Boston Bombings: A Surgical View of Lessons Learned From Combat Casualty Care and the Applicability to Boston's Terrorist Attack

E. J. Caterson, MD, PhD, Matthew J. Carty, MD,* Michael J. Weaver, MD,* and Eric F. Holt, DO MBA, LTCOL, USAF, MC†*

The Boston bombing incident was a recent civilian mass casualty terrorist event that demonstrated effective transfer of the lessons of combat casualty care to inform effective civilian medical care. Thirty-nine patients were seen at Brigham and Women's Hospital and thirteen patients received emergency surgery in the first few hours after the event. The subsequent management, total hospital days 181, total number of operative procedures 72, and discharging service listing of these thirteen patients illustrate the intensive surgical resources necessary after a civilian bomb attack. Plastic surgery played a role in the multidisciplinary collaboration of the limb salvage efforts and this role can inform the importance of other plastic surgery contributions within mass casualty surgical management. We believe that prepositioned collaborative relationships of plastic surgery, vascular surgery, trauma surgery and orthopedic surgery may offer a model of collaboration for limb salvage that can be applied in military and mass casualty medical care if resources permit. In this attack, effective use of tourniquets was implemented by prehospital medical providers that saved lives and limbs and these actions reaffirm the important lessons learned from combat casualty care. Unfortunately, it is likely that more centers will deal with similar events in the future and it is imperative that we as a community of providers take what lessons we can from battlefield medicine and that we collectively prepare for and engage this future.

Key Words: Plastic surgery, terrorism, mass casualty, limb salvage, tourniquet, teamwork, boston bomb attack, combat casualty care

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From the *Brigham and Women's Hospital, Boston, MA; and †Uniformed Services University of the Health Sciences, Bethesda, MD.
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Address correspondence and reprint requests to E. J. Caterson, MD, PhD, Brigham and Women's Hospital, 75 Francis St, Boston, MA 02446; E-mail: ecaterson@partners.org
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This article has been written with the hope that the readers do not ever have the need to use the lessons gained through battlefield trauma care on the streets of their own communities. However, the act of being prepared will provide the best opportunity for medical providers to take leadership and to make decisions to reduce morbidity and mortality in another civilian terrorist attack. It is now the unfortunate reality that civilian terrorist threats will become part of the fabric of our future medical practice. Preparation, multidisciplinary teamwork, capacity, and luck all contributed to the medical care of the Boston bombing victims. My partner Matthew Carty was the surgeon "on call" for the Brigham and Women's Hospital plastic surgery service in Boston, and he, along with Michael Weaver, the orthopedic surgeon "on call," mobilized an exceptional team effort of limb-saving inpatient orthopedic/vascular/trauma and plastic surgery care that lasted over a month at our hospital. However, from the first moments of the hospital care being initiated, it was truly a team effort with orthopedic surgery, plastic surgery, trauma surgery, and vascular surgery standing shoulder to shoulder in the trauma bays and together in the operating rooms (ORs). All total Brigham and Women's Hospital received 39 victims, 28 of them with significant injuries (Fig. 1). Seven critical patients arrived nearly at once, with many of these patients requiring emergency surgery. The first to go to surgery—a patient in shock, who had a field tourniquet replaced in the emergency department (ED) because of a completely severed leg—was resuscitated and on an operating table just 18 minutes after presentation to the trauma bay and close to 35 minutes after the blast itself. The rest of the patients followed to the OR, one after the other, spaced by just minutes. Thirteen patients in total would undergo surgery in the first few hours after the event at Brigham, but an additional few procedures were performed at our affiliated hospitals and transferred the next day for further operative care. The patients with the most severe injuries subsequently underwent multiple debridements before definitive wound coverage and limb salvage that accounted for more than 181 days of inpatient care at our hospital (Fig. 2). In the first few days after the event, our OR plastic surgery nursing teams and anesthesia teams volunteered to run 4 extra plastic surgery rooms on a Saturday, and there was an abundance of staff willing to simply do what we do on a daily basis for these victims. On that first weekend day alone, 7 plastic surgeons gathered as a team with residents and nurses to perform 2 lower-extremity free flaps and 2 major burn debridements in an effort to reduce the backlog of operative needs of our blast-injured Bostonians.

