Is the evolving management of intra-abdominal hypertension and abdominal compartment syndrome improving survival?*

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**LEARNING OBJECTIVES**

After participating in this activity, the participant should be better able to:

1. Distinguish intra-abdominal hypertension from intra-abdominal compartment syndrome.
2. Explain consensus definition and recommendations proposed by the World Society of the Abdominal Compartment Syndrome.
3. Use this information in a clinical setting.

Unless otherwise noted below, each faculty or staff’s spouse/life partner (if any) has nothing to disclose.

Dr. Cheatham has disclosed that he was/is a consultant/advisor for Kinetic Corporation, Inc. Ms. Safcsak has disclosed that she has no financial relationships with or interests in any commercial companies pertaining to this educational activity.

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**Objective:** The diagnosis and management of intra-abdominal hypertension and abdominal compartment syndrome have changed significantly over the past decade with improved understanding of the pathophysiology and appropriate treatment of these disease processes. Serial intra-abdominal pressure measurements, nonoperative pressure-reducing interventions, and early abdominal decompression for refractory intra-abdominal hypertension or abdominal compartment syndrome are all key elements of this evolving strategy.

**Design:** Prospective, observational study.

**Setting:** Tertiary referral/level I trauma center.

**Patients:** Four hundred seventy-eight consecutive patients requiring an open abdomen for the management of intra-abdominal hypertension or abdominal compartment syndrome.

**Interventions:** Patients were managed by a defined group of surgical intensivists using established definitions and an evidence-based management algorithm. Both univariate and multivariate analyses were performed to identify patient and management factors associated with improved survival.

**Measurements and Main Results:** Whereas patient demographics and severity of illness remained unchanged over the 6-yr study period, the use of a continually revised intra-abdominal hypertension/abdominal compartment syndrome management algorithm significantly increased patient survival to hospital discharge from 50% to 72% ($p = .015$). Clinically significant decreases in resource utilization and an increase in same-admission primary fascial closure from 59% to 81% were recognized. Development of abdominal compartment syndrome, prophylactic use of an open abdomen to prevent development of intra-abdominal hypertension/abdominal compartment syndrome, and use of a multi-modality surgical/medical management algorithm were identified as independent predictors of survival.

**Conclusions:** A comprehensive evidence-based management strategy that includes early use of an open abdomen in patients at risk significantly improves survival from intra-abdominal hypertension/abdominal compartment syndrome. This improvement is not achieved at the cost of increased resource utilization and is associated with an increased rate of primary fascial closure. (Crit Care Med 2010; 38:402–407)

**Key Words:** open abdomen; intra-abdominal pressure; intra-abdominal hypertension; abdominal compartment syndrome; survival

*See also p. 692.

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Over the past decade, intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) have evolved from being obscure and poorly understood diseases of the traumatically injured patient to recognized causes of significant morbidity and mortality among the critically ill of all disciplines (1–24). Elevated intra-abdominal pressure (IAP) has been identified as an independent predictor of mortality during critical illness (5, 20). Recently, evidence-based consensus definitions and recommendations for the resuscitation and management of patients with IAH and ACS have been published (1, 2). Central to this evolving strategy are the use of serial IAP measurements to detect the presence of IAH, application of comprehensive medical management strategies to reduce elevated IAP and restore end-organ perfusion, and timely surgical decompression of the abdomen for refractory organ dysfunction (1, 2, 23, 24).

Whereas numerous retrospective studies and reviews have suggested that patient survival is significantly improved by the time and resource intensive approach outlined, prospective interventional trials confirming these benefits have been lacking. Many physicians remain skeptical regarding the clinical importance of elevated IAP and hesitant to use the “open abdomen” to treat IAH and ACS. We therefore sought to determine whether the currently recommended evidence-based medicine strategy for managing IAH/ACS improves patient survival.

MATERIALS AND METHODS

In January 2002, we began a prospective, observational study to confirm the survival efficacy of our evidence-based medicine approach to the management of patients with IAH/ACS. The study was approved by our Institutional Review Board with a waiver of informed consent.

