Original Article

Predictors of Failed Primary Abdominal Closure in the Trauma Patient with an Open Abdomen

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Background: We sought to characterize risk factors for failed closure after damage-control laparotomy and to examine the impact of two broad categories of open abdomen–management technique on rates of fascial approximation.

Methods: We retrospectively reviewed (January 2006–December 2008) all trauma patients with an open abdomen after damage-control laparotomy. Patients with definitive abdominal closure before discharge were classified as successful closure (SC) and those discharged with a planned ventral hernia were classified as failed closure (FC). Univariate stepwise logistical analyses were conducted to identify covariates related to resuscitation volumes and injury severity that were associated with FC. Surgical techniques were dichotomized as fascial based or vacuum based and compared with chi square.

Results: Sixty-two subjects met final eligibility (SC 44, FC 18). SC and FC were similar, with the exception of, respectively, initial base excess (-8.0 ± 4.2 vs -11.4 ± 4.9; $P = 0.009$), injury severity score (ISS; 29.0 ± 15.2 vs 20.6 ± 12.1; $P = 0.04$), and frequency of penetrating injury (47.7% vs 77.8%; $P = 0.03$). Stepwise regression showed significant associations between failed closure and increasing Penetrating Abdominal Trauma Index (odds ratio [OR] 1.06, 95% confidence interval [CI] 1.01–1.11), worsening base excess on arrival (OR 0.79, 95% CI 0.66–0.93), and lower ISS (OR 0.94, 95% CI 0.89–1.00). Fascial-based versus vacuum-based management techniques had no effect on closure rates.

Conclusions: Volume of blood transfused, crystalloid given, and open abdomen management technique were not related to closure rates; however, worsened base excess on arrival, penetrating trauma, higher Penetrating Abdominal Trauma Index, and a lower ISS were associated with FC. The latter was true despite an association also being

Key Points

- Patients with an open abdomen presenting with a penetrating mechanism of injury, increasing Penetrating Abdominal Trauma Index scores, and increasing degrees of physiological distress at the time of presentation are independently associated with the failure of midline approximation at the time of discharge.
- Overall transfusion burden and initial volume of crystalloid given during the first 24 hours of hospitalization were not shown to be associated with closure rates, and we are pursuing the question of whether particular transfusion strategies affect closure rates through our work with the PROMMTT (Prospective Observational Multicenter Major Trauma Transfusion) study.
- Analysis of fascial- versus vacuum-based management of the open abdomen revealed no statistical differences between the technique used and the likelihood of closure.

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found between FC and lower ISS scores, reflecting the propensity of ISS to underestimate injury burden after penetrating injury.

Key Words: closure rates, damage control, open abdomen

Damage-control laparotomy and the subsequent open abdomen are common and have led to decreased postinjury mortality.[1,2] This clinical pathway has brought with it its own set of challenges because a subset of patients with open abdomens are unable to have definitive fascial closure leading to a "frozen abdomen," with the need for visceral skin grafting and planned ventral hernia repair. The incentives to avoid this scenario are great because failed abdominal closure results in increased patient morbidity and complications.[3,4]

In general, management of the open abdomen centers around two broad methods: the use of negative pressure suction to maintain traction toward the midline or direct fascial tension via sutures anchored to the linea alba. Because we have institutional experience with both, we undertook this study with two purposes in mind: We sought to review our experience managing the open abdomen in the trauma patient and to identify any aspects of surgical management or patient characteristics that predicted failed primary closure. We hypothesized that penetrating injuries, an increasing degree of intraabdominal injury, and a larger volume of crystalloid resuscitation would lead to an increased likelihood of planned ventral hernia repair.

Methods

After receiving institutional review board approval from the University of Texas Southwestern Medical Center, all of the patients undergoing exploratory laparotomy for trauma between January 1, 2006 and December 31, 2008 were identified in the Parkland Memorial Hospital trauma database. This group was cross-referenced with the Department of Surgery coding database for "reopening of recent laparotomy" to obtain a list of all of the trauma patients who had an open abdomen. Although an institutional protocol exists that provides guidance in making the choice to perform damage-control laparotomy, the decision to perform a damage-control procedure with an open abdomen is ultimately at the discretion of the attending surgeon. A vacuum-based dressing is our initial temporary abdominal covering of choice. Patients surviving their resuscitation are returned to the operating room 24 to 48 hours after termination of their index laparotomy for definitive management of their injuries and attempted abdominal closure. If closure at first take back is impossible or believed to be ill advised, then the choice of vacuum- or fascial-based open abdomen management is left to the discretion of the attending surgeon staffing the case, as are all of the future choices surrounding timing of return trips to the operating room and open abdomen management techniques to be used. Exclusion criteria were age younger than 18 years, performance of only a single abdominal operation, and performance of initial damage-control laparotomy >24 hours after presentation. Data pertaining to demographics, the presenting clinical status, and outcomes were collected, with categorical values listed as percentages and continuous variables as mean ± standard deviation. All of the operative reports were then reviewed to ascertain the number of abdominal operations performed, surgical techniques used to manage open abdomens, and number of days with an open abdomen. In addition to standard assessments of injury severity, further information on the severity of abdominal injury was ascertained through the calculation of a Penetrating Abdominal Trauma Index (PATI) score[5] on all of the patients, regardless of injury mechanism.

