Resuscitative thoracotomy following wartime injury

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BACKGROUND: The evidence for resuscitative thoracotomy (RT) in trauma patients following wartime injury is limited; its indications and timings are less defined in battle injury. The aim of this study was to analyze survival as well as the causes and times of death in patients undergoing RT within the context of modern battlefield resuscitation.

METHODS: A retrospective cohort study was performed on consecutive admissions to a Field Hospital in Southern Afghanistan. All patients undergoing RT were identified using the UK Joint Theatre Trauma Registry. The primary outcome was 30-day mortality, and secondary outcomes included location of cardiac arrest, time from arrest to thoracotomy, and proportion achieving a return of spontaneous circulation.

RESULTS: Between April 2006 to March 2011, 65 patients underwent RT with 14 survivors (21.5%). Ten patients (15.4%) had an arrest in the field with no survivors, 29 (44.6%) had an arrest *en route* with 3 survivors, and 26 (40.0%) had an arrest in the emergency department with 11 survivors. There was no difference in Injury Severity Scores (ISSs) between survivors and fatalities (27.3 [7.6] vs. 36.0 [22.1], $p = 0.636$). Survivors had a significantly shorter time to thoracotomy than did fatalities (6.15 [5.8] minutes vs. 17.7 [12.63] minutes, $p < 0.001$).

CONCLUSION: RT following combat injury will yield survivors. Best outcomes are in patients who have an arrest in the emergency department or on admission to the hospital. (*J Trauma Acute Care Surg*. 2013;74: 825–829. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic/prognostic study, level III.

KEY WORDS: Resuscitative thoracotomy; war surgery; trauma surgery; damage-control surgery.

Resuscitative thoracotomy (RT) is performed on trauma patients who either have no central pulse or are peri-arrest.[1,2] It is a dramatic maneuver, intended to facilitate the release of pericardial tamponade, control massive hemorrhage and air leaks, or allow open cardiac massage and aortic control, to restore spontaneous circulation. RT has been thoroughly evaluated in civilian practice, with best survival rates observed in penetrating trauma to the thorax (8.8–33.0%), with least favorable outcomes noted in blunt injury (0.5–1.4%).[3–7]

Despite a significantly different wounding pattern, currently UK and US military clinical practice guidelines (CPGs) are largely based on civilian practice owing to a limited evidence base.[8,9] Military patients are predominantly injured by explosive and high-energy gunshot mechanisms.[10] These wounds are often sustained in austere circumstances with lengthier prehospital evacuation times in comparison with civilian emergency medical service systems.[11]

However, within these constraints, there have been a number of reports of successful outcomes following RT in the combat environment,[12] but only a single large series reporting 101 consecutive combat-related RTs performed between 2003 and 2007 with an overall survival rate of 12%.[13] Specifically, there are limited data on the location and timing of cardiac arrest in combat wounded undergoing RT.

Since 2006, the UK Defence Medical Service (DMS) has been providing trauma care in Helmand Province, Southern Afghanistan at the Role 3 hospital in Camp Bastion. Within this time, there have been significant developments in combat casualty care, such as balanced resuscitation strategies, forward critical care, and the use of tourniquets. The UK and US military has incorporated such developments into a paradigm of damage-control resuscitation (DCR) beginning at the point of wounding through to discharge.[14] The aim of this study was to analyze survival, and the causes and times of death in patients undergoing RT within the context of modern battlefield resuscitation. This study aimed to inform clinicians dealing with the complex decision making surrounding RT in the pulseless combat trauma patient.

PATIENTS AND METHODS

A retrospective cohort study was performed on consecutive admissions to a field hospital in Southern Afghanistan following approval from the UK's Joint Medical Command Academic Unit and the US Army's Institute for Surgical

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This study was presented as a poster at the 71st annual meeting of the American Association for the Surgery of Trauma, September 12–15, 2012, in Kauai, Hawaii.