PREPARATION

This article has some purpose to recount a story of caring for this unique patient population but also to give the readership of this journal a moment to reflect on the potential of a similar event in your own community. A major theme is fostering preparation and teamwork through daily collaborative interactions. It was these daily

FIGURE 1. Front entrance of Brigham and Women's Hospital under guard on the night of the Boston bombing attacks.

collaborations that truly aided our patient management throughout this disaster management. As providers, who have all learned from the medical care being provided by the exceptional efforts of our medical staff in the armed forces, we are acutely aware of the exponential effects of battlefield care and its influence on civilian trauma protocols. However, we also wish to draw the distinction between the military surgical teams and the large academic medical centers and comment that there is the potential for a bidirectional exchange of experience that can optimize patient care. The academic medical centers often possess the luxury of excess surgical capacity, and it was this excess capacity that made our approach to limb salvage feasible to maintain the "one patient, one cure" mind-set that can be lost in a mass casualty event. We write this article as a collection of individuals from the Brigham and Women's Hospital in Boston who collectively treated these patients with many other providers from their first moments in our hospital to the ongoing outpatient care that continues. As a craniofacial surgeon, a microvascular/hand surgeon, and as an orthopedic surgeon, we all have a direct role in the polytrauma patient population, and it was this collective experience that allowed us to work collaboratively. In addition to the providers who cared directly for the bombing victims, we have asked our friend and colleague Lt Col Eric Holt from the US Air Force to collaborate with experience from the US military efforts in providing expeditious medical care in nonpermissive environments. Eric has been a good friend, and he has considerable experience and expertise in translating the lessons of tactical combat casualty care (TCCC) to a civilian terrorist attack. Dr Eric Holt has deployed multiple times as a physician for the US Air Force Special Operations command. He himself has also been of the other side of bombing care when he and other military members were severely injured when their vehicle triggered an improvised explosive device (IED) while returning from a combat mission (Fig. 3). In addition to the collective experience of the authors, it warrants mention that the *Journal of Craniofacial Surgery* in July 2010 dedicated an exceptional issue edited by Dr Seth Thaller[1] to the treatment of war-related injury.

In reflecting about the Boston bombings, there were certain moments both individually and collectively, but the initial presentation of injured marathon spectators with smoke-laden clothes shredded by blast drove home the gravity of the scenario for each of us. The smell of smoke/explosives and burned patients arriving with anxious emergency medical services providers was provoking. However, these thoughts of angst, personal security, and safety were quickly passed from the mind as there was work to be done. Almost immediately, preparations to establish a perimeter, screen for radioactive and/or biologic agents, and thus limit the risk of the emergency department becoming an additional soft target of opportunity were instituted. However, we were lucky that there were no additional actions taken against medical facilities except that one other city trauma centers did divert patients because of a perceived bomb threat. It is important to note that the emergency department did become taxed with medical providers descending in an effort to help, and the emergency department very quickly had to funnel staff to the most efficient use of personnel. It is certain that this initial wave of providers forming small trauma teams did facilitate expeditious care, but there was also a need to have clarity of preplanned staging areas for available staff and resources. However, as surgeons, we have reflected together that it was comforting to have had a job to do and to know how to proceed without hesitation. All of the injuries that we evaluated and treated were all injuries that we had treated before, but in truth the additional complexity of a mass

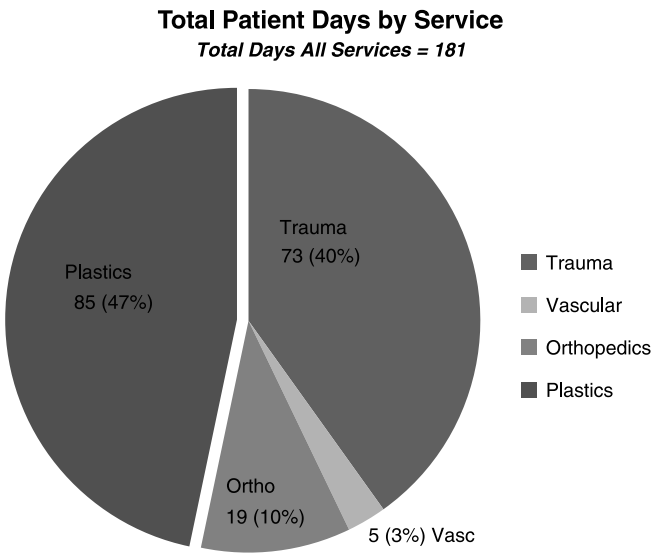

FIGURE 2. Total hospital days (total days all services = 181) by service for the cohort of the 13 bombing victims at Brigham and Women's Hospital who underwent emergency surgery in the first hours after the attack. Plastic surgery played a large role in the longitudinal care of these 13 patients, emphasizing the critical role of plastic surgery within the context of a trauma program.

