients for damage-control surgery, since repeat operations increase morbidity among patients who are only moderately injured.[26]

THE GOLDEN HOUR

During World War I, the French published the first scientific appreciation of the time-sensitive nature of the treatment of shock after injury, in a report entitled "Du Shock Traumatique dans les Blessures de Guerre: Analyses d'Observations." Although the death rate has not been shown to rise precipitously at 60 minutes after injury,[27] the recognition that intervention should occur rapidly helped drive the development of emergency medical systems. "The golden hour" moniker summarized this approach for policymakers, though it overlooks the reality that most deaths from truncal hemorrhage occur within 30 minutes after injury.[28] More recently, data from the wars in Iraq and Afghanistan suggest that battlefield survival after injury was closely linked to the interval from injury and evacuation to the first surgical intervention. This prompted a Department of Defense mandate to evacuate all combat casualties by helicopter within 60 minutes after injury, which did pay off in terms of saving lives.[29,30]

The contemporary understanding of the time-sensitive nature of trauma remains paramount, since the interval between injury and surgical intervention fundamentally determines the outcome, both on and off the battlefield.[28,31] Surgical intervention, however, should not be conflated with triage and resuscitation. Resuscitation is not a substitute for hemorrhage control, and caution should be exercised when resuscitation measures are initiated without a plan for surgical control of hemorrhage. The primary purpose of the golden hour concept is to drive all efforts toward early hemorrhage control, including initial care, triage, rapid evacuation, and resuscitation (Fig. 1). Other trauma systems, such as the European and Australian emergency medical system, approach the golden hour by placing physicians or other advanced providers in the prehospital environment to facilitate early hemorrhage-control maneuvers. From the very moment of injury, our focus needs to be on achieving surgical hemorrhage control. All other maneuvers are supportive of this primary goal.

HIGH-RATIO MASSIVE TRANSFUSION

Bleeding patients need blood. The use of asanguinous intravenous fluids as a resuscitation medium worsens the outcome.[32] Whole blood, or a surrogate that approximates whole blood, should be used for resuscitation, with simultaneous initiation of hemorrhage-control maneuvers.[33] Component therapy, particularly within the context of an organized massive-transfusion protocol, emphasizing a high ratio of packed red cells to plasma (1:1), was first shown to improve outcomes on the battlefield,[34,35] with subsequent wider adoption.[36-38] This approach should be embraced at all facilities that receive trauma patients. Blood products are refrigerated for storage and should be warmed to body temperature through the use of a fluid-warming device during resuscitation. This is an important point, because transfusion of cool blood products in a patient with trauma and hemorrhage will contribute to iatrogenic hypothermia and coagulopathy. The rate of administration should be proportional to the degree of shock and should follow the principles of permissive hypotension. Blood products should be administered at as high a rate as possible (often as fast as 500 ml per minute) in order to obey the principles of hypotensive resuscitation, with a target systolic blood pressure of 80 mm Hg during damage-control surgery. Resuscitation, however, is not a substitute for hemorrhage control. If resuscitation is initiated, then a hemorrhage-control maneuver, including damage-control surgical interventions if appropriate, should be initiated simultaneously.

ULTRASONOGRAPHY

Ultrasonographic examination of the abdominal cavity and pericardium during the discovery phase of care (FAST [focused abdominal sonography for trauma]) is as essential as the measurement of vital signs in initial triage and surgical decision making, particularly in a patient with trauma and hypotension.[39] FAST examination within minutes after the patient's arrival at a hospital (or in some cases even in the prehospital environment) is the current standard of care in the United States, European countries, Australia, Japan, and most other developed countries. An extended FAST examination, which includes additional examination of the bilateral pleural spaces, is especially useful, particularly when plain radiography of the chest is delayed. These ultrasonographic examinations allow detection and semiquantification of intraabdominal hemorrhage, which predicts the need for surgical intervention, and detection of traumatic hemopericardium (a surgical emergency), as well as hemothorax and pneumothorax.[40] This can all be accomplished rapidly at the bedside within moments after the patient has arrived at the hospital. Early identification of these conditions allows the provider to immediately intervene, or set in motion a mechanism to intervene, with a hemorrhage-control maneuver such as laparotomy, tube thoracostomy, or thoracotomy without the need for additional radiographic or laboratory studies.[41]