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TABLE 1. Demographic and Injury Pattern Data of Patients Undergoing RT at the Role 3 Hospital, Camp Bastion

Variable	Dead (n = 51)	Alive (n = 14)	*p*
Demographic data			
Age, mean (SD), y	25.6 (7.6)	23.6 (5.4)	0.314
Male, n (%)	50 (98.0)	14 (100.0)	1.000
Mechanism of injury, n (%)			
Gunshot wound	22 (43.1)	5 (35.7)	0.618
Explosion	29 (56.9)	9 (64.3)	
Trauma scoring			
Mean ISS, mean (SD)	36.0 (22.1)	27.3 (7.6)	0.636
Mean NISS, mean (SD)	47.5 (22.9)	43.4 (12.9)	0.419
Head AIS score ≥ 3, n (%)	9 (17.6)	0	0.090
Neck AIS score ≥ 3, n (%)	2 (3.9)	0	0.452
Chest AIS score ≥ 3, n (%)	29 (56.9)	6 (42.9)	0.352
Abdominal AIS score ≥ 3, n (%)	18 (35.3)	5 (35.7)	0.977
Extremity AIS score ≥ 3, n (%)	21 (41.2)	9 (64.3)	0.253
RTS, mean (SD)	0.98 (1.82)	2.67 (2.32)	0.126
Injury burden, mean (SD)			
No. injuries	6.6 (5.8)	5.6 (2.3)	0.596
No. regions injured	2.8 (1.6)	2.6 (1.4)	0.960
Injuries per body region	2.3 (1.8)	2.3 (0.7)	0.202
No. severe injuries*	1.6 (1.0)	1.4 (0.5)	0.888

*Severe injury is defined as an AIS organ score of 3 or greater.

Research. All patients, both local nationals and NATO personnel, in circulatory arrest (i.e., no palpable central pulse), undergoing RT were identified using the UK Joint Theatre Trauma Registry (JTTR). We defined RT as thoracotomy performed in hospital, in a pulseless patient, with the intention to restore spontaneous circulation.

Data retrieved included the mechanism and severity of injury, admission physiologic status, blood product use, surgical interventions, survival up to 30 days, and causes of death. We were specifically interested in the location when the arrest occurred (in the field, during evacuation, or in the emergency department [ED]) and time from circulatory arrest to thoracotomy, where available. Admission respiratory rate, systolic blood pressure, and Glasgow Coma Scale (GCS) score were used to generate a Revised Trauma Score (RTS), which is inversely proportion to survival.[15] The Abbreviated Injury Scale (AIS) score was used to describe injury pattern and calculate an Injury Severity Score (ISS) and New Injury Severity Score (NISS)—the greater the score, the greater the injury burden.[16] A severe injury to a body region was defined as an AIS score of 3 or greater.

The UK JTTR records the complete follow-up for all UK military patients; however, the day of discharge accounts for the last day of follow-up for all other patients. Thus, to maximize cohort follow-up, all US patients were identified and cross referenced with the US JTTR. This enabled the 30-day follow-up of UK and US patients admitted to Camp Bastion.

The cohort was divided into survivors and nonsurvivors. Comparisons were made using the χ^2 test for categorical data, and differences in means were assessed using *t* test or Mann-Whitney rank-sum test for continuous variables.

RESULTS

Between April 2006 and March 2011, there were 8,402 consecutive trauma admissions to the Role 3 hospital, Camp Bastion, following combat-related injury. Of these patients, 65 (0.7%) underwent RT following circulatory arrest. The arrests occurred in the field in 10 (15.4%), during evacuation in 28 (43.1%), and in the ED in 26 (40.0%) patients. The mean (SD) age was 25 (7) years, with one female patient within the cohort. There were 19 local nationals (29.2%), 28 UK military (43.1%), 14 US military (21.5%), and 4 from other NATO countries (6.2%). The mean (SD) RTS was 1.25 (2.0), ISS was 34 (20), and NISS was 47 (21) in the overall cohort. Of the 65 patients, return of spontaneous circulation (ROSC) was achieved in 33 patients (51%) but was not sustained in 19 of those (57.7%); the overall survival rate was 14 (21.5%).