All patients aged 15 yrs or older who are admitted to the surgical teaching service of our institution and require an open abdomen during their resuscitation and management are screened and evaluated daily by a single individual. Patients are enrolled within 24 hrs of requiring an open abdomen and are subsequently followed-up prospectively on a daily basis throughout their hospitalization using a standardized data collection sheet. Data are entered into a computerized database to record patient demographics, mechanism and severity of injury, temporary abdominal closure method, duration of open abdomen, subsequent abdominal wall reconstruction technique, resource utilization, and survival to hospital discharge among other variables. All patients are managed by a defined group of five board-certified surgical intensivists according to continually revised evidence-based medicine guidelines. Patients are followed-up until discharge from the hospital with subsequent follow-up in our outpatient clinic. For the purposes of this study, patients requiring an open abdomen because of fascial dehiscence or existing enteric fistula have been excluded.

At the time of study initiation in 2002, our management algorithm consisted of serial IAP measurements to diagnose IAH/ACS, fluid and vasopressor resuscitation to maintain systemic and visceral perfusion, and emergent abdominal decompression with temporary abdominal closure when IAP reached 30 to 40 mm Hg (16). Attempts to achieve abdominal closure were generally delayed until the patient’s critical illness had resolved, commonly necessitating either split-thickness skin grafting of the viscera or closure of skin and subcutaneous tissue only, resulting in a fascial defect and need for subsequent incisional hernia repair (15, 16, 18). As the years progressed and new advances in the management of IAH/ACS became known, we revised our management algorithm to reflect these findings. This included adoption of decreasing IAP thresholds for surgical intervention (IAP 25–30 mm Hg) and increased use of the open abdomen at the time of initial laparotomy to avoid detrimental IAP elevations in patients at risk for IAH/ACS (16). Temporary abdominal closure was performed almost universally using the “vacuum-pack” technique (2, 8, 23). Faced with a number of open-abdomen patients requiring subsequent hernia repair, we began an aggressive strategy to close the open abdomen as soon as physiologically feasible (25, 26).

In January 2005, the consensus definitions and recommendations proposed by the World Society of the Abdominal Compartment Syndrome were incorporated into our management algorithm (27). These comprehensive surgical and medical management guidelines emphasize: (1) the need for early serial IAP monitoring when IAH/ACS risk factors are present; (2) improving abdominal wall compliance through sedation, analgesia, and pharmacologic paralysis; (3) evacuating intraluminal contents through nasogastric or rectal decompression; (4) evacuating abdominal fluid collections via percutaneous drainage; (5) correcting positive fluid balance through the use of hypertonic fluids, colloids, and careful diuresis; (6) supporting organ function with vasopressors and judicious goal-directed fluid resuscitation to maintain an abdominal perfusion pressure (calculated as mean arterial pressure — IAP) ≥60 mm Hg; and (7) early surgical intervention when IAP exceeds 25 mm Hg (2, 24, 27). These guidelines highlight the importance of both nonoperative therapies, to prevent and reduce elevated IAP, as well as operative intervention for refractory organ dysfunction and failure.

We defined IAH as a sustained or repeated pathologic elevation of IAP ≥12 mm Hg (1). ACS was defined as a sustained IAP >20 mm Hg associated with new organ dysfunction or failure. Primary ACS was considered to be ACS associated with injury or disease in the abdomino-pelvic region, whereas secondary ACS was considered to be ACS that did not originate from the abdomino-pelvic region. Recurrent ACS was used to identify conditions in which ACS re-developed after previous surgical or medical treatment of primary or secondary ACS.

IAP was measured using the intra-vesicular technique as recommended in the World Society of the Abdominal Compartment Syndrome consensus guidelines (1, 2). IAP measurements are not performed in the operating room or the emergency department in our institution. IAP measurements and abdominal perfusion pressure calculations were performed every 4 hrs in the intensive care unit (ICU) in patients at risk for IAH/ACS and were used to guide both resuscitative therapy, as well as the need for emergent abdominal decompression in the setting of ACS. Pre-decompression IAP and abdominal perfusion pressure values were recorded as an indicator of the severity of IAH/ACS prompting open abdomen management.

The primary clinical reason for use of an open abdomen was carefully evaluated with all patients being assigned one of four indications. “Damage control laparotomy” represented patients who either required abdominal packing for hemorrhage control or had hemodynamic instability, hyperthermia, coagulopathy, or metabolic acidosis intra-operatively requiring an abbreviated surgical intervention. “Surgeon suspicion for IAH” identified otherwise stable patients who were believed to be at high risk for elevated IAP if primary fascial closure was performed (such as patients with markedly edematous bowel), were anticipated to require a large volume fluid resuscitation because of their shock, or required a planned re-exploration not accounted for by the “damage control laparotomy” indication. “ACS” represented those patients who required emergent abdominal decompression after the development of documented primary, secondary, or recurrent ACS. “Septic abdomen” denoted patients in whom intra-abdominal abscess, gross contamination, or intestinal perforation (including new-onset fistula) warranted staged laparotomy for serial “washout” of the abdominal cavity.