FIGURE 3. Vehicle Dr Eric Holt was traveling in after he and several other soldiers triggered an IED while returning from a combat mission in Afghanistan.

FIGURE 4. C-A-T tourniquet. Combat action tourniquet, one the commercial tourniquets actively used by US military and coalition forces.

casualty event had little to do individually with the actual principles of surgical care used.

TEAMWORK

It is important to note that the daily collaborative efforts of working together for an individual patient led to the natural collaborative effort of working together as a team for the care of many patients. Collaboration and teamwork are foundational themes throughout this report, and efforts to foster greater teamwork presumably provide for better care. This event clearly demonstrates that a collaborative multidisciplinary surgical team can bring better care to the bedside for both the routine and during a mass casualty event. We at Brigham and Women's Hospital are fortunate that in addition to routine surgical collaboration we have a culture of larger surgical teams that historically have worked together for face and limb transplantation. Our face transplant team has now performed 5 of the 7 face transplants in the United States, and we have both an upper-extremity and lower-extremity transplant team that encompasses both the same orthopedic and plastic surgery expertise used for the care of the Boston blast injured. It was the preexisting team structure that allowed for a seamless expansion in capacity.

In addition to this prepositioned medical collaboration, we were overall very lucky that the loss of life and permanent disability were not worse for a number of reasons, some being the selection of ordinance, timing, and location of the devices. Certainly, there were many components that worked to our favor as Boston's "Marathon Monday" is a holiday for much of the city, and as a result, the ORs were not at full capacity, and the hospital was not at its normal 92% capacity but was at 84% capacity. However, it was not a holiday for our hospital, so there was still a full complement of OR staff with 30 of the 42 ORs running at the time of the event. During the initial reports on Twitter indicating a mass casualty event, a number of operating surgeons went to the OR desk and discussed with anesthesia leadership that we should hold any elective cases from going back into the OR until we have more information and also that we should take steps to bring in more staff as well as retain the staff currently working. The OR nursing leadership made similar preparations with staff and the timing of the event coincided with the 3 pm nursing shift change, lending a double complement of available OR nursing staff. The other admirable effort was with the resident surgical staffs of orthopedic, plastic surgery, and general surgery resident teams descended on the ED with the staff surgeons. Once in the ED, surgeons with ED providers broke into small trauma teams and prepared many for immediate surgery. As these small trauma teams went to work, there were many ED intubations, surgical team applications, or reapplications of effective tourniquets for life-threatening limb hemorrhage, plastic surgery burn care, and there was also a vision saving lateral canthotomy, all during those first 20 minutes of care. All of this initial triage and subsequent surgical care were possible because of the effective care rendered by the first responders on the scene.

It was these first responders that moved toward the fray and began treating the wounded who were the real heroes of the day. We believe that the prolonged conflicts in both Iraq and Afghanistan have improved civilian prehospital skill sets in dealing with life-threatening limb hemorrhage. It can be stated unequivocally that decisive control of hemorrhage on the battlefield through the adaptation of tourniquets has saved lives. We can attest that the application of effective tourniquets in the Boston bombing event saved lives, and those nameless first responders really made a huge difference. Again, the location of the bomb attacks at the finish line and the proximity of the transport and medical tent assets all worked to expedite care. The most important thing that the prehospital providers never forgot was that they needed to stop the bleeding and get the patient to a higher level of care. Once this task was accomplished, and the patients got to the ED, many of the injuries were identified with direct palpation and physical examination as opposed to the traditional approaches involving confirmatory radiography. The tourniquet applications in the field were initially improvised with belts, cord, and other materials, but in communication with prehospital providers, many of these tourniquets were changed over to other commercially available tourniquets and/or blood pressure cuffs.

The biggest intervention associated with the TCCC course in the military is the effective teaching of tourniquet skills to stop life-threatening hemorrhage (Fig. 4). As part of the medical experience in Iraq and Afghanistan, they have found that early control of severe hemorrhage is critical. US military coalition forces presently have the best casualty treatment and evacuation system in history. Tactical combat casualty care is the course that originally started as a special operations course that has significantly changed landscape of prehospital medical care. If we compare military fatality rates throughout history, the percentage of those wounded who subsequently die has been reduced dramatically. In World War II, of those who were wounded, 19% of these patients died. In Vietnam, of those who were wounded, 15% died, and now the US casualty rate in Iraq and Afghanistan is less than 9%, likely through prehospital intervention.[2] In Vietnam, more than 2500 preventable deaths occurred

FIGURE 5. Demonstration of a 1-person combat drag that allows one to take an injured patient to cover while keeping the ''heads-up'' position to perceive and interpret further threats.

