
An Experience in the Management of the Open Abdomen in Severely Injured Burn Patients

Mark O. Hardin, MD, James E. Mace, MD, John D. Ritchie, MD,
Kevin K. Chung, MD, Katharine W. Markell, MD, Evan M. Renz, MD,
Steven E. Wolf, MD, Lorne H. Blackbourne, MD, Christopher E. White, MD, MSc

Few descriptions of temporary abdominal closure for planned relaparotomy have been reported in burned patients. The purpose of this study is to describe our experience and outcomes in the management of burned patients with an open abdomen. The authors performed a retrospective review of all admissions to our burn center from March 2003 to June 2008, identifying patients treated by laparotomy with temporary abdominal closure. The authors collected data on patient demographics, indication for laparotomy, methods of temporary and definitive abdominal closure, and outcomes. Of 2,104 patients admitted, 38 underwent a laparotomy with temporary abdominal closure. Their median TBSA was 55%, and the incidence of inhalation injury was 58%. Abdominal compartment syndrome was the most common indication for laparotomy (82%) followed by abdominal trauma (16%). The in-hospital mortality associated with an open abdomen was 68%. Temporary abdominal closure was performed most commonly using negative pressure wound therapy (90%). Fascial closure was performed in 21 patients but was associated with a 38% rate of failure requiring reexploration. Of 12 survivors, fascial closure was achieved in seven patients and five were managed with a planned ventral hernia. Burned patients who necessitate an open abdomen management strategy have a high morbidity and mortality. Fascial closure was associated with a high rate of failure but was successful in a select group of patients. Definitive abdominal closure with a planned ventral hernia was associated with no increased mortality and remains an option when “tension-free” fascial closure cannot be achieved. (*J Burn Care Res* 2012;33:491–496)

Current surgical practice in the era of damage control has led to the practice of planned relaparotomy to address intra-abdominal issues that remain after stabilization of a critically ill patient. With these changes in surgical care, open abdomens in critically ill patients have become increasingly common. The open abdomen is an especially complex problem in

severely burned patients and has been associated with a high morbidity and mortality.^{1,2}

Management of a burned patient with an open abdomen may become necessary after abdominal compartment syndrome (ACS), abdominal trauma, and other primary intra-abdominal pathology resulting in an abdominal catastrophe. Decompressive laparotomy for the treatment of ACS has been described in burn patients and universally requires a method for temporary abdominal closure.^{2–4} Likewise, ischemic or perforated bowel diagnosed at the time exploratory laparotomy often induces management with temporary abdominal closure for the purposes of a “second-look” operation to ensure bowel viability. The incidence of such abdominal catastrophes in burn patients is relatively low but increases linearly with burn size and is associated with a high mortality.^{1,5} Finally, damage control surgery for the management of nonburn trauma is another reason for an open abdomen strategy in a burn patient and occurs

*From the United States Army Institute of Surgical Research,
Fort Sam Houston, Texas.*

*Supported by the U.S. Army Institute of Surgical Research.
Presented at the meeting of the American Burn Association, San
Antonio, Texas, March 24–27, 2009.*

*The opinions or assertions contained herein are the private views
of the authors and are not to be construed as official or reflecting
the views of the Department of the Army, Department of the
Defense, or the US Government. This work was prepared as part
of their official duties and, as such, there is no copyright to be
transferred.*

*Address correspondence to Christopher E. White, MD, MSc, FACS,
LTC, United States Army Institute of Surgical Research, 3400
Rawley E. Chambers Avenue, Fort Sam Houston, Texas 78234.
Copyright © 2012 by the American Burn Association.
1559-047X/2012*

DOI: 10.1097/BCR.0b013e3182479b00

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 01 NOV 2012		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE An Experience in the Management of the Open Abdomen in Severely Injured Burn Patients				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Hardin M. O., Mace J. E., Ritchie J. D., Chung K. K., Markell K. W., Renz E. M., Wolf S. E., Blackbourne L. H., White C. E.,				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) United States Army Institute of Surgical Research, JBSA Fort Sam Houston, TX				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

more frequently in military casualties when compared with civilian burn patients.⁶ Regardless of the etiology of an open abdomen, achieving fascial closure, if feasible, is the ultimate goal in all burn patients.

