Navy corpsman assigned to 3rd Battalion, 2nd Marines, applies tourniquet on simulated casualty during counter assault exercise in Okinawa, Japan, May 11, 2022 (U.S. Marine Corps/Micha Pierce)

The Strategic Survivability Triad

The Future of Military Medicine in Support of Combat Power

By George A. Barbee

A man cannot understand the art he is studying if he only looks for the end result without taking the time to delve deeply into the reasoning of the study.

—Miyamoto Musashi

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Future conflicts will be complex and will occur in multidomain environments. This problem requires a solution to protect the force. The answer is the deliberate convergence of three existing and distinct overarching medical concepts employed in the chain of survival. These three critical medical concepts combined—henceforward introduced as the Strategic Survivability

Triad (SST)—are early intervention, rapid control of noncompressible hemorrhage, and early blood administration. The SST will provide the force with a sustainable capability needed in future conflicts to enable combat power projection, improve survivability, and mitigate risk. In addition, this will provide options for commanders and policymakers in the attainment of national objectives.

The newly conceptualized SST seems rudimentary but is analogous to combined arms warfare, joint warfighting, or blitzkrieg operations, where overarching concepts or capabilities combine to create synergistic effects. The beauty of the SST is that it is generalizable for all conflict types and supported by current evidence-based medicine. This article provides solutions and actionable information for the current and future military (some of which can be employed immediately) and to two Key Strategic Issues List areas, "High-Intensity Conflict" and "Modernization."[1] The SST background is discussed, critical points are illuminated by case reports with analysis, and recommendations are provided.

The intended audiences are key leaders and decisionmakers at the operational to strategic level who can influence the Services and joint warfighting enterprise. These include nonmedical and medical personnel and combat, combat service, and combat service support personnel. The goal is to impose the SST in the chain of survival to mitigate the fog and friction of war to improve the survivability of the warfighter and positively affect the planning and execution of campaigns to achieve strategic objectives.

Background: This Is a Strategic Endeavor (the Why)

Employing the SST will unequivocally improve survivability, yet several challenges impede its implementation. First, there is a misguided belief or overreliance on the Golden Hour concept.[2] The Golden Hour is a good starting point for patient evacuation, but the military can do better with a combined early intervention and early evacuation approach. Second, the military has acknowledged the problem of noncompressible hemorrhage, but unrelenting research, data collection, and development are needed to solve this problem set. There are potential options on the horizon in materiel and training, but development and implementation cannot waver. Finally, a concerted effort to adopt the practice of early blood administration is required. There is a potential concern that any blood transfusion is dangerous and has risks. However, the risk associated with blood transfusion is low when juxtaposed against amphibious or airborne joint forcible entry operations against peer or near-peer adversaries.

All battlefields are nonlinear, encompassing multidimensional, multidomain, simultaneous, dynamic, fluid, and layered systems.[3] This clarification is necessary because it relates to the chain of survival and the application of military medicine, its adjuncts, and the support required. The SST will close the gap between the echelons of battlefield medicine and adjunct Tactical Combat Casualty Care (TCCC), and can bridge Prolonged Casualty Care, with the caveat that without good TCCC and the SST, there will be no opportunity to practice Prolonged Casualty Care.[4]

Tactical Combat Casualty Care has excelled in the tactical space by bridging tactical medicine and science with the laudable goal of eliminating preventable death on the battlefield.[5] The SST employed in the strategic space is vital to saving lives and will aid in executing combat power, especially when coupled with ongoing advancements in battlefield medicine.

Overall mortality rate in the recent conflicts in Afghanistan and Iraq (and throughout history)—directly proportional to weapon lethality—is redressed by the SST. Despite a 25 percent rate of potentially preventable death,[6] many studies in the early 21st century tout that the United States has achieved unprecedented survival rates for casualties arriving to combat hospitals.[7] This low mortality rate is directly related to dominating nonpeers and is associated with weapon lethality in Afghanistan and Iraq. The SST's employment will translate to more lives saved, preserving the fighting force and increasing strategic resolve to pursue national objectives.

Although known about for years, the Golden Hour concept was not universally resourced until nearly a decade into the campaigns in Afghanistan and Iraq. In June 2009, Secretary of Defense Robert Gates's directive for operations in Afghanistan prioritized strict adherence to keeping casualty evacuation times under an hour. This directive aspired to achieve parity with medical evacuation (MEDEVAC) operations in Iraq.[8] The Gates memo was a move in the right direction for the care of wounded U.S. Servicemembers, translating to 359 lives saved between 2009 and 2014.[9] Further examination revealed earlier time-to-treatment and evacuation translated to increased survival rates. Evidence-based medicine dictates that early intervention improves casualty outcomes in civilian and military medicine. These data are well worth revisiting because they illuminate hard-learned medical lessons over the past 20 years of conflict and will direct the time-to-treatment dilemma that needs to be overcome.[10]

The peacetime effect, or Walker Dip,[11] is a repeated historical cycle marked by decreased medical capability at the onset of conflict, leading to poor outcomes and then markedly improving.[12] Hard-learned medical lessons are often lost, forgotten, and relearned during the current or next conflict.[13] This is important to note because operational military medicine evolves slowly. Evidence-based changes have been slow and incremental, lack parallelism, and at times have to be relearned. Military medicine's slow progress—and resulting loss of lives—has been a primary concern and a source of frustration for battlefield surgeons for over 50 years.[14] Over the last 20 years of conflict, the U.S. military medical system's materiel advancements having the most significant impact in saving lives on the battlefield were the tourniquet and the use of whole blood. Ironically, the tourniquet and whole blood, which have been used for over 400 and 100 years, respectively, have recently been rediscovered.[15]

Analysis of combat casualty care data from 2001 to 2017 for the conflicts in Afghanistan and Iraq showed decreased case fatality rates (a measure of the overall lethality of the battlefield) from 20 percent to 8.6 percent and 20.4 percent to 10.1 percent, respectively (supporting the peacetime effect and Walker Dip theories).[16] In addition, data reveal that the use of tourniquets, blood transfusions, and rapid evacuation translated to a 44.2 percent mortality reduction.[17] This implies that to improve survivability, the SST must be adopted and ingrained within the joint force's DNA. The SST is a joint endeavor and requires the enterprise to solve, mandate, and implement its course. The Joint Trauma System (designated as the Department of Defense Center of Excellence for Trauma) showcases this effort and works this problem set on behalf of the force and the Military Health System.[18]

The August 26, 2021, attack on Servicemembers at Hamid Karzai International Airport is a sobering but reassuring example of why and how the SST is vital to the preservation of the joint force. The disposition of medical forces favored the static employment of the SST. More blood and treasure would have been lost had not the array of medical assets and resources favored the SST.[19]

Operational Medicine Case Reports with Analysis

Early Intervention (the Evidence). One of the three concepts of the SST is to provide early battlefield intervention within minutes of injury. Early intervention can be categorized as early treatment, early transport to a higher level of care, or a combination of those actions as the scenario dictates. There is a wealth of medical evidence and examples where most trauma patients benefited from the correct balance of early treatment and rapid transport. For example, a study conducted in 1982 of patient stabilization in the field and its effect on mortality for penetrating heart injuries showed an 80 percent survival rate if transport times were minimized.[20] This study was a small civilian-based effort but foreshadowed a better understanding of the effect of time and mortality, especially on penetrating cardiac injuries.