For the purpose of this study, an open abdomen was defined as an explored abdominal cavity without fascial closure. Based on a review of operative notes, subjects were classified into two groups: those in whom primary fascial closure was obtained before discharge from index admission (successful closure group [SC]) and those with a discharge plan of delayed ventral hernia repair (failed closure group [FC]). Surgical techniques for managing the open abdomen were divided into two groups: fascial-based management and vacuum-based management. Subjects who had both fascial- and vacuum-based management at different times in their convalescence had an a priori decision made after review of all of their operative records as to which method constituted the preponderance of their care and were classified as such.

To identify independent risk factors for failure to achieve definitive fascial closure, a univariate analysis was initially conducted of all of the covariates. Those with a P value ≤ 0.20 were considered in the logistic regression model using several variable selection procedures. A parsimonious model was selected that included those variables that produced the best area under the curve and Hosmer-Lemeshow results. Adjusted odds ratios (OR) with 95% confidence intervals (CIs) and adjusted P values were derived. Bivariate analyses were performed using the chi square or Fisher exact test (two-sided) as appropriate to test differences in proportions. The unpaired Student t test was used to compare differences between means. SAS software version 9.2 (SAS Institute, Cary, NC) was used for all of the calculations.

Results

During the 3-year study period, 758 patients, of whom 76 (10%) received a damage-control procedure with open abdomen, underwent exploratory laparotomy for trauma at our institution. Sixty-two subjects met all of the inclusion/exclusion criteria, and the success rate for fascial closure at the time of discharge or death was 71.0% (SC 44, FC 18). As would be expected in cohorts undergoing damage control, high severities of injury were seen in the SC and FC groups both overall (Injury Severity Score [ISS] 29 ± 15 and 21 ± 12, respectively) and in the abdomen (PATI 25 ± 14 and 30 ± 20, respectively). Three deaths occurred in the cohort, all of which were in the SC group and believed to be unrelated to the timing

and method of fascial closure, for an overall mortality rate of 4.8%. Demographic characteristics are listed in Table 1. Notably, the FC group exhibited a greater degree of physiological distress at presentation than the SC group as reflected by worsened base excess ($P = 0.009$). FC subjects also experienced a significantly higher rate of penetrating mechanisms of injury (77.8%) than the SC group (47.7%; $P = 0.03$) and a lower ISS (20.6 ± 12.1 vs 29.0 ± 15.2; $P = 0.04$).

No differences were seen between groups at 24 hours after injury when examining the amount of crystalloid infused, number of units of packed red cells transfused, or base excess (Table 2). The FC group exhibited significantly longer hospital stays ($P < 0.001$) and intensive care unit stays ($P = 0.006$), more days on ventilators ($P = 0.04$), higher total hospital charges ($P < 0.001$), higher total number of surgeries ($P < 0.001$), and more total days with an open abdomen ($P < 0.001$).

The logistic regression model indicated significant associations between FC and increasing PATI (OR 1.06, 95% CI 1.01–1.11), worsening base excess on arrival to the emergency department (OR 0.79, 95% CI 0.66–0.93), and lower ISS (OR 0.94, 95% CI 0.89–1.00). The area under the curve for the model was 0.81.

In the overall analysis of fascial- versus vacuum-based management of the open abdomen, no differences were found between the technique used and the likelihood of closure ($P = 0.08$). When a subgroup analysis was conducted on subjects who still had an open abdomen at 48 hours after injury (SC 18, FC 18), again, no significant difference was seen between vacuum- and fascial-based management techniques on closure rates ($P = 0.30$; Table 3). Of note, all of the patients closed before 48 hours underwent only vacuum-based management.