Management strategies for patients with an open abdomen in the surgical intensive care unit have been previously well described. Various techniques for temporary abdominal closure in critically ill surgical patients have included the use of skin-only closure, loose packing of an open fascial defect, plastic silos (Bogotá bag), the vacuum pack, vacuum-assisted closure (VACTM), the Wittmann PatchTM, and closure with absorbable or nonabsorbable mesh.⁷⁻¹³ When repeated access to the abdominal cavity is no longer needed and the patient's physiology has improved, definitive abdominal closure is usually achieved by fascial closure or a planned ventral hernia.^{14,15} This topic has not been well described in the unique population of burned patients, and in fact no large retrospective reviews are extant describing the management of the open abdomen in these patients. Because the morbidity and mortality of severely burned patients with concomitant abdominal complications is high, it is important to examine the strategies for management of the open abdomen in the severely burned to optimize care with the use of this therapeutic intervention. The purpose of this study was to describe our experience in the management of burned patients with open abdomens and to report the associated morbidity and mortality of this population.

METHODS

We performed a retrospective review of all patients admitted to the intensive care unit at the U.S. Army Institute of Surgical Research (USAISR) Burn Center at Fort Sam Houston, TX, from March 2003 to June 2008. We subsequently identified all civilian and military adult (age, ≥ 18) burn patients who had undergone a laparotomy, either in the theater of military operations or at the USAISR, and required a temporary abdominal closure. The indications for laparotomy included ACS, abdominal trauma, and other acute intra-abdominal processes that underwent a damage control operation with a planned, second-look. We excluded those patients undergoing initial laparotomy with temporary abdominal closure in cases where comfort care measures were instituted immediately after the operation.

We collected the following data:

- Patient demographics: age, gender, and military or civilian status.
- Injury characteristics: mechanism of injury, injury severity score, inhalation injury, percentage of TBSA burned, and the presence of burns involving abdominal skin.
- Treatment characteristics: method of temporary abdominal closure, number of days to closure, and number of abdominal operations undergone.
- Outcomes: mortality, dehiscence, bowel necrosis, sepsis, adult respiratory distress syndrome, multi-system organ failure (MSOF), acute kidney injury, pneumonia, and venous thromboembolism.

Age, gender, military or civilian status, date of injury, and date of laparotomy were determined from the medical record. Burn size (percentage of TBSA) and inhalation injury were determined from the patient's chart as documented by the attending physician. TBSA is determined at the USAISR based on the Lund and Browder Chart.¹⁶ All patients admitted to the USAISR with a probable history of inhalation injury were screened by bronchoscopy on admission. Inhalation injury was defined as bronchoscopic evidence of airway damage (soot, edema, erythema) with a history consistent with inhaled particles of combustion. The indication for exploratory laparotomy was determined from the documented record by the attending surgeon. The diagnosis of ACS, as made by the attending surgeon, was based on the combined findings of abdominal distention, intra-abdominal hypertension (>30 mm Hg) measured by bladder pressure, and oliguria (defined as urine output <30 mL/hr with adequate intravascular volume). The presence of dehiscence and/or bowel necrosis was determined from the operative note. The outcomes of acute respiratory distress syndrome, MSOF, acute kidney injury, pneumonia, and venous thromboembolism were determined from the medical record. Definitive abdominal closure was defined as coverage of abdominal viscera by either fascial closure or by split-thickness skin grafting (STSG).