In-Flight Traumatic Arrest

I never truly understood the finality of death . . . until death came for me.[*]

During a night assault conducted on a remote target in below-freezing temperatures, a U.S. special operations Soldier sustained multiple gunshot and fragmentation wounds to the chest.[†] While under fire, two special operations medics immediately initiated care at point of injury. Although not overtly appreciated through visible, active hemorrhage, the casualty sustained a significant internal injury to his thorax. Visible wounds were dressed, intravenous access was obtained, and a unit of freeze-dried plasma (FDP) was reconstituted for administration.[‡]

On further examination of the casualty and treatment of his chest wounds, his respiratory rate increased, and he began to develop difficulty breathing. The medics immediately recognized the emergent need for chest needle decompression and delivered seven serial interventions to relieve the bilateral tension pneumothoraces that had developed. This scenario occurred over 5 minutes, the casualty became difficult to arouse, lethargic, and symptoms of shock began to develop. At this point, the medics administered Tranexamic acid and FDP, with an improvement of mental status.[§] The casualty was moved through rugged terrain to an extraction site, revaluated, given packed red blood cells, and transported to an awaiting expeditionary tactical surgical element.[¶]

On receipt of the casualty, a quick examination confirmed what the medics had relayed on patient transfer and noted extremely low blood pressure, very high heart, and breathing rates—all evidence of significant injury. After placing two chest tubes and experiencing a loss of 2,400 milliliters of blood from the chest cavity, the patient's condition deteriorated, and immediate preparations were made for emergency surgery. Due to the sub-freezing conditions, surgery was performed in a hypothermia prevention bag, and, on initiation, the casualty underwent a traumatic arrest. The chest cavity was quickly opened, a gunshot wound was identified in the left lung and clamped, and the heart was uninjured but void of blood. Blood products were administered rapidly while the heart was massaged. After 7 minutes, the patient's heart resumed activity, and spontaneous circulation returned.[**] This Soldier is currently studying to be a trauma surgeon to "cobble together some type of honorary repayment to the people who gave his own life back to him just a few short years ago."[††]

[*] Ramin Khalili, "Opening Remarks Deliver Purpose, Emotional Power at 2019 MHSRS," Army Medicine, available at <https://www.army.mil/article/226069/opening_remarks_deliver_purpose_emotional_power_at_2019_mhsrs>; Robert Walker, "Ranger Medic Remarkable Save," video, 2:16, available at <https://www.youtube.com/watch?v=3yGOXV1k_rO>.

[†] Personal discussion with Colonel David R. King, MD, FACS, Trauma and Acute Care Surgeon, Massachusetts General Hospital Trauma Center, October 15, 2020.

[‡] Myles R. McKenzie et al., "A Case of Prehospital Traumatic Arrest in a U.S. Special Operations Soldier: Care from Point of Injury to Full Recovery," *Journal of Special Operations Medicine* 16, no. 3 (2016), 93.

[§] Tranexamic acid (TXA) is an antifibrinolytic drug. Early administration of TXA has been shown to safely reduce the risk of death in bleeding trauma patients when administered under 3 hours of injury. CRASH-2 collaborators et al., "The Importance of Early Treatment with Tranexamic Acid in Bleeding Trauma Patients: An Exploratory Analysis of the CRASH-2 Randomised Controlled Trial," *The Lancet* 377, no. 9771 (March 26, 2011), 1096–1101.

[¶] McKenzie et al., "A Case of Prehospital Traumatic Arrest in a U.S. Special Operations Soldier," 94.

[**] Ibid., 95.

[††] Khalili, "Opening Remarks Deliver Purpose, Emotional Power at 2019 MHSRS."

Further examination of 11 years of civilian statewide trauma system data demonstrated that 95 percent of trauma patients requiring surgical intervention benefited most with intervention within 23 minutes.[21] That data showed the best survival benefit in patients seen within 19 minutes after suffering penetrating trauma, a corollary to combat trauma.[22] Extending the intervention times to 59 minutes for all traumas and 39 minutes for penetrating trauma would translate to 50 percent mortality.[23]

Another study focused on combat casualty data from Iraq between 2003 and 2010 concluded that improved casualty outcomes resulted from increased prehospital capability, provider expertise, and reduced time to surgical care.[24] In 2018, the Johns Hopkins University School of Medicine assessed 2,329,446 records (103,029 of which were included for analysis), comparing survival times of patients suffering from penetrating trauma transported by ambulance versus privately owned vehicles. They compared data from over 298 urban trauma centers and found that arrival by private vehicle transport is associated with greater survivability than ambulance transport. This study was a real test of the "scoop and run"[25] (private vehicle transport) system.[26] This study ultimately illuminated that trauma patients suffering from penetrating injuries transported by private vehicles to a trauma center had significantly higher survival rates than their counterparts transported by ground ambulance systems. This study also demonstrated decreased transport times for patients—a core tenet of SST—equals more significant survival benefit. This seemingly simple problem—time to treatment—is disguised as a tactical issue but has strategic implications that affect the joint force. The fog and friction of war have direct effects on time. These confounders have adverse effects on

Alaska Army Guardsmen from Detachment 2, Golf Company, 2nd General Support Aviation Battalion, 104th Regiment, rehearse medical evacuation procedures with Army Alaska paratroopers from 1st Squadron, 40th Cavalry Regiment (Airborne), 4th Infantry Brigade Combat Team (Airborne), 25th Infantry Division, during medical evacuation and hoist familiarization training, at Landing Zone Ranger on Joint Base Elmendorf–Richardson, Alaska, February 20, 2019 (U.S. Army National Guard/Balinda O'Neal Dresel)

U.S. Marines with 3rd Reconnaissance Battalion, 3rd Marine Division, load simulated casualty onto UH-1Y Venom assigned to Marine Light Attack Helicopter Squadron 369 during casualty evacuation training on Kin Blue, Okinawa, Japan, March 3, 2022 (U.S. Marine Corps/Jerry Edlin)

simple actions such as intravenous access, spinning up a MEDEVAC or casualty evacuation, or loading and unloading patients. These will create delays in care if not rehearsed and practiced.

The linchpin of any trauma system revolves around its ability to positively influence the entire continuum of care. Unequivocally, early medical intervention and timely evacuation of severely wounded casualties are imperative to saving lives. The key to this principle is that the wounded must survive long enough for early care, active medical intervention, and timely evacuation. The military must align efforts to produce that effect. It is important to note that 87 percent of U.S. military deaths occurred in the prehospital setting; more important, 24 percent of those deaths were deemed potentially survivable.[27] A study published in 2019 that examined combat casualty data from Afghanistan and Iraq between 2001 and 2017 showed a 7.5 percent survival benefit in casualties transported within 60 minutes. Put another way, early patient transport prevented 275 additional deaths, or one-third of a battalion's worth of firepower. Coupled with a simple intervention of tourniquet use (which was associated with a 12.9 percent decrease in mortality), the survival benefit increased to 749 patients, or a battalion-equivalent fighting force.[28] As noted, a well-operationalized trauma system consists of a continuum of care, access to prehospital care, effective communications, rapid triage, transport to care, and finally, rehabilitative services.[29] Optimal survival outcomes for trauma patients are realized from increased prehospital expertise and capability coupled with decreased surgical intervention time.

Noncompressible Hemorrhage (the Evidence). Another concept of the SST is hemorrhage control, namely noncompressible hemorrhage (NCH).[30] Unfortunately, NCH remains the leading cause of death on the battlefield.[31] Life-threatening hemorrhage is a time-dependent problem, and trauma management is a matter of pressure and physics.[32] Hemorrhage can be classified as compressible or noncompressible. Compressible hemorrhage is "tourniquet-able," or controlled by direct pressure, while NCH is not tourniquet-able, and direct pressure is not overtly accessible due to anatomic location. During the Vietnam War and the conflicts in Afghanistan and Iraq, hemorrhage was responsible for deaths in 44 percent and 42 to 55 percent of combat casualties, respectively.[33]

Warfighters have used tourniquets to control compressible hemorrhage in tourniquet-able injuries for centuries. The first recorded battlefield use of the tourniquet occurred during the Siege of

Besançon in 1674, during the Franco-Dutch War, to control bleeding before surgery.[34] The U.S. military employed tourniquets from the Civil War to the Vietnam War. Despite evidence, it was believed that tourniquet use would likely result in amputation of the injured limb, and the harmful effects of tourniquets outweighed the benefit.[35] Task Force Ranger's experience in Somalia reinvigorated tourniquet use for its effectiveness at quickly controlling hemorrhage.[36] Seemingly anachronistic, tourniquet use to quickly control hemorrhage has been proven to save lives throughout military history and revalidated throughout the current conflicts in Afghanistan and Iraq.