FIGURE 6. QuikClot Combat Gauze, a kaolin-impregnated gauze that helps activate the clotting cascade to stop bleeding. It is often used in combat to stop active bleeding by frontline medical providers.

in Vietnam secondary to hemorrhage from extremity wounds.[2–4] Currently, extremity hemorrhage is the most frequent cause of preventable battlefield death, and we can extrapolate this to civilian terrorist attacks in which extremity hemorrhage will be the area that lifesaving interventions can be taken in the initial few moments of a terrorist attack. However, it is also important to develop a casualty evacuation/movement plan, especially if there is continuation of a high-threat environment. Therefore, before a first responder takes action to move a patient, a rescue plan should be developed by locating the nearest cover, deciding how best to move that injured person to that cover, assessing the risk to the rescuer and the weight of the casualty, and knowing the distance to bring the casualty to cover. If there is only 1 rescuer to bring a patient to cover, it is best to grab the patient by the collar behind the nape of the neck and to drag the patient behind him/her (the rescuer) toward cover (Fig. 5). In this way, by dragging the patient behind the rescuer, it is possible to maintain a head-up position to visualize the surrounding environment to constantly evaluate further threats and change direction as needed. If you have the ability to carry with multiple personnel, you can use a similar technique as the 1-person drag by having each rescuer grab a side of the collar and move forward, dragging the person behind them for similar reasons. In a tactical situation or any continued threat environment, it may not be possible to move a patient, and one has to consider risks of pain and cervical spine compromise before moving a patient. Therefore, battlefield teaching often centers upon constantly updating the scenario assessment as well as the medical condition of the patients to render the most effective and safe care.

As we know from our military history, almost 90% of all combat deaths occur before the casualty reaches a medical treatment facility.[2,5] Therefore, the fate of the injured often lies in the hands of those who can provide the first care to the casualty. In combat, this includes the care provided by the medics or teammates. In a civilian mass casualty event, the onus of care relies on the help of good Samaritans nearby who respond to the event. It is exceptional to review the photographs of the Boston bombings and see the selfless acts of the first responders to help their fellow citizens despite continued personal risk. It was this very care that was rendered at the scene with the expert application of tourniquets and the halting of life-threatening bleeding that allowed these patients to be evacuated from the site of the bomb blast effectively and for lifesaving/limb-saving surgery to be initiated. A casualty with a femoral artery or femoral vein disruption can exsanguinate in as little as 3 minutes; so therefore, as mentioned, a tourniquet is a critical part of the initial treatment at the point of injury. Even without immediate access to commercial tourniquets, it is clear that in the case of the Boston bombings improvised mechanisms to stop bleeding such as belts, other strips of clothing, or cord likely saved lives. It is important to note that as a medical provider, non–life-threatening bleeding should be ignored until the patient has been removed from the area, considering the potential for a second bomb timed to attack the first responders. However, if there is life-threatening bleeding, it is reasonable and expected as a medical provider to take the time to apply a tourniquet before moving the patient to safety. Extrapolating some of the military's care-under-fire (CUF) course lessons, it has been shown that if the tactical situation permits the initial application of tourniquet has been effective at decreasing mortality both in Iraq and Afghanistan. It is estimated by the data provided to the army surgeon general that an estimated 1000 to 2000 lives have been saved in the war to date through the use of the tourniquet being applied in the prehospital setting. It is also notable that there have been no amputations caused by prehospital tourniquet use in combat and that only 3% of patients have had transient nerve palsies from tourniquet use.[6–9] The tourniquet, when it can be applied, is the first choice for control of life-threatening hemorrhage in the proper situation.

