**Objective:** To evaluate factors that are predictive of delayed abdominal closure in patients injured during military conflict.

**Design, Setting, and Patients:** Seventy-one patients managed with an open abdomen were identified from records at Landstuhl Regional Medical Center from 2005 and 2006. Follow-up data were available from Walter Reed Army Medical Center. Records were reviewed through all echelons of care. Ordinal logistic regression was used to predict delayed abdominal closure.

**Results:** Patients sustained injury from blunt (n = 2), penetrating (n = 30), and blast (n = 39) mechanisms. The median Injury Severity Score was 25 (interquartile range, 17-34). Abdominal injury was observed in 85% of patients, and 48% underwent a massive transfusion. The median time to transfer to the United States was 5.3 days (interquartile range, 4.3-6.8 days). Abdomens were definitively closed downrange (11%), at Landstuhl Regional Medical Center (33%), or at Walter Reed Army Medical Center (56%). The median time until abdominal closure was 13 days (interquartile range, 4-40 days) in 2005 compared with 4 days (interquartile range, 1-14.5 days) in 2006 (P = .02). The multivariate model identified massive transfusion (odds ratio, 3.9), presence of complications (odds ratio, 5.1), and an injury date in 2005 (odds ratio, 3.4) as independently predictive variables for later abdominal closure.

**Conclusions:** Massive transfusion, occurrence of complications, and earlier injury date were predictive of delayed abdominal closure in casualties managed with an open abdomen. These data suggest an evolving approach to the management of severely injured combat casualties that involves earlier abdominal closure.

THE PARADIGM OF DAMAGE control surgery (DCS) has become widely accepted in civilian trauma centers during the past 2 decades. A landmark study from Rotondo and colleagues in 1993 first coined the term damage control, and since that time, multiple studies have extolled the advantages and decreased mortality associated with this model. The damage control concept includes an abbreviated operation to address surgical hemorrhage and prevent gastrointestinal soilage in an expeditious fashion to avoid development of the lethal triad of hypothermia, acidosis, and coagulopathy. Patients leave the operating room after the initial damage control procedure with a temporary abdominal dressing in place and return for definitive surgical care after sufficient resuscitation and physiologic normalization in the intensive care unit. This concept has become the standard of care for severely injured trauma patients in centers throughout the United States and across the world.

Although the term damage control was recently coined for civilian surgical practice, the concept of damage control as a whole has a US Naval origin. Additionally, others have noted that military surgeons have used principles of rapid operation with the goal of immediate infection control as far back as World War II, even though the actual term damage control was not used. Current military damage control principles are essentially the same as civilian practice; however, management of severely injured patients in this setting imposes additional unique challenges. Limited resources and austere conditions require complex interactions between medical providers at multiple levels of care. The battlefield evacuation of patients currently involves transfer across several echelons of care, while assuring that the goals of damage control and resuscita-
tion are achieved. Thus, a soldier treated by a medic on the battlefield may be initially seen for surgical damage control by a forward surgical team at a military level II facility or, depending on the distance from injury point, at a military level III combat support hospital. The patient would then be transported to a combat support hospital (if initial care was from a forward surgical team), where additional damage control procedures and resuscitation would occur. After this, the patient would be evaluated at an Air Force theater hospital, where surgical procedures may occur prior to transport to the level IV facility at Landstuhl Regional Medical Center (LRMC). Further stabilization would be achieved prior to transport to a military level V facility (military medical center) in the United States.

During recent wartime experiences, practitioners have successfully managed patients with open abdomens who were transported across multiple levels of care on 3 continents. Prior military-based studies have evaluated methods for the closure of the open abdomen with different techniques such as serial abdominal closure with Gore-tex mesh10 and use of bioprosthetic material for abdominal wall reconstruction.10 Additional studies have also compared other methods of definitive abdominal closure in this population.11 However, to our knowledge, no study has evaluated the factors that may predict whether the combat damage control abdomen may be closed at different echelons of care.

The objective of our study was to evaluate factors that are predictive of delayed abdominal closure in patients injured during military conflict. The primary outcome measures for comparison were abdominal closure location status and time to closure. Our secondary outcome measure was the total number of abdominal operations performed per patient. We hypothesized that evolution of the management of the open abdomen in the military would result in earlier abdominal closure.

**METHODS**

Institutional review board approval for this study was obtained from Walter Reed Army Medical Center (WRAMC). Patients managed with an open abdomen were identified from records at LRMC in Landstuhl, Germany. Landstuhl Regional Medical Center is an American College of Surgeons–verified level I trauma center, as well as a US military level IV facility that acts as the final level of care before patient transfer to the United States. Follow-up data were available from WRAMC, a military level V facility in Washington, DC, which serves as the highest level of care for those injured in combat.

