Avoidance of Abdominal Compartment Syndrome in Damage-Control Laparotomy After Trauma

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Hypothesis: Abdominal compartment syndrome (ACS) is a morbid complication of damage-control laparotomy. Moreover, the technique of abdominal closure influences the frequency of ACS.

Design: Retrospective cohort study.

Setting: Urban level I trauma center.

Patients: We studied 52 patients with trauma who required damage-control laparotomy during the 5 years ending December 31, 1999, and who survived longer than 48 hours.

Main Outcome Measures: Abdominal compartment syndrome, acute respiratory distress syndrome (ARDS), and multiple organ failure (MOF).

Results: Mean (± SD) age was 33±2 years; 38 (73%) were male. Mechanism of injury was blunt in 29 patients (56%), and mean (± SD) Injury Severity Score was 28±2. Development of ARDS and/or MOF was seen in 23 patients (44%); ARDS and MOF increased mortality from 12% (3/26) to 42% (11/26). Abdominal compartment syndrome was a common complication (17/52), and was associated with an increase in ARDS and/or MOF (12 patients [71%] vs 11 patients [31%] without ACS; P = .02, χ² test) and death (6 [35%] vs 8 patients [23%] without ACS). Primary fascial closure (n = 10) at the initial laparotomy was associated with ACS in 8 (80%) (P = .001, χ² test) and ARDS and/or MOF in 9 (90%) (P = .01, χ² test); skin closure (n = 25), with ACS in 6 (24%) and ARDS/MOF in 9 (36%); and Bogotá bag closure (n = 17), with ACS in 3 (18%) and ARDS/MOF in 8 (47%).

Conclusions: Damage-control laparotomy is associated with frequent complications. In particular, ACS is a serious complication that increases ARDS and/or MOF and mortality. Avoiding primary fascial closure at the initial laparotomy can minimize the risk for ACS.


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The modern era of damage-control laparotomy began with the seminal report of Stone et al from the Grady Memorial Hospital, Atlanta, Ga, in 1982. Compared with a historical control survival of 1 (7%) of 14 patients, 11 (65%) of 17 patients sustaining predominantly penetrating wounds survived after abdominal packing. During the next 5 years, the practice of damage-control laparotomy became widely accepted as the standard of care in the management of trauma manifesting the “bloody vicious cycle” of hypothermia, acidosis, and coagulopathy. With widespread application and intense study, previously unrecognized complications began to emerge. Recently, abdominal compartment syndrome (ACS), defined as end-organ dysfunction secondary to intra-abdominal hypertension, has been emphasized. Although the adverse effects of elevated intraabdominal pressure have been recognized for more than a century, it is only in the 1990s that ACS has been rediscovered and more comprehensively characterized. Despite this concentrated investigation, several important questions remain.

See Invited Critique at end of article

The purpose of this study was to determine the impact of ACS on outcome after damage-control laparotomy in patients who survived the initial 48 hours. Moreover, we sought to determine whether the abdominal closure technique contributed to development of ACS.
We studied all trauma patients admitted to Denver Health Medical Center (DHMC), Denver, Colo, a regional level I trauma center, during the 3 years ending December 31, 1999, and who underwent damage-control laparotomy. Patients were identified and data were tabulated using the following sources: the DHMC Trauma Registry, our postinjury multiple organ failure (MOF) database, operative logs, and patient medical records. The Trauma Registry concurrently collects data on all trauma patients admitted to DHMC. Since 1994, we have maintained a database on trauma patients at risk for development of MOF. Inclusion criteria include an Injury Severity Score (ISS) of greater than 15, age greater than 15 years, and survival for longer than 48 hours. Patients are prospectively identified and observed until death or discharge from the hospital.

Data collected included patient demographics, mechanism of injury, number of laparotomies, technique of abdominal closure after the initial damage-control procedure, occurrence of complications (including ACS, acute respiratory distress syndrome [ARDS], MOF, and death), and technique of abdominal closure before discharge.