If the tourniquet is deemed to be ineffectual, one may need a second tourniquet to be applied above the first tourniquet to control bleeding, and it is important to note that a tourniquet will not work very well over a joint or any other bulky item on the person's clothing. The mistakes to avoid with the tourniquet would be not using one, or using a tourniquet for minimal bleeding, and putting it on too proximally or taking it off when the casualty is in shock or during transport. However, the most common mistake is that the tourniquet has not been made tight enough. The tourniquet if applied properly should eliminate distal pulses, and if the first application is not effective, one should apply a second tourniquet as needed. Experience in Iraq and Afghanistan with military trauma is that the most common tourniquet mistake is that the tourniquet has been put on too late, and after the patient is already in shock, these events may be a direct result of tactical concerns that prevented the initial tourniquet application. So, in a civilian trauma event, there is often no competing mission or tactical concerns, so whenever possible, it should be applied if indicated. If applied effectively, it really hurts, and pain does not indicate that there has been a mistake in the application of the tourniquet, and it certainly does not mean that it should be taken off. Some wounds are located in places where a tourniquet cannot be applied such as the neck, axilla, or groin. In these less compressible sites, hemostatic agents can be used to stop life-threatening bleeding. In military combat, gauze (Fig. 6) is a product that is often used, and the application of the combat gauze is taught in the TCCC course as well as during live tissue demonstrations. Application of this kaolin-impregnated gauze helps to activate the clotting cascade and has been shown to be effective to staunch bleeding on the battlefield. However, to apply combat gauze, you have to hold pressure directly over the site of the bleeding with direct pressure for at least 3 minutes for the combat gauze to be most effective. Often in theater with continued bleeding, additional dressings can be applied over top of the combat gauze to help quell the bleeding until the patient can reach a forward surgical team with operative capacity.

The major important intervention with TCCC is situational awareness, and practical exercises and scenario-based teaching of tourniquets, needle thoracostomy, nasal pharyngeal airways, surgical airways, and fluid/product resuscitation have made forward surgical

care more effective.[3,10–13] Many graduates of the TCCC course and the special operations CUF course and combat lifesaver course have been able to make critical decisions on how to provide medical care in difficult circumstances but also have maintained the context of the greater mission requirements and tactical security. All of these lifesaving lessons should be incorporated into our civilian mind-set when we were dealing with casualties of a potential terrorist attack. We know from 2 landmark articles from the military experience that tourniquets are saving lives on the battlefield.[6–9] In 1 study, during a 6-month period, 31 lives were saved in Iraq alone because of the proper application of tourniquets, and it is estimated that more than 2000 lives have been saved with tourniquets.[6–8] All Rangers and Ranger doctors are trained in TCCC, and the incidence of Ranger preventable death incidence is approximately 3%, and overall, the US military preventable death incidence is 24%. Rangers have taken great pride in their medical awareness under direct hostile fire, moving medical care forward to the point of injury and doing the right thing at the right time.[11,14]

Tourniquets and combat gauze work quite effectively for extremity trauma, but do not work very well for internal bleeding. Tactical care field guidelines recommend tranexamic acid (TXA) be given to casualties with hemorrhagic shock, 1 or more major amputations, penetrating torso trauma, or evidence of severe bleeding. It is most effective if it is given early in care usually within the first hour of injury, but not after 3 hours of injury. There have been 2 large studies, one is called CRASH-2, which is a very large study of more than 20,000 civilian trauma patients, and the second study called MATTERs, which stands for (Military Application of TXA in Traumatic Emergency and Resuscitative Surgery).[15–17] This study involved 896 casualties treated at Bastian Hospital in Afghanistan. Both of these studies demonstrated a significant decrease in mortality with TXA use.[15–17] Tranexamic acid does not promote new clot formation, but it prevents clots from being broken down in the body and helps stop bleeding and helps prevent death from hemorrhage. Possible adverse effects include nausea, vomiting, diarrhea, and visual disturbances, and there is a risk of hypertension. Remember that continued reassessment is paramount in these patients including continued assessments for hemorrhagic shock and altered mental status in the absence of head injury, and weak or absent peripheral pulses are the best field indicators of shock. The point of this vigilance is that we have to treat this blood loss before it happens rather than treat it after the fact, and therefore awareness on how to stop life-threatening blood loss in a mass casualty incident such as the Boston attack can save lives. In hypertensive resuscitation, the goals of fluid resuscitation are one to improve the state of consciousness without sophisticated monitoring; palpating the radial pulse corresponds roughly to a systolic blood pressure of 80 mm Hg. In the prehospital setting, there is a study by Bickell et al,[18] which was published in the *New England Journal of Medicine* in 1994, that if there is uncontrolled hemorrhage too much prehospital fluid resuscitation can interfere with the body's attempt to clot off internal bleeding by diluting the clotting factors and increasing the pressure to which the clot is disrupted by the hydrostatic force exerted by aggressive intravenous fluid resuscitation. So, in the prehospital setting during hypotensive resuscitation, one should not try to restore normal blood pressure, but rather stabilize the patient with correction of systolic heart rate and mental status improvement as the guides of effective resuscitation.[19] In a mass casualty event, as a first responder or even as the primary provider at that point of definitive care, if signs of shock and bleeding are present, it is the control of bleeding if possible that takes precedence over infusion of resuscitation fluid.[20,21] The most important part of managing shock is simply to prevent it. It is important as the prehospital care is extending to make sure that exposure and hypothermia are prevented. A patient's exposure to the elements can be minimized by replacing wet clothing if possible, and getting the patient on to insulated surface such as a blanket of heat-reflective shield. It should be noted that even a small decrease in body temperature can interfere with the clotting cascade and increase the risk of an exsanguination in casualties. It is much easier to prevent shock than it is to treat, especially in the prehospital environment.