A patient with trauma and hypotension does not belong in the computed tomography suite, and this common pitfall can be avoided by use of the bedside FAST examination. An additional pitfall is a false negative result of the FAST examination, which can occur even in experienced hands.[42] If the patient appears to have noncompressible, intracavitary abdominal hemorrhage, despite a negative FAST examination, the provider should suspect a false negative examination and proceed to other diagnostic maneuvers, such as diagnostic peritoneal aspiration or lavage, bilateral tube thoracostomy, or in appropriate cases, emergency exploratory laparotomy.

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a rapidly emerging technique to control noncompressible, intracavitary hemorrhage below the diaphragm.[43] Many surgeons regard this technique as a less invasive alternative to emergency thoracotomy and aortic cross-clamping for a patient who is hemodynamically compromised but does not have evidence of thoracic hemorrhage and is not in arrest.[44] An aortic occlusion balloon is rapidly placed into the aorta through percutaneous or open access to the common femoral artery, usually during initial triage. The balloon can then be positioned in zone I, just proximal to the aortic hiatus of the diaphragm, to temporarily control infradiaphragmatic exsanguination, once

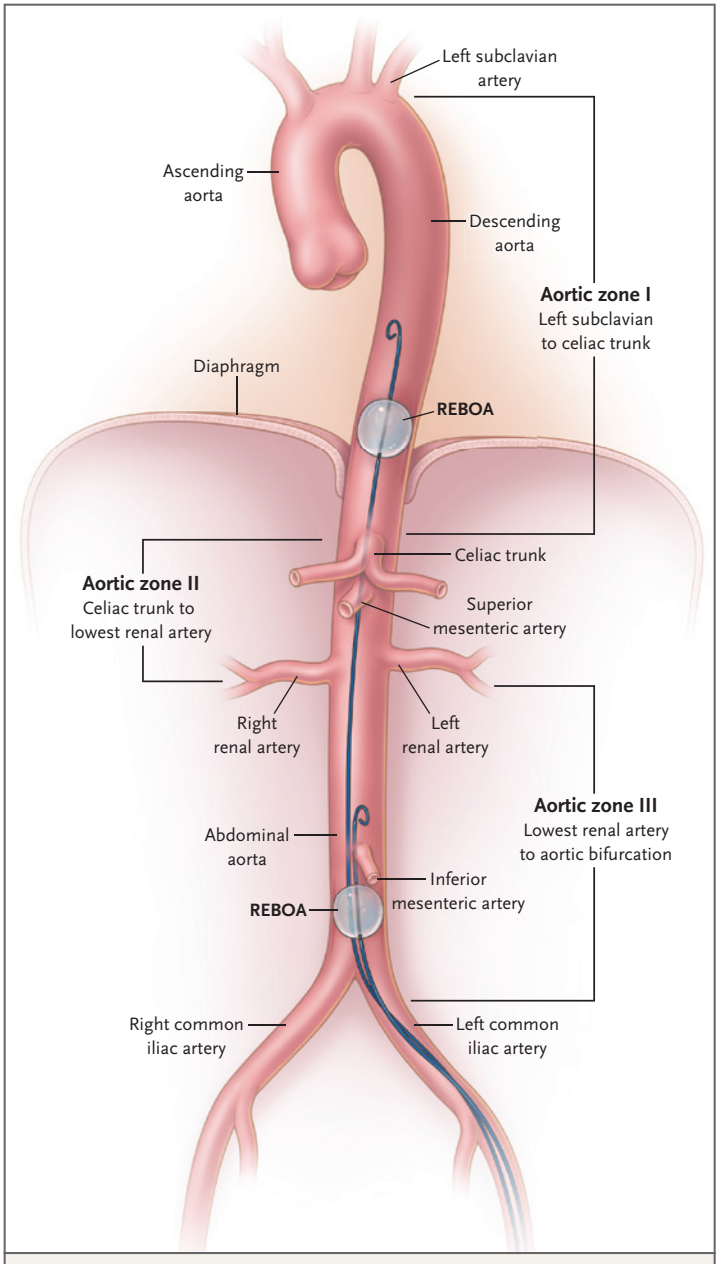

Figure 2. Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA).
Shown are aortic occlusion zones. In zone I, safe positioning of the balloon for control of infradiaphragmatic hemorrhage is shown; in zone III, positioning for control of massive pelvic hemorrhage in the absence of a simultaneous abdominal source of hemorrhage is shown.

supradiaphragmatic hemorrhage has been ruled out (Fig. 2). Alternatively, the balloon can be positioned in zone III to control massive pelvic or junctional hemorrhage, once supradiaphragmatic and intraabdominal hemorrhage have been ruled out.[45,46] The principle of reasonably ruling out hemorrhage in any cavity proximal to proposed balloon occlusion is of paramount importance. Occlusion distal to a vascular injury may result in acceleration of proximal blood loss and death. Techniques that may be used to rule out proximal hemorrhage include ultrasonography (with its known limitations), plain radiography of the chest and pelvis, diagnostic tube thoracostomy, and diagnostic peritoneal aspiration or lavage.