Patient selection criteria included all patients who were managed with an open abdomen who were transported through LRMC in 2005 and 2006, with subsequent transport to WRAMC. Furthermore, only those patients who survived to be transported through all echelons of care and to abdominal closure were included. Seventy-one patients who were seriously injured in theater and managed with an open abdomen during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) were identified. Records were retrospectively reviewed from initial injury through all echelons of care. These data included the first evaluation by a forward surgical team or combat support hospital, treatment at LRMC, and then evaluation and management at WRAMC, where follow-up data were available until hospital discharge or death. The indications for the open abdomen in our study included abdominal injury, suspected intra-abdominal injury, and avoidance or treatment of abdominal compartment syndrome.

Demographic data were reviewed including age, sex, date of injury, mechanism of injury (MOI), Injury Severity Score (ISS), initial laboratory examinations including base excess, and presence or absence of associated intra-abdominal injury. Requirement for massive transfusion (defined as >10 units of packed red blood cells within 24 hours) was identified. Length of stay (LOS) prior to transport to the United States (time in theater after injury plus time at LRMC) was documented. Complications at all levels of care were noted and included pneumonia, respiratory failure, infection, acute renal failure, rhabdomyolysis, technical complications, and missed injury. Blood product administration was documented in all phases of care. Abdominal operation was defined as initial laparotomy, debridements including delayed bowel resection, restorative procedures, washouts, and closure of the abdomen. Restorative procedures included restoration of continuity. These operations were recorded and separated at 3 different levels of care as follows: in theater/downrange (at the forward surgical facility or combat support hospital), at LRMC, or at WRAMC. The total number of abdominal operations, time to closure, and location of final closure were also documented. Patients were classified as having undergone primary fascial closure or closure with an implant. Commonly used implants included dual mesh, Gore-tex, prolene mesh, and alloiderm.

Normally distributed data were presented as means and standard deviations. Nonnormally distributed data were presented as medians with the 25th to 75th interquartile ranges. Ordinal logistic regression was used to predict delayed definitive abdominal closure. Ordinal logistic regression is a generalization of binomial logistic regression whereby the odds ratios for a higher category are compared with all lower categories. Thus, higher in this analysis was equated with a later closure. Downrange was the first/lowest, followed by LRMC, and WRAMC was the last/highest. The odds ratios were the odds of being closed at LRMC compared with being closed down-range as well as the odds of being closed at WRAMC compared with being closed either downrange or at LRMC. Values were regarded as significant if the 95% confidence interval did not cross 1.

Negative binomial regression was used to predict the number of abdominal operations both overall postinjury and at each possible closure location. All predictive models were created using R version 2.12.2 (The R Project for Statistical Computing). Statistical significance was defined as \(P < .05\) for all comparisons.

**RESULTS**

Data were obtained from 71 patients (69 male, 2 female) injured during OIF or OEF and managed with an open abdomen. The average (SD) age was 26.4 (6.9) years. All dates of injury were in 2005 (n=43) or 2006 (n=28). Most patients in this series emanated from OIF during both years.

Patients sustained injury from blunt (n=2), penetrating (n=30), and blast (n=39) mechanisms. Median ISS was 25 (interquartile range [IQR], 17-34). Median base excess (BE) at earliest presentation in theater was –6.5 (IQR, –10.7 to –2.0). Abdominal injury (AI) was observed in 85% of patients (Table), and 48% received a massive transfusion (MT). Injury to the colon was the most common injury observed in this series, followed by...
Injury to the small intestine and spleen. The overall complication rate was 87%. Blood products that were administered included red blood cells (mean unit volumes, 9; IQR, 4-9); fresh frozen plasma (mean, 4; IQR, 2.25-10); platelets (mean, 0; IQR, 0-2); cryoprecipitate (mean, 0; IQR, 0-0.5); and whole blood (mean, 0; IQR, 0-2.25). Median time to transfer to the United States (pre-US LOS) was 5.3 days (IQR, 4.3-6.8 days), with a median LOS in theater of 1.5 days (range, 1.0-2.3 days) and at LRMC of 4.0 days (range, 3.0-5.0 days). Median LOS at WRAMC was 40 days (range, 17.0-62.0 days).