NCH, or non-tourniquet-able injuries, has been a challenge for the military for many years but has only been highlighted as problematic in the past 10 years. An article published in 2010 highlighting recommendations to decrease combat casualty deaths noted that the problem of NCH needs to be addressed to prevent death in the military prehospital setting.[37] A landmark article published in 2012 that reviewed Afghanistan and Iraq battlefield trauma data from 2001 to 2011 showed that most casualties (87.3 percent) died in the prehospital setting. A further extrapolation of that data showed that 75.7 percent of those injuries were deemed nonsurvivable, while 24.3 percent were classified as potentially survivable.[38] Hemorrhage was the leading cause of death of the potentially survivable casualties, and of those, 13.5 percent were tourniquet-able injuries while 86.5 percent were not.[39] A further study reviewed 15,209 U.S. battle injuries from 2001 to 2012 and identified that NCH created a significant mortality burden in combat casualty and recommended a prehospital solution be sought.[40]

The problem of NCH is evident in the civilian trauma community as well. In the U.S. civilian setting, injury is the leading cause of death between the ages of 1 and 44 years, and NCH is second only to head injury for lethality.[41] The first civilian study of the problem of NCH was completed in 2013. It reviewed 3 years of trauma data from the U.S. National Trauma Data Bank and showed a 44.6 percent mortality rate associated with NCH.[42] These articles illuminate the clear and present gap of NCH control, which has been a persistent problem throughout warfare. By understanding battlefield mortality (and its corollaries in civilian trauma) and the implication of NCH on survivability, the enterprise can begin to appreciate the explicit requirement for the SST.

Early Blood Administration (the Evidence). The last component of the SST is early blood administration, preferably whole blood (WB).[43] Blood and blood products, notably WB,[44] are vital components in combat casualty care, prolonged care settings, and Damage Control Resuscitation and Surgery

In-Flight REBOA

The loss of perfusion was confirmed with lack of carotid pulse.[*]

A small, dynamic, and highly mobile expeditionary surgical element faced a dilemma.[†] While forward staged in support of combat operations in a remote location, the team was alerted about a severely injured casualty. Arriving to the patient via rotary-wing aircraft within 27 minutes from time of injury, the team quickly began Damage Control Resuscitation while in flight. On examination, the medical team noted that the patient had a cricothyrotomy in place, a fast (and weak) carotid pulse, and decreased cardiac activity (noted on ultrasound examination).[‡] The team also noted an entrance wound to the right side of the face with an exit wound to the right posterior skull. On confirmation of good airway establishment, the casualty lost vital signs, and the team started chest compressions.[§]

After resuscitation with cardiac medications, packed red blood cells, and Low Titer O Whole Blood, the patient had a return of spontaneous circulation (ROSC). The patient then suffered another loss of pulses, and the team again began aggressive resuscitative measures. After another ROSC, the team, under ultrasound guidance, on a rotary-wing platform, and in low illumination, placed a Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)[¶] catheter in the left femoral artery.[**]

The current Joint Trauma System Clinical Practice Guidelines describe the use for REBOA in penetrating abdominal, pelvic, or junctional injuries in hypotensive patients (systolic blood pressure <90) or traumatic arrest patients.[††] In this case, REBOA was used to improve hemodynamic instability due to hemorrhagic shock that is not currently outlined in standard practice with the intent to maintain adequate brain perfusion. The point is that a well-trained medical team can perform this difficult procedure (or other lifesaving interventions) under arduous, dynamic, and extreme conditions to save lives on the battlefield.

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[*] Shaun R. Brown et al., "Successful Placement of REBOA in a Rotary Wing Platform Within a Combat Theater: Novel Indication for Partial Aortic Occlusion," *Journal of Special Operations Medicine* 20, no. 1 (2020), 34.

[†] Personal discussion with Lieutenant Commander Shaun Brown, U.S. Army surgeon, October 16, 2020.

[‡] Cricothyrotomy (cricothyroidotomy) is a surgical airway made in a life-threatening circumstance where an incision is made through the skin and cricothyroid membrane.

[§] Brown et al., "Successful Placement of REBOA in a Rotary Wing Platform Within a Combat Theater," 34.

[¶] Resuscitative Endovascular Balloon Occlusion of the Aorta is a catheter with an inflatable balloon inserted into the femoral artery and used to occlude large blood vessels to assist in temporary hemorrhage control.

[**] Ibid.

[††] Joint Trauma System (JTS) Clinical Practice Guidelines ID 38, *Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for Hemorrhagic Shock* (Washington, DC: JTS, March 31, 2020).

(DCRS).[45] These products, including WB, are safe, crucial elements for combat casualty care, improve survivability on the battlefield, and quickly transform into a walking blood bank (WBB).[46] WB has been used in combat from World War I to the Vietnam War.[47] Between March 1967 and June 1969, approximately 364,900 transfusions were recorded in Vietnam, with only 38 significant reactions (1:9,600), demonstrating its safety profile.[48] More recent battlefield data indicate that prehospital blood product transfusion given within minutes of injury was associated with greater 24-hour and 30-day survival benefit versus delayed transfusion or no transfusion.[49] Another study of Afghanistan and Iraq combat casualty care data from 2001 to 2017 showed that early blood administration prevented 873 deaths, translating to the overall prevention of 23.8 percent additional deaths.[50] These current findings support that prehospital transfusion in the combat casualty care environment improves survivability.

The use of WB is an unequivocally superior lifesaving product in combat casualty care, civilian-related trauma, and DCRS.[51] Also, fresh WB can be drawn from a pool of identified personnel (donors), given immediately (in extremis at or near the point of injury), or stored for up to 24 hours for later use. A study published in 2020 reviewed data from 2016 to 2019 of 15 successful transfusions of cold-stored low titer O whole blood (LTOWB)[52] at point of injury and determined its feasibility.[53] WB donors can be screened with tandem blood drawn and the blood stored or transported for up to 35 days to optimize the WB supply network. The simplest and safest method for operational use is identifying and screening a pool of LTOWB donors (approximately 21 percent of the population) and forming a dynamic walking blood bank to bridge this gap. WB is peerless as a resuscitative fluid for trauma, and it is a safe transfusion product capable of transforming into a dynamic WBB and improving battlefield survivability.

Aeromedical evacuation and logistics will be challenged on the future battlefield, especially in large-scale combat operations. Resupply of blood and blood products has relied on fixed-wing and rotary-wing resupply, yet U.S. rotary-wing assets have not been used in a peer-on-peer or near-peer conflict.[54] Threats and challenges presented by adversaries and the operational environment justify the requirement of WB in the current and future battlefield at or near the point of injury.

The U.S. capability to conduct resupply in semipermissive and nonpermissive environments has atrophied.[55] The need to access, store, transport, deliver, thaw, and administer blood components on the battlefield due to the cold-chain requirements and logistical tail for current blood therapy will prove challenging for the

Whole Blood at Point of Injury

*Novel and extreme techniques including far forward "buddy transfusions"**

A 33-year-old Active-duty Ranger suffered a significant right-sided complex blast injury from an improvised explosive device during combat operations in a remote location in Afghanistan.† He suffered substantial soft tissue injuries, massive internal injuries to his lungs and abdomen, and significant blood loss. Under cover of darkness and under fire, he was immediately stabilized by medics who, within minutes, immediately placed tourniquets, a pelvic binder, relieved life-threatening pulmonary injuries, initiated intravenous access, and gave Tranexamic acid. The Ranger was given four units of cold-stored whole blood (CSWB), and then the unit activated their Ranger group O low titer walking blood bank.‡ While still engaged in active combat, three units of fresh whole blood (FWB)§ were drawn from co-located unit members who were pre-identified and prescreened.¶

Two units of FWB were given on the ground. The other unit collected was administered on the casualty evacuation aircraft (with two additional units of CSWB) en route to an awaiting Forward Resuscitative Surgical Detachment.** The Ranger underwent a significant resuscitative and surgical course in the days that followed. On post-injury day 3, he arrived at the San Antonio Military Medical Center under the Extracorporeal Membrane Oxygenation team's care and transport.††

* Clayton J. Lewis et al., "Fresh Whole Blood Collection and Transfusion at Point of Injury, Prolonged Permissive Hypotension, and Intermittent REBOA," Journal of Special Operations Medicine 20, no. 2 (Summer 2020), 125.

† Personal discussion with Lieutenant Commander Ryan Knight, Regimental surgeon, 75th Ranger Regiment, August 26, 2020, and October 15, 2020.