The methods of temporary abdominal closure included negative pressure wound therapy (NPWT), Bogotá bag, and Wittmann PatchTM (Starsurgical, Burlington, WI). NPWT was predominantly not only performed with the VAC device (KCI, San Antonio, TX) but also included the use of a generic vacuum pack technique. In general, NPWT was performed by inserting a sterile, plastic dressing beneath the fascia, ensuring that the lateral edges of the dressing completely covered the abdominal viscera. This was followed by placing a laparotomy sponge and suction tubing over the subfascial dressing. Finally, an adherent dressing was placed overlaying the entire system and was secured to the surrounding skin and placed

to suction. Temporary closure with a Bogotá bag was performed by securing a sterile, 3-L irrigation bag that was sewn to the skin edges with continuous monofilament nonabsorbable suture. The Wittmann Patch™, when used, was secured to the free lateral edges of the abdominal fascia using continuous monofilament nonabsorbable suture. The medial flaps of the Wittmann Patch™ adhered to each other by a hook and loop material and were sequentially tightened to reduce the fascial defect over time. Temporary abdominal closure dressings were changed every 24 to 72 hours as per surgeon preference, and the fascia was assessed for the possibility of delayed fascial closure at the time of each dressing change. When delayed fascial closure was not achieved, it was our practice to place absorbable mesh followed by STSG after adequate granulation tissue forms on exposed bowel.

An Excel 2003 (Microsoft Corporation, Redmond, WA) spreadsheet was created for use as a database, and all data were analyzed with SPSS 16.0 (SPSS Inc., Chicago, IL). Categorical variables were compared by χ^2 test. Continuous variables were compared by Student's *t*-test for normal distributions or Mann-Whitney *U*-test for nonparametric distributions. Statistical significance was set at $P < .05$.

RESULTS

We admitted 2,104 patients between March 2003 and June 2008. Forty-five patients underwent a laparotomy with temporary abdominal closure for

decompression of ACS or for repeated access to the abdominal cavity. Seven patients were excluded from the study because comfort care measures were initiated immediately after the operation with no further attempt to close the abdomen (Figure 1). Of the 38 subjects in the final study group, 29 were military casualties and 9 were civilians. Overall, patients with open abdomen management strategy at the USAISR were severely injured with a median TBSA of 55% and an incidence of inhalation injury of 58% (Table 1). The predominant mechanism of thermal injury was flame in both military and civilian patients; however, 86% of military subjects were injured during an explosion, whereas no civilian patients were injured by this mechanism. The demographics and injury characteristics were similar between military and civilian patients with the exception of age. The median age was 49 years (interquartile range [IQR], 34–55) in civilians relative to 23 years (IQR, 21–35) in military casualties ($P < .001$). There was no observed difference in mortality between civilian and military burn patients who required management with an open abdomen.

The indication for exploratory laparotomy was ACS in 31 patients (82%), abdominal trauma in 6 patients (16%), and a perforated gastric ulcer in 1 patient (3%). The abdominal complications requiring laparotomy occurred relatively early in the hospital course in the majority of patients with the initial laparotomy performed on a median postinjury day of 1 (IQR, 0–8). The median number of