The age, sex distribution, and mechanism of injury were similar in the survivor and nonsurvivor groups (Table 1). There is an inclination toward a greater injury burden and severity in the fatalities; however, no parameter achieves statistical significance (Table 1). Of note, there were no severe head injuries in the survivor group, with nine (17.6%) in the nonsurvivor group. Survivors proportionally tended to have less severe thoracic injury ($p = 0.352$), with a greater proportion of severe extremity injury ($p = 0.253$).

Comparing survivors with nonsurvivors, there was no difference in the time (minutes) from incident to hospital admission (70.0 [28.5] vs. 72.0 [35.4], $p = 0.741$). However, the time from loss of pulse to thoracotomy was significantly less in the survivor group (6.15 [5.8] vs. 17.7 [12.63], $p < 0.001$). The longest time between circulatory arrest and thoracotomy in a patient to survive to 30 days was 24 minutes. None of the 10 patients who had an arrest in the field ever had their cardiac output restored. Of the 29 patients who arrested *en route*, 13 (44.8%) had a transient ROSC with 3 30-day survivors (10.3%). There were 26 patients who had an arrest in the ED, 20 (76.9%) of whom had their cardiac output restored; however, it was only sustained in 11 patients (42.3%) to 30 days (Table 2).

TABLE 2. Location of Circulatory Arrest, Presenting Cardiac Rhythm and Timeline Data of Patients Undergoing RT at Camp Bastion

Variable	Dead (n = 51)	Alive (n = 14)	*p*
Circulatory arrest location, n (%)			
In the field	10 (19.6)	0	0.001
Evacuation	26 (51.0)	3 (21.4)	
ED	15 (29.4)	11 (78.6)	
Arrest rhythm, n (%)			
Asystole	7 (13.7)	0	0.002
Pulseless electrical activity	18 (35.3)	13 (92.9)	
Ventricular fibrillation	2 (3.9)	0	
Unknown	24 (47.1)	1 (7.1)	
ROSC at any time	19 (37.3)	14 (100.0)	<0.001
Timeline data, mean (SD), min			
Incident to admission	70.0 (28.5)	72.0 (35.4)	0.741
Time from arrest to thoracotomy	17.7 (12.63)	5.54 (3.8)	<0.001

At thoracotomy, open cardiac massage was used significantly less in patients who survived to 30 days (64.3% vs. 92.2%; p 0.007)—of the five patients undergoing thoracotomy without cardiac massage, their hearts were considered contractile but empty at pericardiotomy. Aortic control—either cross clamping or manual compression—was used similarly in both groups, to enhance cerebral and myocardial perfusion. One survivor required release of a cardiac tamponade and repair of the right ventricular outflow tract following fragmentation injury and ED arrest. Several thoracic hemorrhage control maneuvers (pulmonary tractotomy, nonanatomic lung resection, vascular repair) were used in both groups evenly. A greater proportion of survivors required a concomitant laparotomy for hemorrhage control in the abdomen, although this only trended toward statistical significance (57.1% vs. 31.4%; $p = 0.077$). Table 3 includes a summary of operative procedures within the groups.

There were significantly more blood products used in the resuscitation of patients who ultimately survived ($p < 0.001$; Table 3). The mean fresh frozen plasma (FFP)–packed red blood cell (PRBC) ratio was also higher in the survivor group (0.9 [0.1] vs. 0.7 [0.4], $p = 0.051$). There was no significant difference in the use of tranexamic acid or recombinant factor 7a.