Abdomens were definitively closed downrange (11%), at LRMC (33%), or at WRAMC (56%). Primary fascial closure was performed in 46 patients (65%) and implants were placed in 25 patients (35%). The median total number of abdominal procedures was 5 (IQR, 3-10). All patients underwent initial laparotomy and eventual closure. The median number of additional trips to the operating theater was 3 (IQR, 1-8). Beyond initial laparotomy and closure, most additional procedures were for washout, debridement, and/or abdominal wall tightening. During these procedures, patients underwent 8 cholecystectomies, 1 appendectomy, and 8 bowel resections. Seventeen patients underwent interval procedures for restoration of gastrointestinal continuity. Seven additional patients underwent restoration with concurrent abdominal wall closure. The median total abdominal operations in theater, at LRMC, and at WRAMC were 1 (IQR, 1-2), 1 (IQR, 1-1), and 1 (IQR, 0-7), respectively. The median time until abdominal closure was 13 days (IQR, 4-40 days) in 2005 compared with 4 days (IQR, 1-14.5) in 2006 (P = .02).

A model for abdominal closure location status was created with ordinal logistic regression analysis. This model included the following variables: AI, complications, MOI, MT, and the injury year (2005 vs 2006). Sixty-eight observations were used for model development, with 3 observations excluded for missing data in 1 or more variables. The multivariate model identified MT (odds ratio, 3.9), presence of complications during hospitalization (odds ratio, 5.1), and an injury date in 2005 (odds ratio, 3.4) as independently predictive variables for later abdominal closure (P < .05). Nonsignificant variables in this model included AI and MOI (Figure 1).

Injury Severity Score and BE were separately included in model development. Missing variables resulted in the total number of observations dropping to 56 and 45, respectively. Neither ISS nor BE demonstrated statistical significance for being predictive variables for later abdominal closure (Figure 1).

A model for the total number of abdominal procedures was created using negative binomial regression analysis. This model included the following variables: AI, complications, pre-US LOS, MOI, MT, and year. Sixty-eight observations were used for model development, with 3 observations excluded for missing data in 1 or more variables. This model demonstrated that AI resulted in 1.7 times the total number of operations (P < .05) (Figure 2). This model also demonstrated that a complication resulted in 2.4 times the total number of operations (P < .01) (Figure 2). When ISS and BE were added to this model, the number of observations dropped to 37. Injury Severity Score and BE failed to demonstrate statistical significance in this model.

Models for the number of abdominal procedures performed in theater, at LRMC, and at WRAMC were also respectively created using negative binomial regression. Variables were equivalent to the model for total abdominal procedures and 68 observations were used. No variables were predictive of the number of operations in theater. At LRMC, this model revealed that pre-US LOS was a significant predictor of 1.1 times more LRMC abdominal procedures for each additional day of pre-US LOS (P < .01). At WRAMC, the model demonstrated that the occurrence of a complication resulted in 7.0 times more WRAMC abdominal procedures compared with not having a complication (P < .01) (Figure 3).

In this study, we evaluated the factors that are predictive of delayed abdominal closure in patients injured during military conflict. Prior studies have focused on the advantages of using different abdominal closure techniques; however, to our knowledge, no study has provided a model demonstrating which factors are predictive of closure at the different echelons of combat casualty care. A recent study published by our group compared civilian and military trauma patients during the first 7 days after injury and demonstrated that military DCS patients underwent significantly more surgical procedures than a matched civilian population. Despite the differing surgical requirements, mortality and abdominal closure rates did not differ between groups. This study only assessed the immediate postinjury...
period; thus, the current study was undertaken with the intent of evaluating closure at all echelons of postcombat injury care. The current study identified MT, the presence of complications during hospitalization, and an earlier injury date as independently predictive of later abdominal closure.

The use of DCS has ultimately become the standard of care in civilian trauma practice during the past 2 decades. Historical control studies have revealed a higher survival rate in DCS patients compared with matched non-DCS control subjects. In spite of this, DCS has been associated with significant morbidity including intra-abdominal abscesses, gastrointestinal fistulae, and sepsis. The challenges of caring for these patients are even further compounded in the complexity of a combat environment. Whereas civilian trauma will involve the spectrum of initial care through abdominal closure at the same surgical facility and often with the same surgical team, combat casualties managed with an open abdomen may undergo operations at multiple levels of care across 3 continents and with different surgical operating room staff at each critical stage. Furthermore, the overall operating environment in a combat setting, unlike civilian practice, is often not dictated by the surgeon. Hostile fire, limited resources, and impending mass casualty situations create conditions that are unique to combat circumstances. Our current study evaluated a population of patients injured during OIF and OEF with a median ISS of 25 and in which 48% of patients received a MT. The relative severity of these casualties is comparable to other retrospective studies that have evaluated abdominal closure techniques in DCS patients returning from these 2 military conflicts.