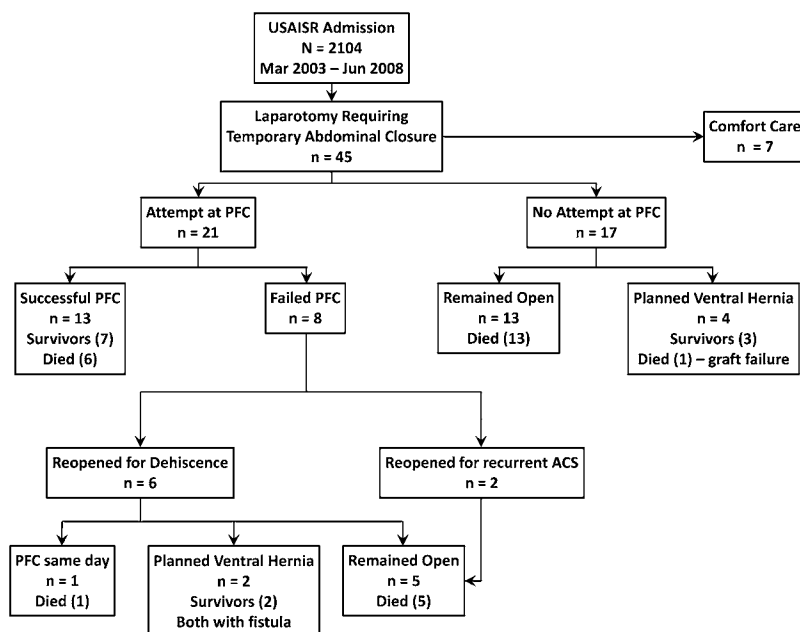


Figure 1. Consort diagram.

Table 1. Overall demographics

Variable	Overall (n = 38)
Age (median, IQR), n = 38	27 (21–38)
Male (%), n = 38	34 (89.5%)
Military (%), n = 38	29 (76.3%)
ISS (median, IQR), n = 32	34 (24–41)
TBSA (median, IQR), n = 38	54.8 (40–71)
Inhalation injury (%), n = 38	22 (57.9%)
Abdomen burned, n = 38	21 (55.3%)

Categorical variables presented as n (%) and continuous variables presented as median (25th–75th percentiles).

IQR, interquartile range; ISS, injury severity score.

abdominal operations required was 4 (IQR, 2–7) with the abdomen remaining open for a median of 11 days (IQR, 4–35).

The overall in-hospital mortality associated with an open abdomen in burn patients at the USAISR is 68%, with the incidence of other significant complications listed in Table 2. In those with burns >50%, the mortality was 78%. Compared with survivors, nonsurvivors had a higher incidence of inhalation injury (69 and 33%, respectively; $P = .037$) and higher median TBSA (58 and 43%, respectively; $P = .049$) but were otherwise similar with respect to patient demographics and injury characteristics (Table 3). Of interest, nine burned patients with an open abdomen (24%) developed an enterocutaneous fistula during their hospital course. Of those developing an enterocutaneous fistula, the duration that the abdomen remained open ranged from 35 to 125 days. Upon univariate logistic regression of duration of open abdomen to the development of a fistula, a duration of 5.3 days with an open abdomen was associated with an odds ratio of 2.0 (95% confidence interval, 1.2–3.3). In other words, the odds of developing of an enterocutaneous fistula in our population doubled every 5 days that the abdomen remained open.

Table 2. Complications associated with open abdomen

Complication	n	%
Mortality	26	68.4
Pneumonia	24	63.2
Sepsis	23	60.5
Acute kidney injury	21	55.3
Bowel necrosis	20	52.6
Multisystem organ failure	12	31.6
Enterocutaneous fistula	9	23.7
Dehiscence	7	18.4
Adult respiratory distress syndrome	7	18.4

Categorical variables presented as n (%).

Table 3. Univariate analysis of survivors versus nonsurvivors

Variable	Survivor (n = 12)	Nonsurvivor (n = 26)	P
Age	23 (21–37)	29 (21–40)	.609
Male	12 (100%)	22 (84.6%)	.385
Military	9 (75%)	20 (76.9%)	.896
Inhalation injury	4 (33%)	18 (69.2%)	.037
Abdomen burned	6 (50%)	15 (57.7%)	.657
Injury severity score	33 (25–34)	34 (26–47)	.229
Total body surface area	43 (34–57)	58 (48–73)	.049
Duration abdomen open	11 (3–39)	11 (4–35)	.792

Categorical variables presented as n (%) and continuous variables presented as median (25th–75th percentiles).