The injury pattern in the Boston bombings was mostly lower-extremity trauma, and this illustrates the importance of knowing how to splint fractures. It is important that if there is an obvious deformity and no pulse one should reduce the fracture into proper position or more anatomic position and recheck for a pulse; the objective of splinting the patient in the prehospital setting is to prevent further injury to the blood vessels and nerves. Splinting may make the patient more comfortable, and it is optimal to try and splint the patient, if possible, before moving the patient unless there are competing safety concerns.

Airway usually takes precedence in the civilian prehospital medical care; however, it is important to note that the current directives for our military personnel are not to perform any immediate airway management while during the CUF phase of an operation.[9,12] The airway is usually never established in a casualty when a unit is under effective fire because of the risk to the unit, and therefore airway management is often deferred until the casualty has been moved to cover. Compromised airways are a relatively infrequent cause of death in combat, accounting for less than 1% to 2% of combat-associated deaths.[2,4,10,20] Unfortunately, in a mass casualty event, it is likely in a resource-scare environment that a patient with no airway has minimal chance of survival. It is for this reason that if there are multiple injured patients the prevention of life-threatening hemorrhages with direct pressure or even improvised tourniquets should take priority. It behooves any craniofacial surgeon to have this skill set in a disaster with the ability to rapidly perform this maneuver as it could be lifesaving especially with significant injury in the head and neck region to secure a stable airway for transport to a higher echelon of care. Airway compromise in the civilian prehospital setting is most often a result of cardiac or respiratory arrest in elderly patients because of pulmonary or cardiovascular disease, but in the mass casualty event, it could be from inhalational injury due to bomb blast or significant maxillofacial trauma. It is notable that obviously the most effective way to secure the airway if the equipment is available would be intubation; however, the cricothyroidotomy should be a known technique in case of failure. Looking at the trauma data from Iraq and Afghanistan, approximately 14% of the prehospital cricothyroidotomies that were performed in theater in both Iraq and Afghanistan were performed after failures to intubate after rapid sequence induction by a physician or a physician assistant. Approximately 38% of the prehospital cricothyroidotomies that have been performed in Afghanistan and Iraq were performed as related to a gunshot wound to the maxillofacial region, and at least the remainder 33% were related to explosion-related injuries, which would be consistent with a civilian terrorist attack.[20–24] The civilian population has been described by Jacobson et al[25] in 1996 in the *Journal of Trauma*, in which they found approximately a failure rate of approximately 6% with a total number of 50 prehospital cricothyroidotomies. Fortune et al[26] in the *Journal of Trauma* in 1997 found approximately 10% failure rate with 56 patients involved in the study. An analysis of battlefield cricothyroidotomy in Iraq and Afghanistan Mabry and Frankfurt[27,28] reports that airway compromise accounts for about 1% to 2% of total combat fatalities, and they examined the prehospital cricothyroidotomy in the military study using the largest studies of civilian medics performing prehospital cricothyroidotomy as historical controls. They found that in battlefield scenarios they documented successful cricothyroidotomy in 68% of the cases in the prehospital setting, whereas 26% of the prehospital cricothyroidotomies failed to cannulate the trachea.[27,28] The majority of these prehospital cricothyroidotomies were performed by combat medics at the point of injury. They did find that physicians

and physician assistants were more successful at performing prehospital cricothyroidotomy than medics in the military setting, with a 15% failure rate for physician assistants and physicians in the field as opposed to a 33% failure rate of cricothyroidotomy in the prehospital setting in theater.[27,28] It is obvious that the tactical constraints make the prehospital cricothyroidotomy in the military scenario a significantly more complex procedure because of constraints associated with providing medical care under enemy fire.