Table 1. Baseline demographics and data on arrival to the emergency department

	SC (n = 44)	FC (n = 18)	*P*
Baseline demographics			
Age, y	34 ± 17	37 ± 12	ns
Male/female, %	93/7	94/6	ns
Blunt/penetrating injury, %	52/48	22/78	**0.03**
Injury severity score	29 ± 15	21 ± 12	**0.04**
Revised trauma score	11 ± 2	10 ± 3	ns
Penetrating Abdominal Trauma Index	25 ± 14	30 ± 20	ns
Parameters on arrival			
Temperature, °C	36 ± 1	36 ± 1	ns
Heart rate, beats/min	115 ± 29	108 ± 22	ns
Respiratory rate, breaths/min	33 ± 27	31 ± 19	ns
Systolic blood pressure, mm Hg	118 ± 28	118 ± 40	ns
Hematocrit, %	36 ± 7	35 ± 7	ns
Base excess	−8 ± 4	−11 ± 5	**0.009**
Intubated, %	39	39	ns
Glasgow Coma Scale	13 ± 4	11 ± 5	ns

Bold type indicates significance.
FC, failed closure; ns, not significant; SC, successful closure.

Table 2. Data at 24 hours after injury and at discharge

	SC (n = 44)	FC (n = 18)	*P*
Parameters at 24 h postinjury			
Crystalloid, L	16 ± 7	17 ± 7	ns
Packed red cells, U	12 ± 12	12 ± 13	ns
Base excess	−1 ± 4	−2 ± 5	ns
Hospital course			
Hospital length of stay, d	25 ± 17	78 ± 52	**<0.001**
Intensive care unit length of stay, d	12 ± 15	26 ± 22	**0.006**
Ventilator days	9 ± 13	17 ± 15	**0.04**
Abdominal surgeries	3 ± 2	10 ± 5	**<0.001**
Open abdomen, d	4 ± 4	54 ± 27	**<0.001**
Total hospital charges, $	237,595	662,840	**<0.001**

Bold type indicates significance.
FC, failed closure; ns, not significant; SC, successful closure.

Discussion

This case-control study found a penetrating mechanism of injury, increasing physiological distress at presentation, increasing PATI scores, and decreasing ISS scores to be independently associated with an increasing likelihood of failed abdominal closure after trauma. Interestingly, the overall transfusion and crystalloid burdens between the FC and SC groups were similar and no independent effect of these covariates, nor of open abdomen management techniques, on closure rates were found.

Our finding that FC was associated with lower ISS scores seems counterintuitive at first. This is likely an artifact given the propensity of the ISS to underestimate the magnitude of the true trauma burden after penetrating injury. By considering the three worst injuries while limiting the calculation to one injury per body region, the ISS clearly underestimates the magnitude of injury burden in the instance of multiple injuries confined to one body region. Because the abbreviated injury score for the abdomen would be prone to this same weakness, we did not believe that it would be a valid surrogate for an assessment of the individual effect of abdominal injury. To

Table 3. 2 × 2 contingency table for open abdomen management strategy and occurrence of SC versus FC

Management	SC	FC
Vacuum based	31	8
Fascial based	13	10

FC, failed closure; SC, successful closure.

that end, we applied the PATI methodology to all abdominal injuries as a best attempt to control for the severity of abdominal injury in cohorts that had high rates of penetrating injury. PATI assigns a baseline risk factor (1–5) to each abdominal organ and then multiplies that risk factor by the severity of injury to that organ (also 1–5). The final PATI score is determined by calculating the sum of all of the injured abdominal organs. PATI scores of ≥25 are at the highest risk for the development of complications, and consequently are indicative of higher severities of injury.

This weakness of the ISS has been borne out by two epidemiologic studies that showed that patients who died after penetrating mechanisms of injury had significantly lower ISS scores than did those who died after blunt injuries.[6,7] Our experience reinforces these findings. We found that the FC group had both a higher rate of penetrating injury and a higher severity of abdominal injury as reflected by their higher overall PATI scores. The differences between blunt and penetrating mechanisms of injury do not stop at scoring systems. Patients with a penetrating mechanism of injury have been shown in epidemiologic studies to die more frequently,[7] more quickly,[8] and more often of a thoracic or abdominal vascular injury[7] than after a blunt injury. In addition, penetrating mechanisms of injury are an independent predictor of massive transfusion,[9] have better outcomes after massive transfusion with a resuscitation using higher ratios of red cells to plasma,[10] and play an integral role in a validated prediction tool for massive transfusion.[11,12] Although none of these studies examined the specific question of fascial closure after damage-control laparotomy, they do provide the basis for a mechanistic explanation of the strength of our signal on the role of penetrating mechanism of injury in FC.