The timing of open abdomen management was also assessed. A “prophylactic” open abdo-
men was defined as one in which the surgeon intentionally left the patient’s abdomen open during the initial operative procedure for one of the four clinical indications outlined. “Emergent” decompression was defined as the need for an open abdomen in a patient exhibiting organ dysfunction or failure (i.e., ACS) who had either not undergone laparotomy or had been closed primarily after previous laparotomy. The patient’s abdominal status at hospital discharge was further defined as: (1) primary fascial closure with or without supplemental prosthetic mesh; (2) split-thickness skin graft of the visera; or (3) skin and subcutaneous tissue closure leaving the fascia open. Both of the latter two methods resulted in an incisional hernia requiring subsequent repair.

Patient demographics were assessed using age, gender, and surgical service. Patient severity of illness was determined using Acute Physiology and Chronic Health Evaluation Score version II, Simplified Acute Physiology Score version 2, and injury severity score (for trauma patients). Resource utilization was evaluated using both ICU and hospital days, as well as days of mechanical ventilation. These data were compared to that of the contemporaneous surgical/trauma ICU patients who did not require an open abdomen to identify changes in general ICU care over time that might represent a potential confounding factor during data analysis. This included calculation of annual survival rates for both the study (open abdomen) and surgical/trauma ICU (non-open abdomen) patients using Simplified Acute Physiology Score version 2 scores to calculate severity-adjusted survival.

Descriptive statistics are reported as either mean ± sd or percentage. Categorical data were analyzed using chi-square analysis. Continuous data were assessed using Student’s t test for normally distributed data and Mann-Whitney U test for non-normally distributed data. Multiple comparison analysis between study years was performed using log-linear analysis for categorical data and either analysis of variance or Kruskal-Wallis analysis of variance by ranks for normally distributed and non-normally distributed continuous data respectively. Tukey’s test was utilized for post hoc comparisons. To identify potential causative factors that lead to improved survival, univariate multiple regression analysis was performed using patient survival as the dependent variable and patient demographics, management algorithm complexity (defined by each individual study year), and timing and indications for open abdomen management as the independent variables. Significant variables identified in the univariate analysis were subsequently entered into a binomial logistic regression analysis to identify factors independently predictive of survival. Significance was defined as a $p < .05$.

**RESULTS**

Between January 2002 and December 2007, 478 consecutive patients were managed with an open abdomen in our institution. The demographics of the study patients remained similar without significant differences throughout the 6 yrs of the study (Table 1). Patient severity of illness demonstrated no significant differences from year to year (Table 2). Resource utilization over the study period demonstrated nonsignificant trends toward decreased ICU, hospital, and mechanical ventilator days (Table 3).

Pre decompression IAP measurements and abdominal perfusion pressure calcul-
Table 5. Outcome

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean days to abdominal closure</td>
<td>20 ± 14</td>
<td>17 ± 19</td>
<td>17 ± 14</td>
<td>16 ± 17</td>
<td>13 ± 16</td>
<td>10 ± 10*</td>
</tr>
<tr>
<td>Median days to abdominal closure</td>
<td>20</td>
<td>8</td>
<td>13</td>
<td>12</td>
<td>6*</td>
<td>6*</td>
</tr>
<tr>
<td>Entero-atmospheric fistula rate, %</td>
<td>8.6</td>
<td>8.0</td>
<td>1.8</td>
<td>6.2</td>
<td>4.7</td>
<td>3.6</td>
</tr>
<tr>
<td>Abdominal closure type, %</td>
<td>59</td>
<td>72</td>
<td>68</td>
<td>72</td>
<td>77</td>
<td>81</td>
</tr>
<tr>
<td>Split-thickness skin graft</td>
<td>12</td>
<td>23</td>
<td>15</td>
<td>19</td>
<td>12</td>
<td>3*</td>
</tr>
<tr>
<td>Skin only</td>
<td>29</td>
<td>5</td>
<td>17</td>
<td>9</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Survival to hospital discharge, %</td>
<td>50</td>
<td>57</td>
<td>52</td>
<td>63</td>
<td>69</td>
<td>72*</td>
</tr>
</tbody>
</table>

All other comparisons are statistically insignificant. *p < .05; **p < .01.