‡ Walking blood bank (WBB) is a pool of pre-identified and prescreened blood donors called on in extremis for emergency blood donation.

§ Fresh whole blood is whole blood collected on an emergency basis from a WBB. Joint Trauma System (JTS) Clinical Practice Guidelines (CPG) ID 21, Whole Blood Transfusion (Washington, DC: JTS, 2018).

¶ JTS CPG ID 21, Whole Blood Transfusion, 123.

** The Forward Resuscitative and Surgical Detachment is a military medical element designed to provide far forward damage control resuscitation and damage control surgery to stabilize casualties for further medical evacuation to the next higher role of medical care. Army Techniques Publication 4-02.25, The Medical Detachment, Forward Resuscitative and Surgical (Washington, DC: Headquarters Department of the Army, December 2020), 1-1.

†† Lewis, "Fresh Whole Blood Collection and Transfusion at Point of Injury, Prolonged Permissive Hypotension, and Intermittent REBOA," 124; Lucas Tomlinson, "'Almost Impossible Mission': The 8,000-Mile Nonstop Flight to Save a U.S. Soldier's Life," Fox News, available at <https://www.foxnews.com/us/almost-impossible-mission-the-8000-mile-non-stop-flight-to-save-a-us-soldiers-life>; Oriana Pawlyk, "'They Weren't Gonna Stop': Inside the 8,000-Mile Race to Save a Wounded Soldier's Life," Military News, available at <https://www.military.com/daily-news/2019/09/28/they-werent-gonna-stop-inside-8000-mile-race-save-wounded-soldiers-life.html>.

joint force. The current and future operational environment makes it necessary to treat and sustain combat casualties in a dynamic setting for extended periods. The gap lies in blood logistics in the combat casualty care and prolonged care settings in the current and future operating environment and the full spectrum of joint force operations.[56]

Recommendations and the Art of the Possible (the How). Variables that may affect casualty outcomes are weapons effects, casualty numbers, weather, geography, illumination, national and strategic goals in risk mitigation, enemy composition, disposition, capability, and capacity.[57] It is important to note that the best medicine on the battlefield is fire superiority. Still, the SST's employment as a contributor to the chain of survival will improve outcomes of combat casualties when the joint force overmatch is challenged. The current juncture has provided overwhelming combat trauma data, and the Nation's military will be best served by synthesizing Joint Trauma System lessons.

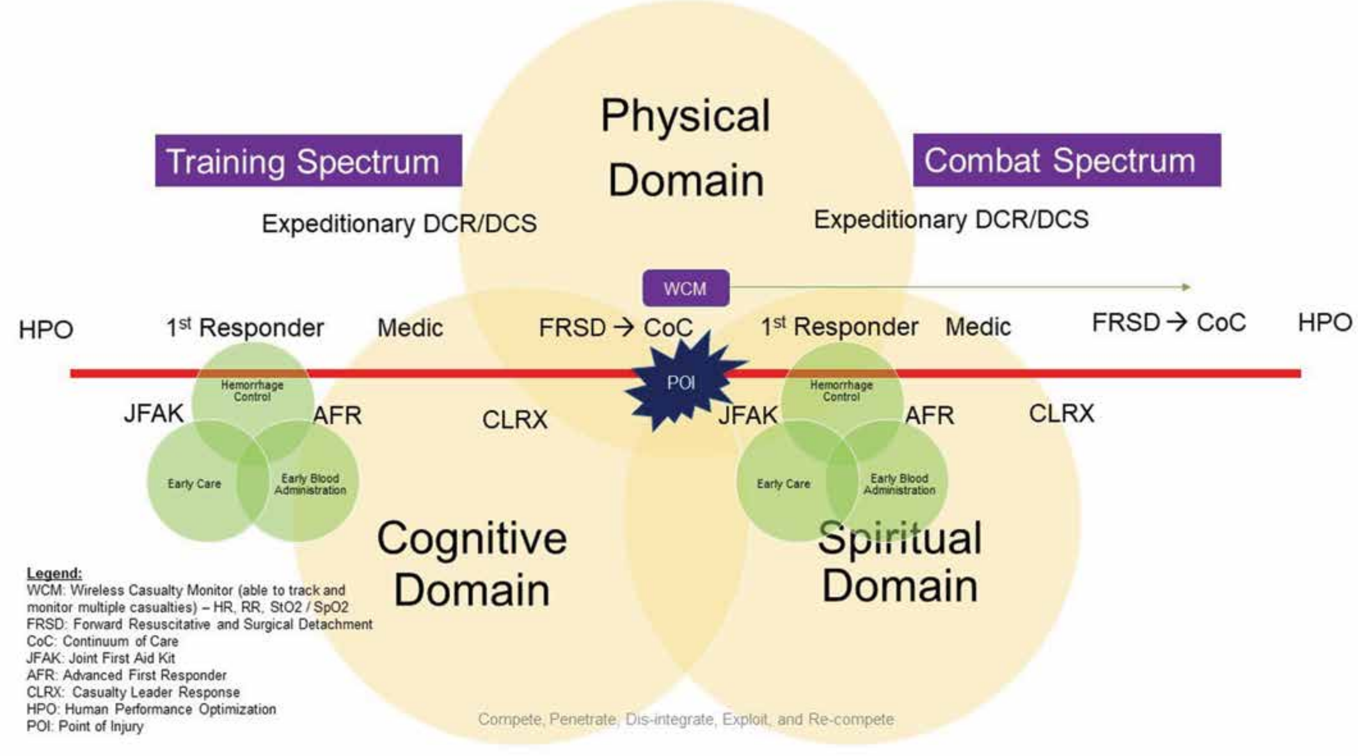
Focusing on the human-centric physical, cognitive, and spiritual domains is foundational to the SST and joint force survivability. Note that all the elements discussed above and in figure 1 are human-centric, not materiel-centric. As new treatment protocols are introduced, people will still be required to train and be trained, perform the interventions required, and decide to be at the right place at the right time to save the most lives. From this foundational approach, four lines of effort arise in convergence to build ready and responsive forces for the joint force: optimize human performance, eliminate preventable death on the battlefield, develop medical leaders, and promote the health of the force. The military must maximize every opportunity to improve battlefield care and seek opportunities to remain dynamic and agile to create a solution.

Implementing the SST is a clarion call to action requiring awareness of the problem, identification of gaps, and a deliberate method to mitigate these gaps. Here, one can either choose to be a zealot or a martyr, and zealots are needed in the pursuit of joint force survivability. The SST goes hand in hand with the building blocks of TCCC: prevent injury (through cognitive, physical, and spiritual conditioning), mitigate injury extent (through contingency training and personal protective equipment), and optimize care of the combat casualty (through flawlessly executed TCCC).[58] The following recommendations for the SST provide a framework for the military to improve the joint force's survivability. They are provided in three time frames: near-term (present to 2 years), mid-term (3 to 5 years), and far-term (5 years or more).

Recommendations

Early Intervention. Risk is inherent in every military operation, and mitigating the risk to mission, force, and the command by medical design is requisite in planning. Early care or evacuation happens not by circumstance but by deliberate planning, training, and effort. Unfortunately, some medical personnel (providers and planners alike) will separate medical readiness from healthcare delivery. This only creates confusion and division; one cannot be effective without the other.