**Abdominal compartment syndrome** was defined as an intra-abdominal pressure of greater than 20 cm H₂O with evidence of impaired organ function, ie, elevated peak airway pressures (>45 cm H₂O), oliguria (<0.5 mL/kg per hour), or cardiovascular dysfunction (hypotension despite adequate volume resuscitation or, if a pulmonary artery catheter is present, oxygen delivery index [calculated as milliliters of oxygen per minute per meter squared] of 600). Intra-abdominal pressure was measured indirectly using an indwelling Foley catheter as previously described.² Denver MOF scores were calculated daily in the intensive care unit (ICU), and MOF was defined as an MOF score of 4 or more.³ Pulmonary dysfunction was graded previously using a modification of the Lung Injury Score of Murray et al⁴ that incorporated the patient’s ratio of PaO₂ to fraction of inspired oxygen (FiO₂), level of positive end-expiratory pressure, radiographic findings, minute ventilation, and pulmonary compliance. Because of the current emphasis on lung-protective ventilation with the use of low tidal volumes and higher levels of positive end-expiratory pressure, we believed that this grading method was no longer clinically relevant. At present, we grade pulmonary dysfunction based solely on the patient’s PaO₂/FiO₂ ratio. Grade 0 indicates PaO₂/FiO₂ of greater than 250; grade 1, from 176 to 250; grade 2, from 100 to 175; and grade 3, of less than 100. We defined ARDS using the following criteria agreed on at the American-European Consensus Conference of acute lung injury indicates PaO₂/FiO₂ of less than 300, and ARDS indicates PaO₂/FiO₂ of less than 200 with diffuse infiltrates on chest x-ray films, no evidence of left atrial hypertension, and acute onset in the presence of a defined risk factor.

The conduct of damage-control laparotomy at our institution has been described in detail elsewhere; we view the process in 5 stages. The first phase is to identify the appropriate candidate. The primary objectives are to stop hemorrhage, to correct underlying coagulopathy, to minimize peritoneal contamination and its secondary inflammatory response, and to enclose the abdominal contents to protect the viscera and minimize protein loss. The final objective of this damage-control phase is closure of the abdominal cavity. The method of closure depends on whether skin approximation produces excessive intra-abdominal hypertension. Initially, towel-clip closure of the skin is preferred because it is quick and easy. When skin approximation is not possible, a temporary silo is constructed by sutting a 3-L cys-toscopy irrigation bag (Bogotá bag) to the skin edge with a continuous No. 2 nylon suture. The second phase is intraoperative reassessment for hemorrhage control. We spend 30 minutes after initial abdominal closure in the operating room focusing on restoration of the patient's physiological status, specifically reversing hypothermia and coagulopathy. The abdomen is then reopened and assessed for adequacy of hemostasis, and as the most important point, for existence of residual mechanical bleeding. This practice has allowed us to minimize both early return to the operating room for ongoing hemorrhage and the amount of packing necessary for hemostasis. With bleeding effectively controlled, the abdomen is reclosed as outlined above. The patient is transferred to the ICU for continued physiological restoration in the third phase. Once coagulopathy, hypothermia, and acidosis have been corrected, the patient can be returned to the operating room for definitive management of the injuries in the fourth phase. Options for abdominal closure at this juncture include definitive fascial closure, skin closure alone, and prosthetic closure (ie, Bogotá bag or synthetic mesh closure with subsequent split-thickness skin grafting). The final phase is abdominal wall reconstruction in those patients in whom fascial approximation was precluded.

Data were analyzed using commercially available software (SPSS version 10.0 for Windows; SPSS Inc, Chicago, Ill) on a personal computer (Dell Optiplex GX110; Dell Computer Corporation, Round Rock, Tex). Categorical variables were analyzed using χ² or Fisher exact test where appropriate. Continuous data were analyzed by means of the t test. Multivariate analysis (logistic regression for dichotomous outcome variables and multiple linear regression for continuous outcome variables) was used when necessary to control for multiple variables. Significance was defined as P<.05. Unless otherwise indicated, data are given as means±SD.