The majority of deaths (45 patients or 88.2%) occurred intraoperatively with a mean (SD) time from admission to death of 33 (33) minutes. Only 13 of these patients (28.9%) had ROSC, although none were sustained for a significant period. All 45 patients died of hemorrhage and irretrievable cardiovascular collapse, although 9 patients had also sustained a severe head injury. Nineteen patients were successfully resuscitated, achieving sufficient cardiovascular stability to be transferred to the intensive care unit (ICU). Ultimately, three patients died within 24 hours following refractory hypotension, fulminate multi-organ failure and coagulopathy. Two patients had sustained hypoxic brain injuries, dying on postoperative Days 1 and 2. The mean (SD) time from admission to death in patients surviving to ICU was 19.8 (26.8) hours.

TABLE 3. Operative Maneuvers and Resuscitation Data of Patients Undergoing RT at Camp Bastion

Variable	Dead (n = 51)	Alive (n = 14)	p
Surgical intervention. n (%)			
Cardiac massage	47 (92.2)	9 (64.3)	0.007
Aortic control	51 (100.0)	12 (85.7)	0.682
Lobectomy	2 (3.9)	2 (14.3)	0.153
Release of tamponade	0	1 (7.1)	0.054
Bronchial repair	1(2.0)	0	0.597
Vascular repair	2 (3.9)	1 (7.1)	0.611
Laparotomy	16 (31.4)	8 (57.1)	0.077
Resuscitation			
PRBC, mean (SD), U	10.3 (12.2)	36.1 (38.6)	<0.001
FFP, mean (SD), U	7.8 (10.9)	33.1 (32.3)	<0.001
Cryoprecipitate, mean (SD), U	0.45 (1.14)	2.79 (2.97)	<0.001
Platelets, mean (SD), U	0.81 (1.84)	5.29 (5.36)	<0.001
Fresh Whole Blood, mean (SD), U	0	2.5 (5.7)	0.003
Tranexamic acid use, n (%)	9 (17.6)	3 (21.4)	0.711
Recombinant factor 7a use, n (%)	10 (19.6)	6 (42.9)	0.090

Of the remaining 14 patients, one local national was discharged walking from intensive care on Day 14 and onward to a local Afghan facility on Day 22. Seven UK and six US patients underwent strategic aeromedical evacuation to their respective countries for continued care, with follow-up available for all patients to 30 days.

DISCUSSION

We report a series of 65 patients undergoing emergency RT for circulatory arrest following combat injury with 14 survivors (21.5%). Most survivors had an arrest in the ED, with a minority occurring during medical evacuation. No patient who had an arrest in the field achieved a return of spontaneous circulation, and no patient with a severe head injury survived beyond 24 hours. Of the patients in whom cardiac output was restored long enough to be transferred to the ICU, a quarter ultimately died of either physiologic exhaustion or hypoxic brain injury within 3 days of injury. In the remaining 14 patients, 13 have been followed up to 30 days, and 1 local national patient was been discharged at 22 days.

This registry study is limited by its retrospective nature in that we may not have identified all eligible patients and are unable to report detailed neurological outcomes. We are also unable to comment on the use of cardiopulmonary resuscitation in the field because this prehospital data are not recorded within the JTTR. However we are confident that we have captured all relevant cases by extensive cross-checking databases with operating surgeons. In addition, we have derived causes of death from the registry data, which are not as comprehensive as a formal autopsy.

Factors associated with survival, in the civilian literature, include injury pattern and length of warm ischemia.[1,2] Survival rates have been reported as high as 38% the in subgroup analyses of patients who presented with thoracic stab wounds and tamponade.[17–19] However, a review by the trauma subcommittee of the American College of Surgeons[4] identified an overall survival rate of 7.8% in 7,035 thoracotomies, 11.2% for penetrating and 1.6% for blunt injury. Best results have been found in patients with cardiovascular collapse from cardiac tamponade following isolated cardiac chamber injury.[19,20] Time between arrest and restoration of cardiac output is variable in survivors,[21] although a maximum of 30 minutes is generally accepted.[7,22]