Both MT and the presence of a complication during hospitalization were found to be independently predictive of later abdominal closure rates. Massive transfusion is often regarded as one of the classic triggers for DCS. Prior civilian trauma studies have demonstrated that increased blood transfusions are significantly associated with failure of primary abdominal closure. The interesting aspect of the current model, as determined by ordinal logistic regression, was the fact that MT was independently predictive of later abdominal closure; however, having an associated intra-abdominal injury was not predictive of later closure. Thus, the concept of damage control resuscitation must be paired with DCS to assure the best chance of earlier abdominal closure in these circumstances. Emerging therapies in hemorrhage control techniques and factor replacement therapy may be advantageous because massive resuscitation may be avoided.

A high infectious complication rate has also similarly been associated with the inability to achieve early primary abdominal closure in civilian trauma patients. Our study demonstrated a high overall complication rate of 87%. Although this complication rate may seem relatively elevated compared with civilian studies, this figure is in accordance with other studies of combat DCS.
While evaluating methods of closure in DCS patients returning from OIF and OEF, Vertrees et al.11 noted a significant complication rate, with an overall morbidity of 60% to 100%, depending on closure type. The complexity of multistage combat surgery poses unique challenges; through continued improvement in combat DCS techniques, transport, and postinjury care, a reduction in overall complication rates may result in a decrease in the number of abdominal operations and the potential for earlier abdominal closure.

The 2 most common MOIs in this study included blast and penetrating injury mechanisms. In previous studies, our group demonstrated that military and civilian trauma centers treat significantly different injury mechanisms.18 Furthermore, modern battlefield weaponry is not comparable to civilian practice. High velocity automatic rifles and high-powered explosives such as improvised explosive devices create wounding patterns in casualties that are different than handgun-based and blunt trauma–based civilian injuries.19 Other studies involving DCS in OIF and OEF have noted disproportionate numbers of blast injuries compared with penetrating mechanisms,11 and our study also supports this epidemiology. However, an ordinal logistic regression model in this study failed to demonstrate that MOI was predictive of delayed abdominal closure in this patient population.

Perhaps the most important significant predictive variable of delayed abdominal closure in our study is an injury date in 2005 as opposed to an injury date in 2006. These data suggest an evolving approach to the management of severely injured combat victims that involves earlier abdominal closure. Similar findings were noted by Vertrees and colleagues, who found that in soldiers returning from OIF and OEF in 2003, mean (SD) time from injury to definitive abdominal closure was 63 (56) days, as opposed to 2007 when the mean time was 20 (12) days.11 Thus, increasing military use and experience with management of the open abdomen ultimately aids in earlier abdominal closure. Just as civilian DCS evolution has resulted in higher survival rates,14 military DCS will also continue to progress, advance, and improve over time.

The indications for the open abdomen in our study included abdominal injury, suspected intra-abdominal injury, and avoidance or treatment of abdominal compartment syndrome. Additionally, the tempo of combat surgery and the need for frequent transport necessitates leaving the abdomen open for speed and to facilitate re-exploration at subsequent echelons of care. The identification of delayed bowel injury from high-powered ballistic injuries and blast injuries as seen in 8 patients in this series also necessitated leaving the abdomen open. This practice is also a limitation of our study, as the exact rationale for leaving the abdomen open may not be precisely elucidated. There are also other limitations to this study. It is retrospective in nature and data points were confined to availability from theater, at LRMC, and at WRAMC. Patients who died and were not cared for at LRMC and WRAMC were excluded; thus, the representative study population only includes patients who survived transport through all echelons of care. Collection of data from combat and austere environments is often difficult; consequently, modeling may be limited to a de-
gree because of missing data. Missing data combined with a small sample size and multiple covariates were a further limitation of performing a multivariate logistic regression in this population.

In summary, our study evaluated factors that are predictive of delayed abdominal closure in patients injured during military conflict. An ordinal logistic regression model identified MT, the presence of complications during hospitalization, and an injury date in 2005 as independent predictive variables for later abdominal closure. Nonsignificant variables included ISS, AI, and MOI. Combat DCS represents the standard of care for current US military operations. Continued assessment of damage control resuscitation, surgical techniques, and transport care will ultimately aid in reducing morbidity and mortality in military patients in the future.

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REFERENCES