Fifty-six patients underwent damage-control laparotomy during the 5-year study, and 4 died within the first 48 hours after injury. Of the remaining 52 patients, 38 (73%) were male; mean age was 33±2 years (range, 16-78 years). Injury mechanism was blunt in 29 patients (56%), and the mean ISS was 28±2. Twenty-eight patients (54%) had significant liver injuries, and 17 (33%) sustained splenic trauma. Abdominal vascular and hollow viscus injuries were present in 18 and 23 patients, respectively. Twenty-nine patients (56%) sustained multiple intra-abdominal injuries. Acute respiratory distress syndrome or MOF developed in 23 patients (44%) and increased the mortality rate from 12% (3/26) to 42% (11/26).
Abdominal compartment syndrome was a frequent complication, occurring in 17 patients (33%). On univariate analysis, there was no significant difference in age, ISS, sex, or mechanism of injury between patients with and without ACS (Table 1). Patients in whom ACS developed had a significantly higher risk for development of ARDS/MOF (71% vs 31% without ACS; *P* = .02). Similarly, there was a trend toward a longer hospital stay in patients with ACS. Mortality was not significantly different between patients with and without ACS. Multivariate analysis (to control for the effects of age and injury severity) confirmed the significant association between ACS and increased MOF (odds ratio, 8.0; *P* = .008) and prolonged hospital length of stay (*P* = .007).

Abdominal closure techniques after the initial damage-control procedure appear to contribute to subsequent ACS, MOF, and ARDS (Table 2). Abdominal compartment syndrome occurred in 80% of patients who underwent fascial closure at the initial operation compared with 24% and 18% in patients undergoing skin closure and Bogotá bag placement, respectively (*P* = .001). With the use of logistic regression to control for the effect of age and injury severity, primary fascial closure was associated with an 11-fold increase in ACS (odds ratio, 10.7; 95% confidence interval, 1.7-68.0). Similarly, ARDS and MOF were significantly more frequent in patients undergoing primary fascial closure (90% vs 36% and 47% for skin and Bogotá bag closure, respectively). This is particularly compelling when it is assumed that primary fascial closure was reserved for patients with a more favorable situation in the operating room.

The average number of operations until definitive abdominal closure was 3.7. The mean number of operations was greater in patients in whom ACS developed (3.4 vs 2.9 without ACS; *P* < .001). Patients in whom ACS developed were less likely to achieve definitive abdominal fascial closure before discharge. Moreover, definitive fascial closure was possible in 88% of patients who required 3 or fewer laparotomies. In contrast, patients requiring 4 or more operations achieved definitive fascial closure much less frequently (88% [22/25] vs 15% [2/13]; *P* < .001, Fisher exact test).

The resurgent application of the damage-control concept has been a remarkable advance in surgical and trauma care; however, significant refinements continue to be introduced. Widespread use of damage-control laparotomy has led to recognition and intensified scrutiny of resulting complications, in particular ACS. This report confirms the high frequency of complication in patients undergoing damage-control laparotomy, including ACS, ARDS, MOF, and death. These complications likely reflect the patient’s severity of injury; however, it appears that ACS is a significant independent contributing factor. Abdominal compartment syndrome occurred in 17 (33%) of 52 patients undergoing damage-control laparotomy and was associated with a much higher incidence of ARDS and MOF (71% vs 31% without ACS; *P* = .02). More importantly, our study suggests that primary fascial closure at the termination of the initial damage-control laparotomy contributes to the development of ACS as well as subsequent organ failure.

By definition, ACS results when intra-abdominal pressure exceeds a critical threshold and leads to severe disturbances in various organ functions. When not recognized and treated, ACS is invariably fatal. Fortunately, it is easily treated by means of abdominal decompression, which readily reverses adverse physiological consequences. We observed that ARDS or MOF develops in many patients, despite early recognition of ACS and prompt decompression of the abdomen. This suggests that ACS may serve as a second insult, which triggers the evolution of MOF despite abdominal decompression.