However, military trauma is significantly different from civilian in both mechanism and anatomic wounding pattern.[10] In the current conflict, there is preponderance toward blast injury and high-energy transfer ballistic injury yielding heavily contaminated wounds with substantial tissue destruction.[23] Thus, the civilian experience of RT has limited applicability to military wounded. The evidence for the use of RT in the military is currently limited to case series[12] and cohort studies[13,24]

Our results are comparable with the best civilian outcomes, despite an injury pattern dominated by extrathoracic injury and exsanguination. These outcomes have been achieved by several components related to the treated population and system of treatment. First, our patients were generally young and fit with a significant physiologic reserve permitting a degree of resilience to major insults. Second, the treatment of patients commenced at the point of wounding, which while in this cohort did not prevent any patients arresting, it may have extended time with a spontaneous circulation. Furthermore, upon admission to the field hospital, all patients received aggressive DCR to restore volume and achieve surgical hemostasis, combined with field critical care.

The largest series to date looks at the outcomes following emergency thoracotomy from a US combat support hospital in Iraq in 2003 to 2007. Edens et al.[13] reported a 12% survival rate in a consecutive series of 101 patients injured by all mechanisms (blunt and penetrating). There were no survivors in the seven patients injured by a blunt mechanism. The primary location of wounding was the thorax (40%), abdomen (30%), extremities (22%), and the head/neck (2%).

Our series extends these findings to the Afghan theater, although there are differences in injury pattern and resuscitation. We report a higher proportion of patients with severe extremity injury (46.2%), which is characteristic of the dismounted complex blast injury, a signature injury of the war in Afghanistan (Fig. 1).[25] Patients who are hypovolemic from a severe limb injury may be more likely to achieve an ROSC if the circulating volume is rapidly restored. Our study reports more than twice the average PRBC (36 U vs. 15 U) and four times the average FFP (33 U vs. 7 U) used per survivor than in the study of Edens et al. Balanced resuscitation is associated with improved outcomes.[26]

Our results are further complimented by a prospective observational study of 52 patients with military traumatic circulatory arrest at Camp Bastion performed by Tarmey et al.[24] They reported 14 patients (27%) exhibiting ROSC, although only sustained in 4 (8%). RT was performed in 12 patients, including the 4 who survived to discharge. The majority of deaths (79%) occurred within an hour and the longest duration of arrest associated with survival was 24 minutes. It is important to note that our study overlaps with their work, although we have only examined the subgroup of patients undergoing RT.

They concluded that despite higher ISSs compared with those of contemporary civilian studies and the high prevalence of exsanguination, outcomes were similar. They identified short arrest times, presence of electrical activity, and cardiac movement on ultrasonography to be associated with successful resuscitations. Unfortunately, we are unable to report the role of ultrasonography, and although we do not know the presenting rhythm of 38.5% of our cohort, 92.9% of survivors were in a pulseless electrical activity rhythm.

Figure 1. A typical example of a patient sustaining a dismounted complex blast injury with bilateral traumatic lower extremity amputation.

The UK and US military have both published CPGs for the use of RT, of which we are able to comment on the penetrating component of the guidelines. The UK DMS CPG starts with an assessment for the presence of "signs of life"—absence in the field suggests that RT is futile and contraindicated in such circumstances.[9] The guideline goes onto suggest that RT should only be performed if it can be accomplished within 5 minutes from the loss of signs of life. The US military's CPG is similar but specifies that RT should only be performed within 10 minutes from the loss of a pulse in patients without an isolated head injury.[8]

Our data largely support these guidelines, which recognize the time critical nature of RT and the futility in the presence of head injury and arrest in the field. However, the data presented suggest that the time limits proposed within current CPGs are too conservative—the longest time from arrest to RT in a survivor within this series was 24 minutes. Clearly military surgeons are performing RT beyond these time—this may be caused by a lack of prehospital information or the exercising of clinical judgment. We would suggest amending the UK and US CPGs to increase the length of time to 30 minutes within which RT may be of benefit to pulseless combat casualties.