Table 6. Univariate predictors of survival

<table>
<thead>
<tr>
<th></th>
<th>Survivors</th>
<th>Non-Survivors</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n</td>
<td>289</td>
<td>189</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Age, yrs</td>
<td>40 ± 17</td>
<td>49 ± 19</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Gender, male</td>
<td>77%</td>
<td>67%</td>
<td>0.16</td>
</tr>
<tr>
<td>Traumatic injury</td>
<td>81%</td>
<td>63%</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>APACHE-II score</td>
<td>18 ± 9</td>
<td>27 ± 9</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>SAPS-2 score</td>
<td>39 ± 12</td>
<td>53 ± 17</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>ISS score</td>
<td>23 ± 11</td>
<td>30 ± 14</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Prophylactic open abdomen</td>
<td>84%</td>
<td>63%</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Open abdomen indications</td>
<td>45%</td>
<td>40%</td>
<td>0.25</td>
</tr>
<tr>
<td>Damage control laparotomy</td>
<td>45%</td>
<td>40%</td>
<td>0.25</td>
</tr>
<tr>
<td>Surgeon suspicion for IAH</td>
<td>33%</td>
<td>25%</td>
<td>0.07</td>
</tr>
<tr>
<td>ACS</td>
<td>13%</td>
<td>30%</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Septic abdomen</td>
<td>13%</td>
<td>8%</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Table 7. Multivariate predictors of improved survival

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Significance</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS</td>
<td>-1.69335</td>
<td>&lt;.0001</td>
<td>0.18</td>
<td>0.09-0.37</td>
</tr>
<tr>
<td>Prophylactic open abdomen</td>
<td>1.17098</td>
<td>&lt;.0001</td>
<td>3.23</td>
<td>1.78-5.85</td>
</tr>
<tr>
<td>APACHE-II score ≥ 25</td>
<td>-1.10534</td>
<td>.001</td>
<td>0.33</td>
<td>0.18-0.62</td>
</tr>
<tr>
<td>Study year, per yr</td>
<td>-0.151142</td>
<td>.018</td>
<td>0.86</td>
<td>0.76-0.97</td>
</tr>
<tr>
<td>Age, per yr</td>
<td>-0.0096016</td>
<td>.13</td>
<td>0.99</td>
<td>0.98-1.00</td>
</tr>
<tr>
<td>SAPS-2 score ≥ 52</td>
<td>0.450669</td>
<td>.15</td>
<td>1.45</td>
<td>0.85-2.89</td>
</tr>
<tr>
<td>Traumatic injury</td>
<td>0.231176</td>
<td>.37</td>
<td>1.26</td>
<td>0.76-2.10</td>
</tr>
<tr>
<td>Gender, male</td>
<td>-0.0226406</td>
<td>.93</td>
<td>0.98</td>
<td>0.61-1.57</td>
</tr>
</tbody>
</table>

ACS, abdominal compartment syndrome; APACHE II, Acute Physiology and Chronic Health Evaluation, version II; SAPS-2, Simplified Acute Physiology Score, version 2; ISS, injury severity score; IAH, intra-abdominal hypertension; ACS, abdominal compartment syndrome.

A significant improvement in patient survival to hospital discharge from 50% in 2002 to 72% in 2007 (p = .015). Both univariate and multivariate analyses were performed to determine which factors were predictive of improved survival. In the univariate analysis, open-abdomen survivors were significantly more likely to be younger, male, traumatically injured, less critically ill, and to have undergone a prophylactic open abdomen rather than emergent decompression for ACS (Table 6). After severity of illness adjustment using Simplified Acute Physiology Score version 2 scores, there remained a significant difference in survival between patients receiving a prophylactic versus emergent open abdomen (p = .0006). In the multivariate analysis, development of ACS, use of a prophylactic open abdomen at the time of initial laparotomy in patients at risk, Acute Physiology and Chronic Health Evaluation Score version II score ≥ 25, and study year (indicating the complexity of the management algorithm) were identified as independent predictors of improved survival with a Hosmer-Leme show goodness-of-fit statistic of 11.5 (p = .18), indicating that the model accurately predicted patient outcome (Table 7).
To determine whether improvements in general ICU care over the course of the study could have resulted in the improved patient survival independent of our IAH/ACS management algorithm, annual study patient survival was compared to that of the surgical/trauma ICU patients who did not require an open abdomen. Whereas study patient survival was seen to increase annually, non-open-abdomen patient survival remained unchanged with similar demographics (Fig. 1). Using Simplified Acute Physiology Score version 2 scores for both patient populations, severity-adjusted annual survival rates were calculated to remove patient acuity as a possible confounding factor. After accounting for these potential differences in severity of illness, study patient survival is seen to improve significantly when the 2002 to 2004 (pre-comprehensive management algorithm) versus 2005 to 2007 (post-comprehensive management algorithm) time periods are compared (p = .001).