In the application of best practices learned in our recent military engagements, one must remember that in a mass casualty event we are often in the initial moments in a resource-scarce environment with continued threats possible. Therefore, some lessons from USSOCOM tactical trauma protocols can serve as guidance. The MARCH algorithm is one such guide to the sequence of treatment priorities in caring for the combat casualty: M stands for massive hemorrhage and control of life-threatening bleeding, and the reason that this precedes the airway as is taught in ATLS and ACLS is that it is often difficult to secure an airway without specialized intubation or cricothyroidotomy equipment, but that massive hemorrhage or the control of life-threatening bleeding can often be done with direct pressure or an improvised tourniquet. In the MARCH algorithm, after the life-threatening hemorrhage has been controlled, establishing an airway and maintaining a patent airway (Airway/Respirations) with specialized equipment if available are the AR in March: respiration, decompressing suspected tension pneumothorax, sealing open chest wounds, and supporting with ventilation and oxygenation as required. In C, circulation, establish an intravenous access and administer fluids as required to treat shock; and H stands for head injury, hypothermia, preventing/treat hypertension, hypoxia to prevent worsening of traumatic brain injury, and preventing and treating hypothermia.

CONCLUSIONS

In Boston, there were certainly issues in our favor that led to preservation of life and limb. This is in contrast to data that report civilian bombings are in general 3 times more destructive because of the lack of perimeters, situational awareness, and specialized protection in the form of body and/or vehicle armor in civilian or "soft target" bomb attacks. However, in Boston, we were prepared because of the advanced planning for multiple medical emergencies as part of the marathon race preparations. These prepositioned emergency medical assets were integral to initial care at the scene and rapid transport much like in the military evacuation system of field trauma care and rapid transport to a higher echelon of care. Again, it was these prepositioned assets that narrowed the timing from scene to OR well within the "golden hour." In addition with the timing of the bombing coinciding with the nursing shift change and with excess holiday OR capacity, there was no delay in ability to receive patients directly into the hands of waiting surgical teams for the initial damage control surgical interventions (Fig. 7). We in Boston have taken many lessons from our surgical colleagues treating the war injured and have learned that timely and effective interventions can be strung together along the chain of transport to provide excellent care. However, we had a significant advantage in this civilian mass casualty over the current paradigm of the military forward surgical team, and it was that a collaborative multidisciplinary subspecialized surgical team was available and able to enhance the survival and potential limb salvage of these patients. It is impractical in a resource-constrained environment such as the battlefield to have waiting a team containing vascular surgery, trauma surgery orthopedic surgery, and plastic surgery immediately available and directly involved in the care of the patients from their initial evaluation. We are privileged to have this advantage of collaborative efforts, but it prompts one to consider telemedicine initiatives that the far-forward surgeon can have greater multidisciplinary support to enhance lower-extremity salvage in the combat injured. It is important to note that plastic surgery was a dedicated and integral part of this trauma response going from room to room, collaboratively guiding limb-length preservation and tissue preservation. Because of the nature of the injuries, there was a large role for plastic surgery to play as the primary team for a large portion of the Boston bombing victims (Fig. 8).

In this fashion, we believe that this prepositioned collaborative relationship of plastic surgery to vascular, trauma, and orthopedic surgery at our own institution may offer a model of collaboration for limb salvage. However, one must cautiously consider the longitudinal efforts of these collaborative efforts in a health care

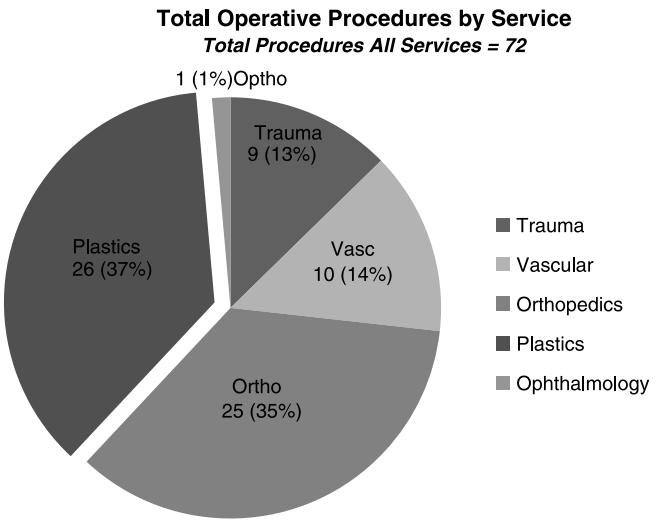

FIGURE 7. Total number of operative procedures (n = 72) performed on the cohort of the 13 Boston bombing victims who underwent emergency surgery in the first few hours by service. Plastic surgery, 26 procedures, and orthopedic surgery, 25 procedures, were performed on the majority (72%) of the operative interventions because of the large proportion of extremity injuries and subsequent efforts for limb salvage. It is this interdisciplinary collaboration that is imperative for a cohesive effort of limb salvage.