Temporary abdominal closure was performed most often with the use of NPWT (90% of cases) followed by the Bogotá bag (42%) and Wittmann Patch™ (24%). The rate of fascial closure was 26% in patients managed with NPWT, 22% in patients managed with the Wittmann Patch™, and 12% in patients managed with a Bogotá bag. Because the majority of patients were managed with more than one method of temporary abdominal closure, we did not attempt to statistically compare the rate of successful fascial closure by the specific method of temporary abdominal closure employed.

After the goals of temporary abdominal closure were achieved, it was our practice to attempt definitive abdominal closure by closing fascia whenever “tension-free” closure was feasible. As such, fascial closure was attempted in 21 of 38 patients. The median duration of an open abdomen was 3 days (IQR, 2–10) in cases where fascia was successfully closed with the longest duration being 14 days. Failure of attempted fascial closure was unexpectedly high with eight patients requiring reexploration—six for fascial dehiscence and two for recurrent ACS (Figure 1). Four of six patients (67%) with the complication of fascial dehiscence subsequently developed an enterocutaneous fistula. Two patients with fascial dehiscence survived to hospital discharge, and these patients were definitively closed with a planned ventral hernia. Overall, failure of attempted fascial closure was associated with a mortality of 75%, and ultimately, only 7 of 38 patients (18%) managed with an open abdomen survived with their fascia closed at the time of discharge.

Of particular concern were the two patients who developed ACS after delayed primary fascial closure. Despite treatment with decompressive laparotomy, both patients developed near-total bowel necrosis

and died secondary to MSOF after the repeat laparotomy. Both patients were military casualties who had required decompressive laparotomy in theater for treatment of ACS, and fascial closure was then attempted on postinjury day 5 at the same time as excision and grafting.

STSG over granulated bowel was performed as part of a planned ventral hernia strategy in four patients who had undergone no previous attempt at fascial closure. Of these four patients, three survived to hospital discharge, and one patient's postoperative course was complicated by graft failure over bowel and eventual death with an open abdomen. Definitive abdominal closure (abdominal coverage at the time of death or discharge) was therefore achieved in 19 patients (50%) and was achieved by fascial closure in 14 patients and by a planned ventral hernia with STSG in 5 patients (Figure 1). Of those who survived to hospital discharge, the abdomen was definitively closed by fascial closure in seven patients and by STSG in four patients.

DISCUSSION

At our institution, the incidence of an abdominal complication in burn patients necessitating an open abdomen management strategy at our institution is 18 per 1,000 admissions. The overall in-hospital mortality in burn patients with an open abdomen at the USAISR Burn Center is 68%. Because the morbidity and mortality of severely burned patients requiring temporary abdominal closure is high, we must critically review our management practices in this group of patients so that any further complications may be minimized.

We observed a high proportion of military casualties with the complication of an open abdomen, consistent with the results of Markell et al¹, which showed a higher incidence of abdominal complications in the military burn patients compared with civilians. In addition, Wolf et al⁶ showed that although military and civilian burn patients admitted to the USAISR Burn Center may have a similar burn size, military burn patients have higher injury severity scores, a higher incidence of inhalation injury, and a longer time from burn injury to burn center arrival. These differences between military burn patients represent a fundamental difference in the cause of thermal injury, which is predominantly explosion in military casualties, and is associated with a high incidence of associated nonburn trauma. Furthermore, military burn patients injured during overseas contingency operations must undergo global evacuation through multiple echelons of care before arrival at

the USAISR Burn Center.¹⁷ Despite these differences, the demographics and injury characteristics between military and civilian burn patients with an open abdomen were fairly similar with the exception of age and mechanism of injury. In addition, the likelihood of survival to discharge after this complication was equally poor in both the military and the civilian patients.