DISCUSSION

This prospective, observational study represents the largest trial to-date evaluating the benefits of a comprehensive, evidence-based medicine approach to the management of patients with IAH or ACS. As our management algorithm has changed based on the evolving medical literature, we have witnessed significant decreases in the incidence of ACS, clinically significant decreases in ICU, ventilator, and hospital days, and a marked improvement in the rate of and time to same-admission definitive abdominal closure. Most importantly, we have seen significant increases in both raw and severity-adjusted patient survival to discharge. These improvements appear to be temporally related to changes in our management algorithm that were made after the December 2004 International Consensus Conference on IAH and ACS (1, 2). This combined, multi-modality management strategy is based on four general principles: (1) serial IAP monitoring; (2) goal-directed optimization of systemic perfusion and organ function; (3) institution of medical interventions to reduce IAP and the end-organ consequences of IAH/ACS; and (4) prompt surgical decompression for IAH/ACS refractory to these therapeutic interventions (24). Of these, the institution of broad-ranging nonoperative medical interventions to reduce IAP and earlier use of the open abdomen represent the greatest changes to our evolving management algorithm.

Patient demographics, severity of illness, and the indications for open abdomen management remained unchanged throughout the duration of this 6-yr study. As a result, the marked improvement in abdominal closure rate and significant increase in patient survival to discharge do not appear to be related to a general improvement in overall ICU care, a less critically ill patient population, or a routine practice to “leave the abdomen open” after laparotomy. In fact, our use of the open abdomen has actually decreased by >50% since implementation of the World Society of the Abdominal Compartment Syndrome guidelines. When open abdomen management is used, it is most commonly performed either prophylactically at the time of initial laparotomy or for lower IAP thresholds before development of ACS when nonoperative management strategies to reduce IAP and improve systemic perfusion have failed. The open abdomen thus becomes a therapeutic intervention rather than just a method of abdominal management after development of ACS, a condition to be avoided with its five-fold increase in mortality (Table 7). Given the stable patient population throughout the study and the finding that a prophylactic open abdomen is associated with a greater than three-fold increase in survival from IAH/ACS, we propose that a prophylactic open abdomen to avoid ACS, rather than delayed emergent decompression once ACS has developed, represents a key contributing factor to the significant improvement in survival recognized in this study.

Through earlier abdominal decompression in selected patients at risk for IAH/ACS, we have also found that patients do not have the severity of IAH/ACS seen in years past and are thus able to tolerate earlier and more definitive abdominal wall closure. Primary fascial closure before hospital discharge is now possible in the majority of our patients. Such improvements are not related to changes in temporary abdominal closure technique as we almost exclusively used the “vacuum-pack” technique throughout the study period. Split-thickness skin grafting is now relegated only to either those few patients who have decompression late in the course of their critical illness and have severe visceral edema develop or those in whom enterostomal fistulas develop and cannot be primarily closed. Such an aggressive approach to primary fascial closure might be anticipated to result in an increased incidence of recurrent ACS (27, 28). As a result of earlier open abdomen management, however, we have not witnessed such an occurrence.

Despite the proven morbidity and mortality of IAH/ACS, some physicians remain reluctant to use open abdomen management out of concern for causing permanent disability or mortality to their patients. Vidal et al recently identified the mortality of IAH to be 53% and ACS 80% in a prospective study in which the treatment algorithm did not include open abdomen management (20). Our current mortality of 28% suggests that open abdomen management is an important factor in improving survival from IAH/ACS. This is further supported by a recent prospective observational trial of ACS patients by Parsak et al, in which the odds ratio for increased mortality associated with nonoperative management alone was 5.2 (22). We have recently prospectively demonstrated that long-term phys-
CONCLUSIONS

In conclusion, a comprehensive evidence-based management strategy that incorporates both operative and nonoperative interventions designed to reduce IAP significantly improved survival among patients treated with an open abdomen for IAH/ACS. Such improvements were not achieved at the cost of increased resource utilization. We encourage other institutions to adopt such an evidence-based approach to the patient with IAH/ACS.

REFERENCES