Although associated with more organ failure, ACS did not significantly increase mortality (35% with ACS vs 23% without ACS; *P* = .51). This seems counterintuitive, considering the high mortality associated with ARDS and MOF. The most likely explanation is that our sample size is too small to identify a significant difference in mortality. Power analysis demonstrates that there is only a 14% chance of detecting this difference in mortality with our sample size. Two hundred thirty patients in each group are required to identify the observed mortality difference at a significance level of .05.

Several authors have suggested that ACS and its sequelae can be avoided by leaving the abdomen open.

### Table 1. Demographic and Outcome Data in Patients With and Without ACS*

<table>
<thead>
<tr>
<th></th>
<th>ACS (n = 17)</th>
<th>No ACS (n = 35)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean ± SD, y</td>
<td>38 ± 5</td>
<td>30 ± 2</td>
<td>.24</td>
</tr>
<tr>
<td>Sex, No. F/M</td>
<td>5:11</td>
<td>8:27</td>
<td>.73</td>
</tr>
<tr>
<td>Injury Severity Score, mean ± SD</td>
<td>25 ± 2</td>
<td>30 ± 2</td>
<td>.63</td>
</tr>
<tr>
<td>Hospital length of stay, mean ± SD, d</td>
<td>37 ± 5</td>
<td>26 ± 3</td>
<td>.06</td>
</tr>
<tr>
<td>ARDS/MOF, No. (%)</td>
<td>12 (71)</td>
<td>11 (31)</td>
<td>.02</td>
</tr>
<tr>
<td>Mortality, No. (%)</td>
<td>6 (35)</td>
<td>8 (23)</td>
<td>.51</td>
</tr>
</tbody>
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*ACS indicates abdominal compartment syndrome; ARDS, acute respiratory distress syndrome; and MOF, multiple organ failure.
†Determined using Fisher exact test.

### Table 2. Association Between Abdominal Closure Technique and Complications*

<table>
<thead>
<tr>
<th>No. (%) of Patients</th>
<th>Primary Fascial Closure</th>
<th>Skin Closure</th>
<th>Bogotá Bag</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS</td>
<td>8 (80 †)</td>
<td>6 (24)</td>
<td>3 (18)</td>
</tr>
<tr>
<td>ARDS/MOF</td>
<td>9 (90 †)</td>
<td>9 (36)</td>
<td>8 (47)</td>
</tr>
<tr>
<td>Mortality</td>
<td>2 (20)</td>
<td>8 (32)</td>
<td>4 (24)</td>
</tr>
</tbody>
</table>

*Abbreviations are given in the first footnote to Table 1. 
†*P* = .001, χ² test. 
‡*P* = .01, χ² test.
Abdominal compartment syndrome is a frequent complication in patients requiring damage-control laparotomy. When ACS develops, it increases the incidence of ARDS and MOF, prolongs hospital stay, and increases mortality. Avoiding primary fascial closure at the termination of the initial laparotomy can minimize the risk for ACS. Moreover, routine postoperative monitoring of intra-abdominal pressure is indicated in any patient undergoing damage-control laparotomy; when elevated, prompt decompression should be considered even in the absence of overt physiological consequences.

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REFERENCES


**DISCUSSION**

George C. Velmahos, MD, Los Angeles, Calif: The Denver Group, one of the most prolific research groups in the country, is continuously and consistently enriching our trauma knowledge by making numerous important contributions. This time their work relates to a complex and somewhat mystical clinical entity, the ACS, a constellation of systemic manifestations caused by the acute increase in abdominal pressure and leading to organ failure. The study explores the association of ACS and damage-control laparotomy.