The fact that we were not able to demonstrate a difference in closure rates between fascial-based or vacuum-based surgical approaches is consistent with a systematic literature review and clinical management update on open abdomens promulgated by the Eastern Association for the Surgery of Trauma.[13] This guideline states that the most common type of fascial traction device and vacuum-based systems are safe (level II) and that a generic vacuum system serves as the current gold standard simply because it is the least expensive (level III). In considering the question of open abdomen management, the authors report, "There does not seem to be a single [temporary abdominal closure] that is superior to the others commonly in use. It is largely a matter of surgeon preference, and without direct comparison of the commonly used techniques a single method cannot be recommended."[13] A trial in which subjects were randomized to vacuum-based versus fascial-traction–based strategies also failed to demonstrate a difference between these two strategies.[14] FC rates of 15% to 28%[15,16] have been reported for vacuum-based fascial management and of 18% to 22%[17,18] for fascial-based systems at other level I trauma centers during the same approximate time period as the present study. It was disconcerting to find an FC rate of 29% in our cohort in which a combination of these techniques were used. Although a protocol was in place at the time of this study for the initiation of damage-control laparotomy, one was not in place for open abdomen management. To that end, our divisional practice has evolved to a general practice pattern that consists of using a vacuum-based system at the time of damage-control laparotomy and at the completion of the initial take back if midline approximation is not possible. If an open abdomen is still required at the second take back (and therefore third operation), then a commercially available, fascial-based, hook-and-burr system is placed. No set criteria existed for declaration of FC and visceral skin grafting either at the time of this study or at present. It should be noted that because the management of the open abdomen is not standardized at our institution, some subjects crossed over between vacuum-based and fascial-based management strategies at some point in their convalescence. For these subjects, a subjective decision had to be made by the investigators as to which approach constituted the bulk of their care, which could in turn have served as a source of bias.

We were surprised to find that the amount of crystalloid and/or blood transfused did not have an impact on the likelihood of closure given the known association between infusions of large amounts of these fluids/products and bowel edema. It should be noted that the time period of the present study overlapped with our institution's first iterations of a massive transfusion protocol and our move away from crystalloid-based resuscitations to an earlier and more aggressive use of blood products and education of prehospital providers and our anesthesia colleagues on the benefits of this shift in strategy. Consequently, our mean 24-hour crystalloid volumes were high compared with our present local practice for this severely injured cohort.

An explanation for this finding of no relation between crystalloid volume and closure rates may lie in their relation with the shock state. Although we cannot speak to these groups' duration of shock, we were able to show that the intensity of the shock state was significantly higher in the FC group at the time of presentation. The finding that the FC group was sicker at presentation but had equivalent transfusions and crystalloid at 24 hours after injury reflects a possible inadequacy of the 24-hour time point as a marker for detecting the effects of infusion and transfusion on closure rates. Because the FC group had a significantly higher incidence of penetrating mechanism of injury and penetrating trauma often is amenable to more expeditious surgical control of hemorrhage than a blunt injury, it is possible that the curves tracking the duration and depth of the shock state in these groups would look markedly different in the early stages of their interventions and resuscitations while still being similar at 24 hours after injury. This is a variant of the "survival bias" that plagues retrospective studies of this type.[19] Because these were severely injured cohorts, it is also possible that a threshold effect for these covariates as they affect closure rates was exceeded by the cohort to the point that their effect was no longer seen.

We looked at these variables as broad categories, so it is also possible that undetected confounding may have existed. One possibility for the latter is the ratio of packed red cells to plasma transfused. At the time of this study, our institutional massive transfusion protocol called for the infusion of 2 U of plasma for every 5 U of red cells. Furthermore, during that time it had not always been our institutional practice to transfuse all of the plasma in the last cooler upon cessation of the massive transfusion protocol in a given patient. This, in turn, led to variable ratios. Although the preponderance of the evidence has suggested that higher ratios lead to a survival advantage,[10,20,21] no data to date have examined the effect of ratio on the likelihood of successful midline fascial closure. Our group is examining this question in the context of our participation in the Prospective Observational Multicenter Major Trauma Transfusion (PROMMTT) study.

Conclusions

In summary, this study demonstrated that a penetrating mechanism of injury, increasing PATI scores, and increasing degrees of physiological distress at the time of presentation are independently associated with the failure of midline approximation at the time of discharge. Although an overall transfusion burden was not shown to be associated with closure rates, we are pursuing the question of whether particular transfusion strategies affect closure rates through our work with the PROMMTT study.

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