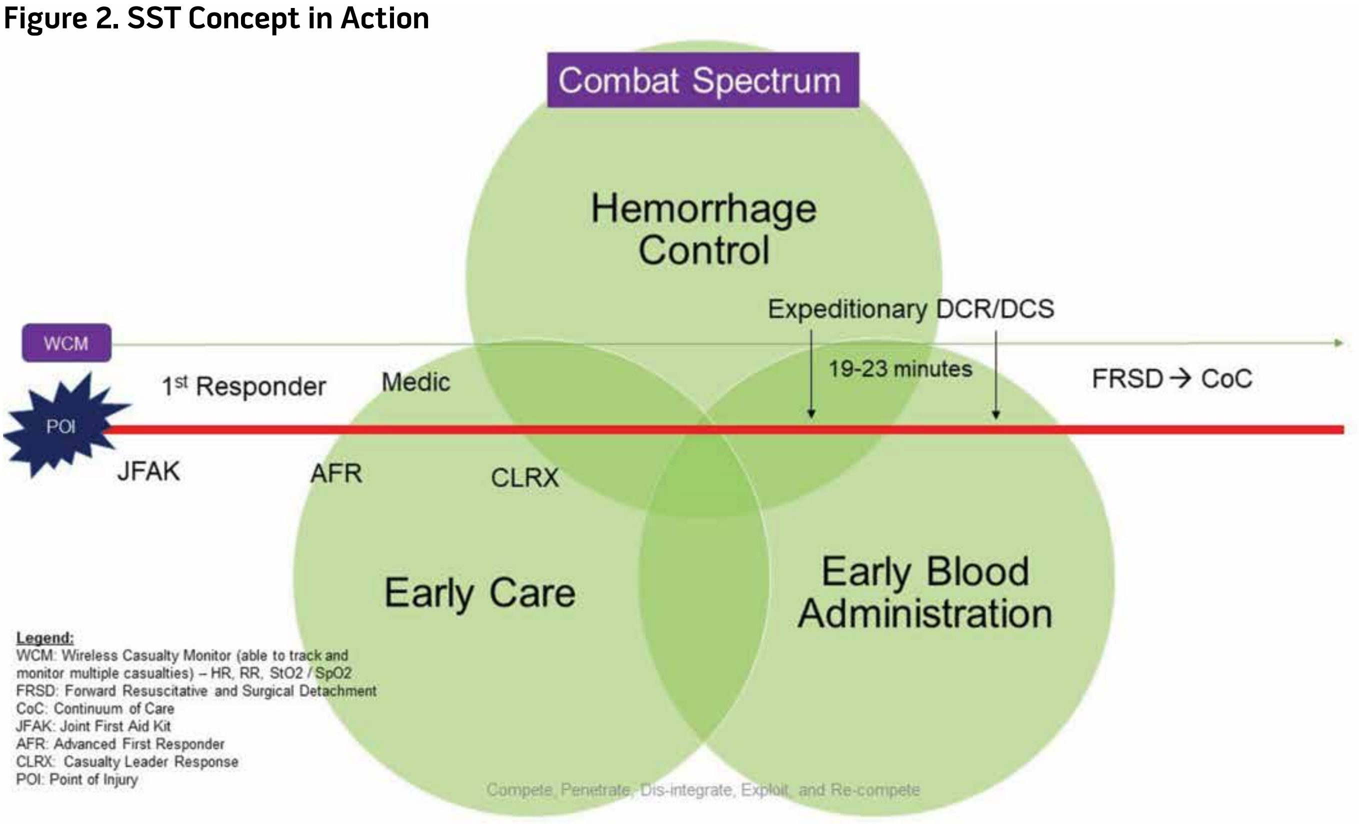
Figure 1. Holistic Continuum of Care



Near-term. Integrate fundamental elements of SST into existing organizational structures. Make TCCC ubiquitous, trained, and employed across the joint force. Ensure that a unit casualty response system is codified, implemented, and rehearsed at the tactical and operational levels. This response system should outline standards for nonmedical personnel, medics, leaders, and casualty transport, and should cover actions for one or many casualties.[59] Train military medics to the highest level capable. The essential principle of this training is to be overtly capable of delivering a live, warm, and noncoagulopathic patient to surgical care as quickly as possible and maintain that level of competence.[60] Ruthlessly pursue metrics that evaluate eliminating preventable death on the battlefield and care of the combat casualty.

Mid-term. Continue to cultivate strategic partnerships with the American College of Surgeons and the Military Health System (in conjunction with the Defense Health Agency) to further enhance civilian-military relationships to create training platforms for the sustainment of critical wartime skills. This will cultivate a culture of optimizing care for the injured patient and establish greater civilian-military medical collaboration. This will also inculcate the principles of a learning organization. In addition, continue to enable, enhance, and develop medical strike teams that focus on highly mobile and expeditionary DCRS. These medical strike teams can

Figure 2. SST Concept in Action



A brigade-size ground force element (GFE) with multifunctional capability contacts an enemy force during hours of limited visibility. The GFE sustains multiple casualties in the initial moments of contact. First responders immediately begin to control overt bleeding. The advanced first responders (AFR), assigned one per squad, assist in bleeding control, obtain intravenous access, and perform casualty warming. Moments later, the medic arrives, assesses the situation, places wireless casualty monitoring and tracking devices (WCM) on the casualties. These WCMs are linked to the medic's smart device and provide predictive analysis of casualties' status and outcomes, simultaneously sending a status update or ping to the ground force commander and the joint force headquarters. This ping alerts the continuum of care enterprise, most importantly, a medical strike team. The joint battle staff are also pinged to ensure global that integration of combat power, anticipated blood requirements, logistical concerns, and transportation needs are synchronized for the GFE. The GFE has now mounted a counterassault, initiated their casualty response plan, and cross-domain synergy has provided layered effects for lethality, protection, and survivability. The GFE begins to target, degrade, and eliminate the enemy force. Within minutes, the medic and the AFR have bleeding controlled, blood products are being delivered to the sickest casualties, packaging for movement, and the medical strike team is en route with an anticipated arrival time of N+20 minutes to provide care and transport, platform agnostic. The ping sent via the WCM can also communicate across the continuum of care and to U.S.-based facilities and the Joint Trauma System to facilitate care and anticipate patient holding and movement requirements and continuous performance improvement.

Navy corpsmen assigned to 1st Marine Division activate Valkyrie blood transfusion under supervision of evaluators during expeditionary medical integration course, Camp Pendleton, California, May 5, 2022 (U.S. Marine Corps/Dana Beesley)

be adaptive to any role of care but are flexed and optimized to concentrate in the spaces between doctrinally defined roles of care on the battlefield.[61] These medical strike teams can also be leveraged to assist in operational and strategic evacuation, providing mobile or expeditionary DCRS on various platforms. The medical strike teams can also accompany contact, blunt, or surge forces to support calibrated force posture, enhance multidomain formations, and optimize convergence by leveraging time, space, and joint force capabilities. Develop simple autonomous casualty tracking devices that are interoperable across the continuum of care. These devices should employ vital signs and provide predictive analysis of patient outcomes but not increase caregiver cognitive load at any level of care. Drone evacuation of patients will enhance casualty transport and push medical and nonmedical "speedballs" forward to enhance logistical reach.[62] The logistical speedballs can be managed by predictive analysis through artificial intelligence/machine-learning support to optimize early and, if required, supportive medical care.

Far-term. Develop devices that are both diagnostic and therapeutic and are semiautonomous to autonomous. The current military medical market is replete with diagnostic devices, but devices that can provide a solution and lifesaving interventions will be required for the future hyper-dynamic environment. This is not unlike the current Automatic External Defibrillator, which, with some fundamental training, a layperson can operate to save a life. A simple example would be an ultrasound device that detects a chest injury and simultaneously provides the necessary intervention. In addition, consider using Extracorporeal Membrane Oxygenation or other far-forward resuscitative and surgical efforts targeted at those previously termed *nonsurvivable*, which comprise 52.1 percent of acute pre–military treatment facilities deaths that occur within minutes to hours.[63]

Noncompressible Hemorrhage Control. Aggressively and actively pursue an NCH solution at the national level and by the joint force and potentially led by the Joint Trauma System. As discussed, NCH is a problem for both military and civilian traumatologists; this implies an opportunity for a synergistic solution and action. What may be required is a fresh perspective that is not anchored by the confines of looking at the same conundrum to confront an old and persistent problem.

Near-term. Ensure that every medic is equipped and adequately trained in treating NCH with approved external compression devices.[64] Next, employ resuscitative endovascular balloon

U.S. Airmen assigned to Special Operations Task Force–East Africa Critical Care Air Transport Team perform medical casualty care response exercise from Camp Lemonnier, Djibouti, to tactical forward operating base in East Africa, July 3, 2021 (U.S. Air Force/Daniel Asselta)

occlusion of the aorta (REBOA) at the lowest yet safest level possible.[65] Some restraint must be used for this capability, but balance risk versus reward in terms of lives saved through objective assessment. Simple training in early identification, problem recognition, and employment of a bleeding control bundle[66] has been demonstrated to decrease mortality by up to 30 percent.[67] An initial balance may span or even be found between noninvasive, minimally invasive, and invasive procedures. Ensure providers charged with DCRS can perform REBOA. Ensure medical providers are engaged in medical and surgical practices at high-volume/high-acuity centers to prepare to provide these interventions.