The study analyzes 52 critically injured patients who had damage-control laparotomy for devastating intra-abdominal injuries and survived the first 48 hours. Half of them developed ARDS and/or MOF, and one fourth of them died. The development of ACS was independently associated with MOF and/or ARDS. More importantly, ACS developed more frequently among patients who had their fascia closed at the end of damage-control laparotomy compared to patients who had only the skin closed or were left with what we call an open abdomen, ie, were closed over a plastic cystoscopy bag. Based on a relatively simple analysis, which did not take into account additional factors influencing the decision of abdominal wound management, the authors concluded that fascial closure should be avoided after damage-control laparotomy because it increases the likelihood of ACS and subsequent MOF/ARDS.

The study is retrospective, and, although data were pulled from 3 different sources, it is subject to the usual inherent limitations of this study design. I have 3 questions for the authors. The first question refers to the association of ACS and MOF/ARDS. Is it the ACS itself or the delay in its diagnosis and treatment that causes MOF/ARDS? In the manuscript, I found no description of the interval between the end of the first operation and the subsequent decompressive laparotomy for ACS. Given the best of our intentions, it is possible that in the middle of the night clinical and bladder pressure monitoring is not done as diligently as it should be by our overworked residents and nurses, and therefore some patients are diagnosed and treated late. Do you have any data on this?

The second question refers to the association between the method of abdominal wound management and the development of ACS. There are many factors that influence this decision: the presence of packing, the need for additional massive resuscitation, the respiratory and hemodynamic parameters at the end of laparotomy, the type of intra-abdominal injuries, the type of extra-abdominal injuries, etc. There is no analysis of all these factors. You arbitrarily isolated one factor, the management of the abdominal wound, and held it responsible for the development of ACS in the absence of an in-depth analysis of other confounding variables. In other words, should you rerun your analysis between patients with and without ACS by including all these factors to examine if the method of abdominal wound management stands out as an independent risk factor for the development of adverse outcome?

My third question relates to the management of open abdomen. If you advocate a liberal policy for leaving the abdomen open at the end of damage-control laparotomy, do you have any data on the final outcome of these patients who were left open at the first place? The repeated procedures for final closure add to the risk. A late operation to correct these massive hernias is—according to our experience—extremely morbid. Do you have a straightforward comparison of patients managed by open abdomen and patients closed primarily? This comparison should include outcomes of subsequent hospitalization for correction of the abdominal defect.

I would also like to add a technical question. Although we were using for many years one single large 3-L bag, we have now converted to the “vacuum pack” technique and realized anecdotally a significant improvement in the ability to close the abdomen within the same hospital stay. Do you have any experience with this technique?

In summary, and despite the above questions, I believe this is a fine study with a provocative conclusion that should force all of us to think about the multiple unknowns related to the ACS.

Dr Offner: Dr Velmahos’ first question asked whether or not organ failure was related to the ACS itself or to a delay in the diagnosis and the treatment of ACS. The answer is likely a combination of the two. The majority of patients who developed ACS did so within 24 hours, and we are very aggressive at our institution with routine perioperative bladder pressure measurements and have a dedicated ICU resident whose only job is to stay in the ICU 24 hours a day. We have made it clear to them that this is an important problem and that they need to be on top of it. So I think that we recognize ACS early and decompress the patients very quickly. I do believe, though, that ACS can represent a second hit in the 2-hit model of MOF. This is at least partially supported by the fact that although patients responded very quickly to abdominal decompression with correction of their underlying physiological derangement, many of them progressed to MOF.

Your second question relates to our multivariate analysis and other variables that should have been or could have been included in this analysis. In fact, we looked at many of the variables that you mentioned, and in each case there was no difference between patients who did and did not develop ACS. I apologize for not making that more clear in the manuscript.

In the multivariate analysis of the technique of abdominal closure, despite inclusion of those other variables in the model, there was an 11-fold increase in the risk of developing ACS in patients who underwent primary fascial closure.