Temporary abdominal closure was most often performed by NPWT with fascial closure achieved in 26% of cases. In recent reports of nonburned patients with an open abdomen managed by negative pressure wound therapy, the rate of fascial closure has been higher, ranging from 55 to 100%.^{7,9,11,18} In the limited number of patients (n = 9) we managed with a Wittmann PatchTM, the observed fascial closure rate of 22% was also lower than the rate of 65 to 76% reported in larger retrospective reviews.^{12,13} The lower observed rate of fascial closure we have observed at the USAISR in comparison to nonburned patients receiving similar methods of temporary abdominal closure is at least potentially due to a high incidence of mortality in our patients before any attempt at definitive abdominal closure. There may also be a fundamental difference in the physiology of severely burned patients and critically ill trauma patients which may affect the likelihood of fascial closure after an abdominal complication.

A potential benefit of using negative pressure therapy for temporary abdominal closure may be that it allows for definitive fascial closure at a later date than what has traditionally been acceptable. A recent prospective evaluation of VAC showed that fascial closure could be delayed up to 21 days after laparotomy. In our population of burn patients, we found that the duration of the open abdominal management before definitive fascial closure ranged from 1 to 14 days. Vertrees et al^{19,20} have reported a series of 56 nonburned combat casualties with an open abdomen who were managed by a serial abdominal closure technique that combines VAC with the placement of a dual-sided mesh to be serially approximated at the midline. Using this technique for temporary abdominal closure and definitive closure supplemented by either a polypropylene or a biologic mesh, these authors showed that fascial closure was achieved in 77% of patients with a mean closure date of 33 days. The use of this technique has not been studied in burn patients, but it may further extend the timing threshold of fascial closure and be another potential alternative to planned ventral hernia.

We found that the development of an enterocutaneous fistula was associated with an increased duration of an open abdomen. No patient with the

complication of fistula had definitive abdominal coverage before 35 days postlaparotomy. Multiple logistic regression demonstrated that the risk of a fistula formation doubled for every 5 days that the abdomen remained open. The risk of injury to the underlying bowel and subsequent fistula formation remains a significant factor in the desire to provide definitive closure of the abdomen as soon as possible.^{15,21}

Although fascial closure was achieved in 21 of 38 severely burned patients with an open abdomen, significant rate of failure occurred after fascial closure (38%). The necessity of relaparotomy after fascial closure was associated with a high morbidity and mortality rate (75%) in our patient population. Both patients who developed recurrent ACS were closed at the time of burn eschar excision and grafting operation and consequently received large perioperative resuscitations. Although we do not have large numbers of patients to appropriately evaluate the timing of fascial closure in relation to excision and grafting, it seems reasonable to question the judgment of this practice. Fascial closure remains the ideal goal in all burn patients who require temporary abdominal closure; however, failure of fascial closure was associated with significant morbidity and mortality. Therefore, we must therefore exercise good judgment in the selection of patients and timing of fascial closure.

Based on the results from this retrospective review, we will continue the use of NPWT for temporary abdominal closure in our patients with an open abdomen. In addition to containing and protecting the abdominal viscera, VAC, in our experience, allows for granulation of the underlying viscera and is effective in preventing the lateral retraction of fascia from the midline. The fascia should be continually reassessed for the feasibility of "tension-free" closure at the time of each dressing change or abdominal wash-out, and the fascia should be closed when possible. We cannot comment on the timing of return to the operating room for dressing change as it was left up to the attending surgeon and represents a weakness in our study. Delayed primary fascial closure remains the goal in burn patients with an open abdomen to prevent the morbidity and mortality associated with a prolonged duration of an open abdomen. The desire to close an abdomen quickly in a severely burned patient should be offset, however, by the observation of the high rate of failure of delayed fascial closure and the rate of death at the USAISR. Definitive abdominal closure by STSG as part of a planned ventral hernia strategy appears to be a safe alternative to fascial closure in burn patients and should be considered in any burn patient with an open abdomen beyond 14 days.