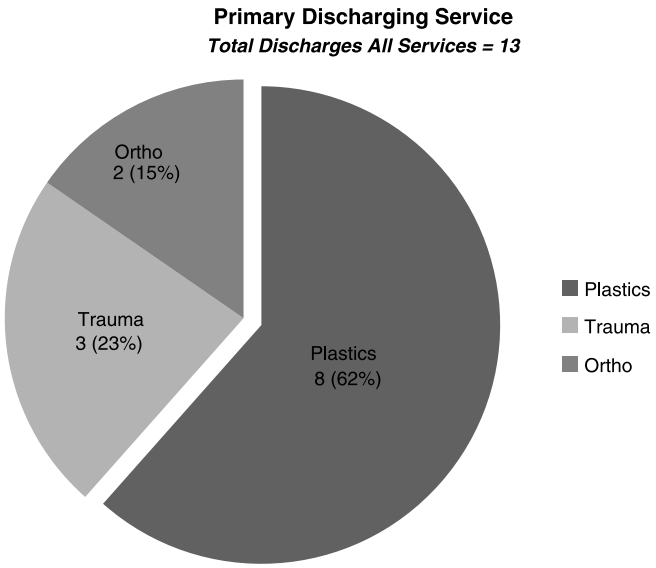

FIGURE 8. Distribution of discharging service for the cohort of the 13 patients who underwent emergency surgery in the first few hours after the attack discharged from the Brigham and Women's Hospital. More than 60% of the patients were discharged from the plastic surgery service indicating the important role plastic surgery can play with burn and complex wound management for definitive care of mass casualty patients.

environment that is encouraging less resource utilization as opposed to more intervention. It is notable that in general our patients, who underwent limb salvage, did indeed have a greater number of operative procedures and did progress to rehabilitation at a slower rate than did patients who underwent early amputation. Therefore, a longitudinal study should be undertaken to demonstrate the utility of a multidisciplinary approach to limb salvage and compare the cost-benefit of an approach that may involve multiple surgeons and multiple interventions as opposed to a single surgical intervention. Regardless, it is the daily professional iterations with other services that have made this interaction in this time of need patient centered.

Throughout this event and the care of these patients, it is important to recognize that this response was not a single institutional response but rather was the collective effort of the entire city and medical community coming together to make a difference. Fortunately, we were never resource constrained by the influx of a large number of patients, and we have to thank the timing of the event to credit this measure of excess capacity. However, if there is any overarching lesson, multidisciplinary teamwork, preparation, and dedication are the keys to success in effectively dealing with a mass casualty event. It is important to perform an assessment of performance after such an event to use and disseminate knowledge to make these attacks less effective by making our responses more efficient and effective. Other subsequent articles will consider the city-wide data regarding the treatment after this mass casualty event, and it will be of interest to consider differences in treatment centers with less involvement in a multidisciplinary limb salvage effort. It may be that our efforts of limb salvage were overexuberant that nearly 50% of our patients who needed emergency surgery after the attack received a free flap for limb salvage. Although this approach is resource intensive and likely involves a greater number of operative interventions in the immediate aftermath of a blast injury, the patients and their outcomes will judge these efforts over time. However, if one is not constrained by resources or overwhelmed with patient volume, the opportunity for limb amputation will always remain if the treating team fails to provide the patient with functional limb.

This particular event created a blast injury pattern that was characterized by significant flash burns to exposed areas (face and extremities) with limited depth (4–5 cm) of penetrating shrapnel (face, neck, and extremities) and direct limb-destroying overpressure to those closest to the device. Typical military injuries from IED blast often involve higher energy and more effective explosive devices, but yet with armored vehicles and body armor, often there are injury patterns to exposed regions such as the face and extremities. Most plastic surgeons have trauma experience as part of their previous training in general surgery, and with plastic surgery having significant expertise in facial trauma, hand surgery, burn surgery, and complex soft tissue wound management, it makes the plastic surgeon an ideal candidate to coordinate surgical care with a broad perspective on functional recovery. As a result, military planners should consider adding this plastic surgery manpower to their existing trauma structure and training or recruiting additional providers for this flexible surgical utility. However, plastic surgery has admittedly in many centers focused on an elective practice and has played a less engaged role in trauma as the reconstructive surgeon. Therefore, the community of reconstructive surgeons must continue to engage and demonstrate the advantages of a multidisciplinary approach to mass casualty events. On a final note, more centers will likely deal with similar events in the future, and it is imperative that we as a community of providers take what lessons we can from battlefield medicine and that we collectively prepare for and engage this future.

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