Mid-term. Focus aggressively on efforts that can arrest NCH. Look outside the scope of medicine and consider projects or proposals that demonstrate good scientific merit for hemorrhage control. Streamline the research and development process. Presently, there are potential NCH products that have been under research and development for more than 8 years. Develop adjunct therapies that can improve intrinsic coagulation.

Far-term. Invest in promising nanotechnology, nanofibers, and tissue-targeted therapy that arrest hemorrhage.[68] Incentivize and challenge military and civilian combat casualty care research. Divest of minimally or nonproductive portfolios and redundant programs. Promote seedling research and consider phased research that is uncertain yet holds great promise.

Early Blood Administration. The evidence confirming that WB is the resuscitation fluid of choice for the combat casualty suffering from traumatic injury is unequivocal. Those who refute the evidence are anchored by inherent bias. This bias only creates friction for WB use and limits the potential to save more lives. Ensure that the Joint Trauma System is staffed and resourced to drive innovative solutions and possesses the ability to collaborate with civilian partners. A key strategic partner is the Armed Services Blood Program; continue to empower it to create novel solutions and policies.

Near-term. Blood, preferably WB, should be carried at the lowest medical level possible and available throughout the continuum of care. This implies a new but not unsolvable logistical project. At the tactical level, combat medics, corpsmen, combat paramedics, and medical technicians (collectively hereafter referred to as "medics") and providers must be trained to carry, store, draw, and administer WB at or near the point of injury and through the continuum of care. Training should also emphasize the storage and delivery of blood and blood products across the continuum. Update current Department of Defense policy to reflect changes in blood delivery enhancement and transfusion and work toward a shared understanding with the Food and Drug Administration to bring this critical capability to fruition. Ensure blood compatibility (ABO typing) testing is accurate and screen and identify LTOWB donors for employment as universal donors. For the joint force, this would be a dynamic walking blood bank. A translational example for replication in the joint force for operational use is a carrier strike group, operated by approximately 7,500 personnel equaling a donor pool of about 1,575 personnel providing WB through prescreened donors to support unified land operations.[69] Finally, a solid understanding of WBB requirements and employment needs to be shared across the military. This can be achieved through global integration.

Mid-term. Work across the joint, interagency, intergovernmental, and multinational environments for novel solutions to extend the shelf life, carrying capability, carrying capacity, and delivery of blood and blood products across the tactical through strategic environments. Examples include (but are not limited to) bio-enhancement, bioengineering, refrigeration, and storage. Seek and create novel solutions to extend the shelf life of blood and blood products. Other capabilities include enhanced delivery of blood for the military. These could come in the form of enhanced aerial delivery, drone delivery, casualty drone backhaul, or robotic delivery.

Far-term. Leverage science and technology to look at the possibility of farming or harvesting blood. For example, seek capabilities to draw one unit of blood from a donor and turn that unit into two or more WB units capable of transfusion. The CRISPR (clustered regularly interspaced short palindromic repeats) and CRISPR-Cas9 (CRISPR associated protein 9)[70] genome editing tools can be used to enhance the capability of blood through the expression of factors that may benefit the sickest or most injured combat casualties. These recommendations need further research and a shared understanding with authorities that manage regulatory requirements, thus necessitating a bridging and mitigation strategy. If the enterprise placed equal effort on this as it did for COVID-19 vaccine development, we could be positioned for a solution.

Conclusion: A Clarion Call to Action

The Strategic Survivability Triad begins with the chain of survival and integrates three overarching medical concepts—early intervention, rapid control of noncompressible hemorrhage, and early blood administration. The SST's value and relevance for the military are justified by providing current evidence-based medicine and analysis. Holistically operationalizing the SST will save lives and improve combat casualty care. The SST will also enhance the chain of survival in multidomain operations and the continuum of war, support the full actualization of combat power, and realize U.S. strategic objectives, all while preserving the joint force. The careful array, employment, and convergence of the SST will immediately and unequivocally improve the joint force's survivability on the current and future battlefield while mitigating risk.

The United States is seemingly entering an interwar era. There has never been a more critical and necessary time than now for military medical innovation, ingenuity, and action. The interwar period is where hard-learned medical lessons cyclically and mercilessly fall prey to the peacetime effect or the Walker Dip. These lessons are lost, forgotten, or even doubted. In contrast, military medical leaders must redouble efforts in analysis, research, application, and training in the interwar era to improve trauma readiness and outcomes through evidence-driven performance improvement.[71] This task has been given to the Joint Trauma System but needs to resonate throughout the medical force to fill in the gaps of the Walker Dip.

Over the last 20 years, robust work has been done on collecting, analyzing, and publishing combat casualty data. Translation of that data into actionable solutions is the next step. More than ever, the urgent and direct need for revolutionary medical action is required to save lives on the battlefield and decrease the mortality and morbidity of the joint force. This is a clarion call to action. Some have advocated that national commitment to research is required to continue advancing trauma care outside of warfare, even in areas that, despite sparse data, may offer great promise to lives saved.[72] The framework outlined in the zero-preventable deaths landmark report will provide strategic direction.[73] Academic, medical, and scientific collaboration with like-minded and zealous civilian partners will amplify the joint force's battlefield survivability. Ensuring battlefield survivability is an ongoing no-fail mission. Operationalizing the SST into a strategic pursuit will require zeal, vision, and acceptance; our nation deserves no less. **JFQ**

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Notes

[1] Steve Cunningham, *Key Strategic Issues List (KSIL) 2021–2022* (Carlisle, PA: U.S. Army War College Press, July 7, 2020), available at <https://press.armywarcollege.edu/cgi/viewcontent.cgi?article=1403&context=articles_editorials>.

[2] The *Golden Hour* is a medical term with the premise that an injured patient has 60 minutes from the time of injury to receive definitive care. After 60 minutes, mortality and morbidity dramatically increase.

[3] Aaron Mehta, "'No Lines on the Battlefield': Pentagon's New War-Fighting Concept Takes Shape," *Defense News*, August 14, 2020, available at <https://www.defensenews.com/pentagon/2020/08/14/no-lines-on-the-battlefield-the-pentagons-new-warfighting-concept-takes-shape/>.

[4] Richard N. Lesperance, Steven Adamson, and Jennifer M. Gurney, "Lessons Learned During Prolonged Care of Combat Casualties by a Minimally Manned Surgical Team," *Military Medicine*, July 17, 2021.

[5] *Tactical Combat Casualty Care* (TCCC) refers to trauma management guidelines used in the operational setting. Its focus is on preventable death resulting from combat.

TCCC is the Department of Defense (DOD) standard of care for first responders (medical and nonmedical). The TCCC All Service Member course replaced Service trauma skills currently taught in first aid and self-aid buddy care courses, per DOD Instruction 1322.24, *Medical Readiness Training* (Washington, DC: DOD, March 16, 2018).

[6] The term *preventable death* denotes control of external hemorrhage, relief of airway obstruction, and relief of tension pneumothorax. The term is nearly synonymous with potentially survivable injuries. *Potentially survivable injuries* imply opportunities for performance improvement while preventable death may be perceived as wrongdoing. See Brian J. Eastridge et al., "Death on the Battlefield," *Journal of Trauma and Acute Care Surgery* 73, no. 6, suppl. 5 (2012), S435; Russ S. Kotwal et al., "Eliminating Preventable Death on the Battlefield," *Archives of Surgery* 146, no. 12 (2011), 1350–1358.

[7] Robert L. Mabry and Robert DeLorenzo, "Challenges to Improving Combat Casualty Survival on the Battlefield," *Military Medicine* 179, no. 5 (2014), 477; Kotwal et al., "Eliminating Preventable Death on the Battlefield."