REFERENCES

1. Markell KW, Renz EM, White CE, et al. Abdominal complications after severe burns. *J Am Coll Surg* 2009; 208:940-7.
2. Hershberger RC, Hunt JL, Arnoldo BD, Purdue GF. Abdominal compartment syndrome in the severely burned patient. *J Burn Care Res* 2007;28:708-14.
3. Hobson KG, Young KM, Ciraulo A, Palmieri TL, Greenhalgh DG. Release of abdominal compartment syndrome improves survival in patients with burn injury. *J Trauma* 2002;53:1129-33.
4. Ivy ME, Possenti PP, Kepros J, et al. Abdominal compartment syndrome in patients with burns. *J Burn Care Rehabil* 1999;20:351-3.
5. Kowal-Vern A, McGill V, Gamelli RL. Ischemic necrotic bowel disease in thermal injury. *Arch Surg* 1997;132:440-3.
6. Wolf SE, Kauvar DS, Wade CE, et al. Comparison between civilian burns and combat burns from Operation Iraqi Freedom and Operation Enduring Freedom. *Ann Surg* 2006;243:786-92.
7. Barker DE, Kaufman HJ, Smith LA, Ciraulo DL, Richard CL, Burns RP. Vacuum pack technique of temporary abdominal closure: a 7-year experience with 112 patients. *J Trauma* 2000;48:201-6.
8. Boele van Hensbroek P, Wind J, Dijkgraaf MG, Busch OR, Carel Goslings J. Temporary closure of the open abdomen: a systematic review on delayed primary fascial closure in patients with an open abdomen. *World J Surg* 2009;33:199-207.
9. Garner GB, Ware DN, Cocanour CS, et al. Vacuum-assisted wound closure provides early fascial reapproximation in trauma patients with open abdomens. *Am J Surg* 2001;182:630-8.
10. Ivatury RR, Nallathambi M, Rohman M, Stahl WM. Open management of the posttraumatic septic abdomen. *Am Surg* 1990;56:548-52.
11. Stone PA, Hass SM, Flaherty SK, DeLuca JA, Lucente FC, Kusminsky RE. Vacuum-assisted fascial closure for patients with abdominal trauma. *J Trauma* 2004;57:1082-6.
12. Tieu BH, Cho SD, Luem N, Riha G, Mayberry J, Schreiber MA. The use of the Wittmann Patch facilitates a high rate of fascial closure in severely injured trauma patients and critically ill emergency surgery patients. *J Trauma* 2008;65:865-70.
13. Weinberg JA, George RL, Griffin RL, et al. Closing the open abdomen: improved success with Wittmann Patch staged abdominal closure. *J Trauma* 2008;65:345-8.
14. Fabian TC, Croce MA, Pritchard FE, et al. Planned ventral hernia. Staged management for acute abdominal wall defects. *Ann Surg* 1994;219:643-50.
15. Schechter WP, Ivatury RR, Rotondo MF, Hirshberg A. Open abdomen after trauma and abdominal sepsis: a strategy for management. *J Am Coll Surg* 2006;203:390-6.
16. Lund CC, Browder NC. The estimation of area of burns. *Surg Gynecol Obstet* 1944;79:352-8.
17. Chung KK, Blackbourne LH, Wolf SE, et al. Evolution of burn resuscitation in Operation Iraqi Freedom. *J Burn Care Res* 2006;27:606-11.
18. Cothren CC, Moore EE, Johnson JL, Moore JB, Burch JM. One hundred percent fascial approximation with sequential abdominal closure of the open abdomen. *Am J Surg* 2006;192:238-42.
19. Vertrees A, Greer L, Pickett C, et al. Modern management of complex open abdominal wounds of war: a 5-year experience. *J Am Coll Surg* 2008;207:801-9.
20. Vertrees A, Kellicut D, Ottman S, Peoples G, Shriver C. Early definitive abdominal closure using serial closure technique on injured soldiers returning from Afghanistan and Iraq. *J Am Coll Surg* 2006;202:762-72.
21. Mastboom WJ, Kuypers HH, Schoots FJ, Wobbes T. Small-bowel perforation complicating the open treatment of generalized peritonitis. *Arch Surg* 1989;124:689-92.