Your third question related to outcome from open management of the abdomen. I think this is a very important question, because it likely represents the biggest barrier to leaving the abdomen open from the beginning. In our experience, like yours, many of these patients do not get closed and have to come back 6 months to a year later for a fairly complicated and sometimes morbid abdominal reconstructive procedure. I don’t really have the data to answer your question. What I can tell you from our data is that if the patients are not closed by the sixth day post injury, they usually cannot be closed primarily. In those patients who developed ACS, only 20% had definitive abdominal closure prior to discharge. Eighty percent should not be closed and required a subsequent abdominal reconstructive procedure.

Lastly, you asked about the use of the Wound Vac [Kinetic Concepts Inc, San Antonio, Tex]. One of my colleagues has recently become very enthusiastic about the Wound Vac. We have had preliminary experience in only 2 patients with this technique. My understanding of the technique is that it is supposed to allow us to remove fluid from the wound and hopefully facilitate earlier or definitive closure during the initial hospitalization. However, that has not been our experience. What our experience has shown is that the Wound Vac promotes granulation tissue and has relegated us to performing a split-thickness skin graft in such patients.
This review of a 5-year experience with damage-control laparotomy by Offner et al provides concisely recorded data for thoughtful reflection. The results are quite good, yet I fear that avoidance of compartment syndrome at all costs is not an appropriate goal for many cases.

If, during initial exploration, the freshly shed blood clots and there is no ongoing complicating coagulopathy, then clearly the abdomen should be closed without such undue tension as would create a compartment syndrome and its attendant difficulties, ie, acute respiratory distress and/or multiple organ failure. Abdominal closure can thereby be selective and may be based on fascial approximation, mere skin closure, or insertion of some prosthesis, with overlying skin left either open or closed. However, if coagulopathy is overt, only the tamponading effect of an abdomen closed under tension can allay further massive bleeding, can obviate the need for infusion of even greater amounts of blood than would otherwise be required, and thus can permit a more rapid correction of the clotting disorder.

Coagulation studies are useful as a guide to which components must be replaced, yet these tests do not reliably predict that the coagulopathy has been sufficiently reversed to allow a safe return to laparotomy. Rather, it is the crude clotting time that is the most accurate of routine indicators.

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JAMA
Phenotypic Characteristics Associated With the APC Gene I1307K Mutation in Ashkenazi Jewish Patients With Colorectal Polyps
Sapna Syngal, MD, MPH; Deborah Schrag, MD, MPH; Myron Falchuk, MD; Nadine Tung, MD; Francis A. Farraeye, MD; Daniel Chung, MD; Mary Wright; Amy Whetsell; Glenn Miller, PhD; Judy E. Garber, MD, MPH
Context: The I1307K mutation of the APC gene is found in approximately 6% of the Ashkenazi Jewish population and is associated with elevated risk of colorectal cancer. The incidence of the mutation in patients with colorectal adenomas is unknown.
Objectives: To determine the carrier rate of the I1307K mutation in Ashkenazi Jewish patients with a history of colorectal polyps but without colorectal cancer and to compare phenotypic characteristics and family history of carriers vs noncarriers.
Design, Setting, and Patients: A total of 231 patients who had at least 1 large bowel polyp diagnosed between January 1, 1992, and January 31, 1999, at 1 of 5 centers in Boston, Mass, were included, of whom 183 were Ashkenazi Jewish. DNA was isolated from cheek swab samples.
Main Outcome Measures: Presence of the I1307K variant in the APC gene.
Results: The I1307K variant was identified in 22 (14%) of 161 Ashkenazi Jewish patients with a history of adenomatous polyps and in 1 (5%) of 20 Ashkenazi Jewish patients with hyperplastic polyps. The phenotypic features of adenomas, family history of polyps, colorectal cancer, and other cancers were indistinguishable between I1307K carriers and noncarriers.
Conclusions: The frequency of the APC I1307K mutation is elevated in Ashkenazi Jewish patients with adenomatous polyps, but not hyperplastic polyps. The I1307K mutation represents a novel paradigm for cancer-predisposing genes, as it is associated with moderately increased risk of neoplasia without other associated distinguishing phenotypic features. (2000; 284:857-860)
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