REBOA allows temporary control of massive hemorrhage below the level of occlusion while a definitive hemostatic intervention is undertaken. The choice of hemostatic intervention is made on the basis of the injury pattern; the intervention is usually an emergency surgical procedure (laparotomy), pelvic angioembolization, pelvic external fixation, preperitoneal pelvic packing, or a combination of all these interventions. Abdominal visceral ischemia limits the occlusion time to less than 30 minutes, but ideally, the occlusion time should be as short as possible.[47,48] Specialized techniques, such as intermittent REBOA, may be helpful in safely extending ischemic time.[49] REBOA remains an intervention with an evolving set of indications, contraindications, techniques, and pitfalls. When used appropriately by experienced providers, REBOA may improve the outcome for the subgroup of patients with the most severe injuries and the most extensive bleeding. The dangers of REBOA include total visceral ischemia, lower-limb loss, exacerbation of traumatic brain injury, spinal cord ischemia, and rapid proximal blood loss. This intervention, which is now commonly used at some specialized trauma centers, warrants attention and additional research.

SUMMARY

Initial care of the severely injured patient has changed substantially in recent decades, in many ways stimulated by the global wartime experience. Continued advancement of trauma care outside of warfare requires a national commitment to research, especially in some areas with great promise but with little data or incomplete acceptance (Table 2). Trauma care requires an extremely aggressive surgical approach, despite incomplete, imperfect, and rapidly changing

Table 2. Additional Recent Advances in the Care of Severely Injured Patients.

Intervention	Purpose
Whole blood	Hemostatic resuscitation with type-specific whole blood
Low-titer group O blood	Resuscitation with whole, group O blood, low anti-A and anti-B titer
Hypertonic saline	Treatment of intracranial hypertension and prevention of bowel edema in the open abdomen
Freeze-dried plasma	Prehospital administration of reconstituted plasma for treatment of coagulopathy
Needle decompression	Prehospital treatment of presumed tension pneumothorax
Junctional tourniquets	Control of bleeding from groin and axilla (sites where a conventional tourniquet cannot be applied)
Chemical body warmers	Active prevention of heat loss
Partial REBOA	Incomplete occlusion of the aorta to prolong ischemia time
Intraperitoneal dialysate	Prevention of loss of abdominal domain in the open abdomen

information. This approach should be undertaken immediately, beginning at the point of injury. Wider adoption of these advances is necessary to improve survival for severely injured patients, particularly those with massive blood loss.

Disclosure forms provided by the author are available with the full text of this article at NEJM.org.

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