However, it is important to recognize the dynamic nature of warfare, especially when in an expeditionary phase. Our data demonstrate that ROSC was possible in half our patients but only sustained in a fifth, requiring significant operative and critical care resources. These outcomes were achieved in a mature facility, with significant resources and personnel and may not extend to further forward austere locations.

The importance of a short arrest time would suggest that earlier prehospital thoracotomy may be sensible. The facility for prehospital thoracotomy exists within the DMS on the medical emergency response team aeromedical platform, and several have been performed with no survivors to date (UK JTTR, unpublished data). A previous analysis suggested that military wounding is not amenable to such an approach owing to the multicavity nature of high-energy transfer military projectiles.[27] Our study highlights the importance of hemostatic resuscitation in military circulatory arrest—it is likely that a thoracotomy performed without aggressive DCR is probably limited in its effectiveness.

We have reported 3 (16%) of 19 patients who had a sustained ROSC but died of fulminate multiple-organ failure in ICU. These types of patients, who ultimately die despite correction of their physiologic instability, are becoming increasingly recognized as a specific subgroup. Recently the term *exsanguination shock* has been used to describe this group; however, the mechanism of this process remains elusive.[28] Undoubtedly, there are multiple, complex cellular processes evolving in these severely injured patients, which if understood may assist in directing the future care of trauma patients.

SUMMARY

RT is a procedure that surgeons deployed in conflict zones need to be comfortable performing because appropriate application can yield unexpected survivors. Survival rates are similar to well performing civilian centers, although the injury pattern is significantly different. Hemorrhage is the leading cause of arrest, often from abdominal and extremity trauma, with head injuries carrying a very poor prognosis. Short arrest times and in-hospital or *en route* arrest locations are associated with greater survival. RT for patients having an arrest at the point of wounding and seems to be futile. Survivors require significant operative, critical care and transfusion resources.

AUTHORSHIP

J.J.M., H.P., M.A.K., and J.P.G. conceived and designed the study. T.E.R., M.J.M., L.H.B. acquired the data and material support, which J.J.M. analyzed. All authors interpreted the data and wrote the manuscript.