[8] "Changes by Robert Gates Kept U.S. Troops Alive in Afghanistan," *Columbus Dispatch*, October 3, 2015, available at <https://www.dispatch.com/story/news/military/2015/10/03/changes-by-robert-gates-kept/23778371007/>; Robert M. Gates, Memorandum for the Commander, U.S. Central Command, "Afghanistan MEDEVAC Assessment," DOD, June 15, 2009.

[9] Russ S. Kotwal et al., "The Effect of a Golden Hour Policy on the Morbidity and Mortality of Combat Casualties," *JAMA Surgery* 151, no. 1 (2016), 15–24.

[10] Frederick B. Rogers and Katelyn Rittenhouse, "The Golden Hour in Trauma: Dogma or Medical Folklore?" *The Journal of Lancaster General Hospital* 9, no. 1 (Spring 2014), 12, available at <http://jlgh.org/JLGH/media/Journal-LGH-Media-Library/Past%20Issues/Volume%209%20-%20Issue%201/Rogers9_1.pdf>.

[11] During the 2013 Military Health System Research Symposium in Fort Lauderdale, Florida, Commodore Alasdair Walker, the United Kingdom's Military Health Services' Medical Director, described a concept called the "Walker Dip." Dr. Walker discussed the inadequate medical care available to British forces during the Crimean War. He traced recurrent historical cycles whereby medical care improves during conflicts, but the lessons are forgotten and relearned during the next war. See Robert L. Mabry, "Challenges to Improving Combat Casualty Survival on the Battlefield," *Joint Force Quarterly* 76 (1st Quarter 2015), 83.

[12] Personal discussion with Dr. Robert Mabry, Principal Deputy Assistant Secretary of Defense for Health Affairs, July 2, 2020.

[13] Personal discussion with Dr. Jeremy W. Cannon, MD, S.M., FACS, Division of Traumatology, Surgical Critical Care & Emergency Surgery, Perelman School of Medicine at the University of Pennsylvania, November 16, 2020.

[14] Eastridge et al., "Death on the Battlefield," S435.

[15] Frank K. Butler and John B. Holcomb, "The Military Learned to Stop the Bleeding: Many Civilian Lives Could Be Saved by Using Tourniquets," *Wall Street Journal*, December 20, 2020, available at <https://www.wsj.com/articles/the-military-learned-to-stop-the-bleeding-11608499774>.

[16] John B. Holcomb et al., "Understanding Combat Casualty Care Statistics," *The Journal of Trauma: Injury, Infection, and Critical Care* 60, no. 2 (February 2006), 398.

[17] Jeffrey T. Howard et al., "Use of Combat Casualty Care Data to Assess the U.S. Military Trauma System During the Afghanistan and Iraq Conflicts, 2001–2017," *JAMA Surgery* 154, no. 7 (2019), 600, 606.

[18] "Joint Trauma System," Department of Defense Center of Excellence for Trauma, available at <https://jts.amedd.army.mil>.

[19] Personal discussion with Lieutenant Commander Ronald D. Hardin and Major Jigar Patel, U.S. Army surgeons, September 21, 2021.

[20] Alfred S. Gervin and Ronald P. Fischer, "The Importance of Prompt Transport in Salvage of Patients with Penetrating Heart Wounds," *The Journal of Trauma: Injury, Infection, and Critical Care* 22, no. 6 (June 1982), 443, 446.

[21] Personal discussion with Colonel Kyle N. Remick, MD, FACS, Special Assistant to Combat Support Agency Director, National Capital Region Market Trauma and Emergency Medical System, Professor and Associate Chair for Operations, Uniformed Services University, Walter Reed Department of Surgery, December 14, 2020.

[22] Kyle N. Remick et al., "Defining the Optimal Time to the Operating Room May Salvage Early Trauma Deaths," *The Journal of Trauma and Acute Care Surgery* 76, no. 5 (2014), 1256.

[23] Ibid.

[24] Russ S. Kotwal et al., "The Effect of Prehospital Transport Time, Injury Severity, and Blood Transfusion on the Survival of U.S. Military Casualties in Iraq," *The Journal of Trauma and Acute Care Surgery* 85, suppl. 1 (2018), S117.

[25] *Scoop and run* is a prehospital medical concept based on transportation with little or no medical intervention. This is opposite to the prehospital concept of *stay and play.* "Researchers have discovered what gang members have known all along—that you're more likely to survive a serious injury if you get yourself to hospital than if you wait for an ambulance." See Zosia Kmietowicz, "In Cases of Serious Injury 'Scoop and Run' Improves Survival Compared with Ambulance," *BMJ*, September 22, 2017.

[26] Michael W. Wandling et al., "Association of Prehospital Mode of Transport with Mortality in Penetrating Trauma," *JAMA Surgery* 153, no. 2 (2018), 107, 108.

[27] Kotwal et al., "The Effect of Prehospital Transport Time, Injury Severity, and Blood Transfusion on the Survival of U.S. Military Casualties in Iraq," S112.

[28] Howard et al., "Use of Combat Casualty Care Data to Assess the U.S. Military Trauma System During the Afghanistan and Iraq Conflicts, 2001–2017," 600.

[29] Donald Berwick, Autumn Downey, and Elizabeth Cornett, eds., *A National Trauma Care System: Integrating Military and Civilian Trauma Systems to Achieve Zero Preventable Deaths after Injury* (Washington, DC: National Academies Press, 2016), 89.

[30] A *noncompressible hemorrhage* is a hemorrhage that arises from within the torso. Traditionally, gaining access and purchase to these sites requires surgical intervention. For this article, the term *noncompressible truncal hemorrhag*e was intentionally avoided to maintain simplicity and have a broader scope.

[31] Eastridge et al., "Death on the Battlefield," S434.

[32] S.E. van Oostendorp, E.C.T.H. Tan, and L.M.G. Geeraedts, Jr., "Prehospital Control of Life-Threatening Truncal and Junctional Haemorrhage Is the Ultimate Challenge in Optimizing Trauma Care; A Review of Treatment Options and Their Applicability in the Civilian Trauma Setting," *Scandinavian Journal of Trauma, Resuscitation, and Emergency Medicine* 24, no. 110 (2016), 2.

[33] J.S. Maughon, "An Inquiry into the Nature of Wounds Resulting in Killed in Action in Vietnam," *Military Medicine* 135, no. 1 (1970), 8–13; Eastridge et al., "Death on the Battlefield," S434; Shawn C. Nessen et al., "Unrealized Potential of the U.S. Military Battlefield Trauma System: DOW Rate Is Higher in Iraq and Afghanistan Than in Vietnam, but CFR and KIA Rate Are Lower," *The Journal of Trauma and Acute Care Surgery* 85, suppl. 2 (2018), S7.

[34] David R. Welling et al., "A Brief History of the Tourniquet," *Journal of Vascular Surgery* 55, no. 1 (2012), 286.

[35] Frank K. Butler, Jr., "Military History of Increasing Survival: The U.S. Military Experience with Tourniquets and Hemostatic Dressings in the Afghanistan and Iraq Conflicts," *Journal of Special Operations Medicine* 15, no. 4 (Winter 2015).

[36] Ibid.; John F. Kragh et al., "Historical Review of Emergency Tourniquet Use to Stop Bleeding," *American Journal of Surgery* 203, no. 2 (2012), 9; Robert L. Mabry et al., "United States Army Rangers in Somalia: An Analysis of Combat Casualties on an Urban Battlefield," *The Journal of Trauma: Injury, Infection, and Critical Care* 49, no. 3 (September 2000), 526.

[37] Lorne H. Blackbourne et al., "Decreasing Killed in Action and Died of Wounds Rates in

Combat Wounded," *The Journal of Trauma: Injury, Infection, and Critical Care* 69, no. 1 (July 2010), S1.

[38] Eastridge et al., "Death on the Battlefield," S433.

[39] Ibid., S434.

[40] Adam Stannard et al., "The Epidemiology of Non-Compressible Torso Hemorrhage in the Wars in Iraq and Afghanistan," *The Journal of Acute Care and Surgery* 74, no. 3 (2013), 831–833.

[41] David R. King, "Initial Care of the Severely Injured Patient," *New England Journal of Medicine* 380, no. 8 (February 21, 2019), 763; Oostendorp, Tan, and Geeraedts, "Prehospital Control of Life-Threatening Truncal and Junctional Haemorrhage," 2.