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DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Hunt PA, Greaves I, Owens WA. Emergency thoracotomy in thoracic trauma-a review. *Injury*. 2006;37:1–19.
2. Morgan B, Garner J. Emergency thoracotomy—the indications, contraindications and evidence. *JR Army Med Corps*. 2009;155:87–93.
3. Moore EE, Knudson MM, Burlew CC, Inaba K, Dicker RA, Biffl WL, Malhotra AK, Schreiber MA, Browder TD, Coimbra R et al. Defining the limits of resuscitative emergency department. *J Trauma*. 2011;70: 334–339.
4. Ad Hoc Subcommittee on Outcomes, American College of Surgeons-Committee on Trauma. Practice management guidelines for emergency department thoracotomy. *J Am Coll Surg*. 2001;193:303–309.
5. Rhee PM, Acosta J, Bridgeman A, et al. Survival after emergency department thoracotomy: review of published data from the past 25 years. *J Am Coll Surg*. 2000;190:288–298.
6. Lustenberger T, Labler L, Stover JF, Keel MJB. Resuscitative emergency thoracotomy in a Swiss trauma centre. *Br J Surg*. 2012;99:541–548.
7. Kandler K, Konge L, Rafiq S, Larsen CF, Ravn J. Emergency thoracotomies in the largest trauma center in Denmark: 10 years' experience. *Eur J Trauma Emerg Surg*. 2011;38:151–156.
8. US Army Institute of Surgical Research, Joint Theater Trauma System Clinical Practice Guideline on Emergency Resuscitative Thoracotomy. Available at: http://www.usaisr.amedd.army.mil/assets/cpgs/Emergent_Resuscitative_Thoracotomy_11_Jun_12.pdf. 2012;(June):2–5. Accessed September 12, 21012.
9. UK Defence Medical Service. Clinical Guidelines on Operations. Indications for Emergency Thoracotomy, 2008.
10. Champion HR, Holcomb JB, Lawnick MM, Kelliher T, Spott MA, Galarneau MR, Jenkins DH, West SA, Dye J, Wade CE et al. Improved characterization of combat injury. *J Trauma*. 2010;68:1139–1150.
11. Hodgetts T, Mahoney P. Military pre-hospital care: why is it different. *JR Army Med Corps*. 2009;155:4–10.
12. Morrison J, Midwinter M, Jansen J. Ballistic thoracoabdominal injury: analysis of recent military experience in Afghanistan. *World J Surg*. 2011;35:1396–1401.
13. Edens JW, Beekley AC, Chung KK, et al. Longterm outcomes after combat casualty emergency department thoracotomy. *J Am Coll Surg*. 2009;209: 188–197.
14. Dawes R, Thomas GOR. Battlefield resuscitation. *Curr Opin Crit Care*. 2009;15:527–535.
15. Champion HR, Sacco WJ, Copes WS, et al. A revision of the trauma score. *J Trauma*. 1989;29:623.
16. Baker SP, Neill BO, Se B, Haddon W, Long WB. The Injury Severity Score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma*. 1974;14:187–196.
17. Baxter BT, Moore EE, Moore JB, et al. Emergency department thoracotomy following injury: critical determinants for patient salvage. *World J Surg*. 1988;12:671–675.
18. Molina EJ, Gaughan JP, Kulp H, et al. Outcomes after emergency department thoracotomy for penetrating cardiac injuries: a new perspective. *Interact Cardiovasc Thorac Surg*. 2008;7:845–848.
19. Seamon MJ, Shiroff AM, Franco M, et al. Emergency department thoracotomy for penetrating injuries of the heart and great vessels: an appraisal of 283 consecutive cases from two urban trauma centers. *J Trauma*. 2009;67:1250–1257.
20. Henderson V, Smith R, Fry W. Cardiac injuries: analysis of an unselected series of 251 cases. *J Trauma*. 1994;36:341–348.
21. Branney SW, Moore EE, Feldhaus KM, Wolfe RE. Critical analysis of two decades of experience with postinjury emergency department thoracotomy in a regional trauma center. *J Trauma*. 1998;45:87–94
22. Frezza E, Mezghebe H. Is 30 minutes the golden period to perform emergency room thoratomy (ERT) in penetrating chest injuries? *J Cardiovasc Surg (Torino)*. 1999;40:147–151.
23. Eastridge BJ, Hardin M, Cantrell J, Oetjen-gerdes L, Zubko T. Died of wounds on the battlefield: causation and implications for improving combat casualty care. *J Trauma*. 2011;71:4–8.
24. Tarmey NT, Park CL, Bartels OJ, et al. Outcomes following military traumatic cardiorespiratory arrest: a prospective observational study. *Resuscitation*. 2011;82:1194–1197.
25. Army Dismounted Complex Blast Injury Task Force. *Dismounted Complex Blast Injury Report*. Washington, DC: Department of Defense; 2011.
26. Borgman MA, Spinella PC, Perkins JG, Grathwohl KW, Repine T, Beekley AC, Sebesta J, Jenkins D, Wade CE, Holcomb JB. The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital. *J Trauma*. 2007;63:805–813.
27. Morrison JJ, Mellor A, Midwinter M, Mahoney PF, Clasper JC. Is prehospital thoracotomy necessary in the military environment? *Injury*. 2011;42:469–473.
28. Blackbourne LH, Baer DG, Cestero RF, Inaba K, Rasmussen TE. Exsanguination shock: the next frontier in prevention of battlefield mortality. *J Trauma*. 2011;71:S1–S3.