[42] Mehreen Kisat et al., "Epidemiology and Outcomes of Non-Compressible Torso Hemorrhage," *Journal of Surgical Research* 184, no. 1 (2013), 418.

[43] *TCCC Guidelines* (Washington, DC: Deployed Medicine, Joint Trauma System [JTS], December 15, 2021).

[44] Whole blood (WB) collected in the anticoagulants CPD (citrate-phosphate-dextrose) or CPDA-1 (CPD-adenine) is a Food and Drug Administration–approved product when appropriately collected, stored, and tested for transfusion-transmitted disease by a licensed blood donor center. See JTS Clinical Practice Guideline (CPG) ID 21, *Whole Blood Transfusion* (Washington, DC: JTS, May 15, 2018).

[45] *Damage control resuscitation* (DCR) is a complementary strategy to damage control surgery; the goal of DCR is to stabilize a casualty enough for surgery. DCR prioritizes nonsurgical interventions to reduce morbidity and mortality from trauma and hemorrhage. The major principles of DCR are to restore homeostasis, prevent or mitigate the development of tissue hypoxia, oxygen debt, the burden of shock, and coagulopathy. *Damage control surgery* focuses on surgical interventions that address life-threatening injuries and delay all other surgical care until metabolic and physiologic derangements have been treated. See JTS CPG ID 18, *Introduction to Damage Control Resuscitation* (Washington, DC: JTS, July 2019).

[46] Eve Meinhardt, "'Walking Blood Banks' Fill Gap for Medical Care in Field Environment," *Army.mil*, October 8, 2019, available at <https://www.army.mil/article/224502/walking_blood_banks_fill_gap_for_medical_care_in_field_environment>.

[47] Jennine L. Callum and Peter H. Pinkerton, "Evacuation, Resuscitation, and Transfusion Near 'The Front,' First World War, 1918," *Transfusion* 58 (November 2018), 2476–2477.

[48] Spurgeon H. Neel, *Medical Support of the U.S. Army in Vietnam 1965–1970* (Washington, DC: Headquarters Department of the Army, 1991), 116–123.

[49] Stacy A. Shackelford et al., "Association of Prehospital Blood Product Transfusion During Medical Evacuation of Combat Casualties in Afghanistan with Acute and 30-Day Survival," *JAMA* 318, no. 16 (2017), 1581, 1586, 1590.

[50] Howard, "Use of Combat Casualty Care Data to Assess the U.S. Military Trauma System," 606.

[51] Phillip C. Spinella et al., "Warm Fresh Whole Blood Is Independently Associated with Improved Survival for Patients with Combat-Related Traumatic Injuries," *Journal of Trauma* 66, no. 4 (2009), S69, S71, S75; JTS CPG ID 21, *Whole Blood Transfusion*; John B. Holcomb and Donald H. Jenkins, "Get Ready: Whole Blood Is Back Again, and It Is Good for Patients," *Transfusion* 58, no. 8 (August 2018), 1821–1823; Shawn C. Nessen et al., "Fresh Whole Blood Use by Forward Surgical Teams in Afghanistan Is Associated with Improved Survival Compared to Component Therapy Without Platelets," *Transfusion* 53, suppl. 1 (2013), 109S; Alan D. Murdock et al., "Whole Blood: The Future of Traumatic Hemorrhagic Shock Resuscitation," *Shock* 41, suppl. 1 (2014), 67–68; Geir Strandenes et al., "Low Titer Group O Whole Blood in Emergency Situations," *Shock* 41, suppl. 1 (2014), 74.

[52] *Low titer O whole blood* (LTOWB) is whole blood from group O donors that has anti-A and anti-B antibody titers, is measured to ensure a low titer of antibody (for example, <1:256 saline dilution, immediate spin method), is designated LTOWB, and is used as "universal WB." JTS CPG ID 21, *Whole Blood Transfusion*.

[53] Andrew D. Fisher et al., "Low Titer Group O Whole Blood Resuscitation: Military Experience from the Point of Injury," *The Journal of Trauma and Acute Care Surgery* 89, no. 4 (2020), 838.

[54] Field Manual (FM) 3-04, *Army Aviation* (Washington, DC: Headquarters Department of the Army, April 2020), 1-5, 3-36; Army Techniques Publication 4-02.2, *Medical Evacuation* (Washington, DC: Headquarters Department of the Army, July 2019), 1-1, 2-3, 2-13, 2-16; Matthew Fandre, "Medical Changes Needed for Large-Scale Combat Operations: Observations from Mission Command Training Program Warfighter Exercises," *Military Review*, May–June 2020, 41; Joint Publication (JP) 4-02, *Joint Health Services* (Washington, DC: The Joint Staff, December 11, 2017, Incorporating Change 1, September 28, 2018), VI-12, F-11; FM 4-02.1, *Army Medical Logistics* (Washington, DC: Headquarters Department of the Army, October 2015), 3-15, 7-1, 7-5.

[55] Brent Thomas et al., *Toward Resiliency in the Joint Blood Supply Chain* (Santa Monica, CA: RAND, 2018), iii, 16, 47.

[56] JP 3-0, *Joint Operations* (Washington, DC: The Joint Staff, January 17, 2017, Incorporating Change 1, October 22, 2018), I-3–1-4; JP 3-18, *Joint Forcible Entry Operations* (Washington, DC: The Joint Staff, May 11, 2017, Incorporating Change 1, January 9, 2018, val. June 27, 2018), IV-13, B-5; JP 3-31, *Joint Land Operations* (Washington, DC: The Joint Staff, October 3, 2019), I-3, 1-4, V-1.

[57] Kotwal et al., "The Effect of Prehospital Transport Time, Injury Severity, and Blood Transfusion on Survival of U.S. Military Casualties in Iraq," S117.

[58] Russ S. Kotwal et al., "Leadership and a Casualty Response System for Eliminating Preventable Death," *The Journal of Trauma and Acute Care Surgery* 82, no. 6, suppl. 1 (2017), S11.

[59] Ibid., S11–S12.

[60] Andrew D. Fisher et al., "Tactical Damage Control Resuscitation," *Military Medicine* 180, no. 8 (2015), 873.

[61] JP 4-02, II-4; FM 4-02, *Army Health System* (Washington, DC: Headquarters Department of the Army, November 2020), 1-10–1-13.

[62] A *speedball* is a package that delivers emergency or on-demand resupply in military operations. Speedballs can be prepackaged or made on demand and delivered via various methods.

[63] Eastridge et al., "Death on the Battlefield," S432.

[64] As of August 1, 2019, there are three junctional tourniquets and devices recommended by the Committee on Tactical Combat Casualty Care, available at <https://learning-media.allogy.com/api/v1/pdf/67fb9587-eb0a-4ea0-ba3d-a0840e2a71a8/contents>.

[65] As of May 31, 2021, there are two REBOA (resuscitative endovascular balloon occlusion of the aorta) devices: the ER-REBOA and the COBRA-OS.

[66] *Bleeding control bundle* is an evidence-based set of actions, protocols, and/or equipment that is specifically targeted at arresting hemorrhage.

[67] Blessing T. Oyeniyi et al., "Trends in 1029 Trauma Deaths at a Level 1 Trauma Center: Impact of a Bleeding Control Bundle of Care," *Injury* 48, no. 1 (2017), 1, 4.

[68] Courtney E. Morgan et al., "Tissue-Factor Targeted Peptide Amphiphile Nanofibers as an Injectable Therapy to Control Hemorrhage," *ACS Nano* 10, no. 1 (2016), 899–909.

[69] Personal meeting with U.S. Army Forces Command Surgeon, XVIII Airborne Corps Surgeon, and XVIII Airborne Corps Deputy Surgeon for Clinical Operations, December 16, 2019.

[70] *CRISPR* is a tool for editing genomes, and it allows researchers to modify DNA sequences and alter gene function.

[71] Adopted from the "JTS Mission Statement," DOD Center of Excellence for Trauma, available at <https://jts.amedd.army.mil>.

[72] King, "Initial Care of the Severely Injured Patient," 768.

[73] Berwick, Downey, and Cornett, eds., *A National Trauma Care System.*