Management of Acute Compartment Syndrome

89

Ming-Jim Yang, Frederick A. Moore, and Janeen R. Jordan

Case Presentation

An 82 year old female with a history of liver cirrhosis secondary to hemochromatosis, coronary artery disease, CHF, and COPD was brought through the ED after a head-on motor vehicle collision. She complained initially of abdominal pain and right leg pain. Physical exam revealed a tender and distended abdomen in the right and left upper quadrants and a visible right lower leg deformity with a 4 cm wound over the lateral aspect of her thigh with exposed bone. A FAST exam was positive in the right upper quadrant. CT scan revealed a grade 2 liver laceration with active contrast extravasation (Fig. 89.1), a grade 3 splenic laceration, and a distal comminuted femur fracture (Fig. 89.2). An emergent hepatic and splenic artery embolization was performed followed by application of an tibial traction pin.

Postoperatively, she continued to have episodes of hypotension requiring continued resuscitation. Within the first 24 h, the patient received 6 L of crystalloid, 3 U pRBC, and 500 cc of albumin. Despite the resuscitation, the patient developed acute renal failure requiring CVVH.

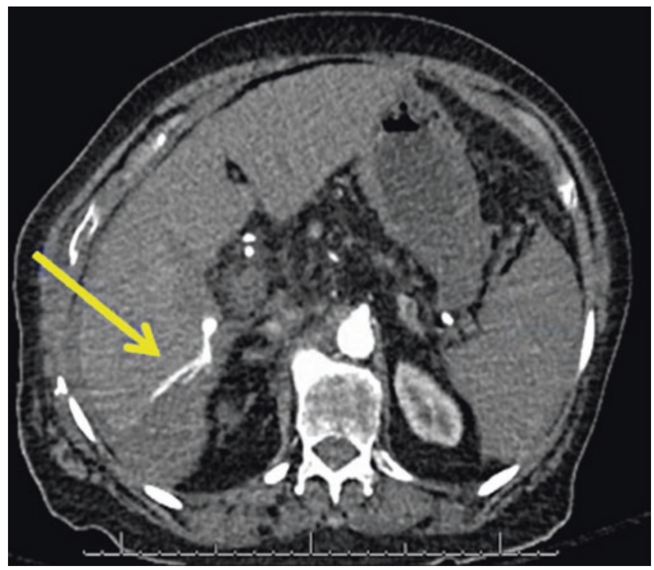

Fig. 89.1 CT Scan abdomen, Grade 2 liver laceration with active contrast extravasation

Question
What differential diagnoses should be considered?

Answer Abdominal and extremity compartment syndrome.

Old age, trauma and high volume resuscitation are risk factors for abdominal and extremity compartment syndromes. Since clinical exam is unreliable in predicting intra-abdominal pressures (IAP), surveillance of intra-abdominal pressures using transbladder pressure monitoring should be implemented. The fractured leg should be assessed with serial exams and intracompartmental pressure measurements. For this patient, transbladder pressures were monitored every 4 h.

Postinjury day 3, she presented with poor oxygenation while still on mechanical ventilation with peak pressures of 41 cmH_2O. IAP was found to be 29 mmHg. She was taken emergently to the operating room for a decompressive laparotomy. Her open abdomen was managed using a damage control technique employing a negative pressure therapy (NPT) dressing. She continued to experience hypotensive episodes requiring cystalloid boluses.

On post-decompression day 2, her nurse noted increased swelling of her right lower extremity. On physical exam, passive movement of the leg seemed to cause her "agitation" that would not improve with normal doses of pain medication. Intracompartmental pressures in her right anterior compartment showed an absolute value of 40 mmHg with a diastolic blood pressure of 57 mmHg. An emergent 4 com-

M.-J. Yang · F. A. Moore · J. R. Jordan (✉)
Department of Surgery, University of Florida, Gainesville, FL, USA

R. C. Hyzy, J. McSparron (eds.), *Evidence-Based Critical Care*, https://doi.org/10.1007/978-3-030-26710-0_89

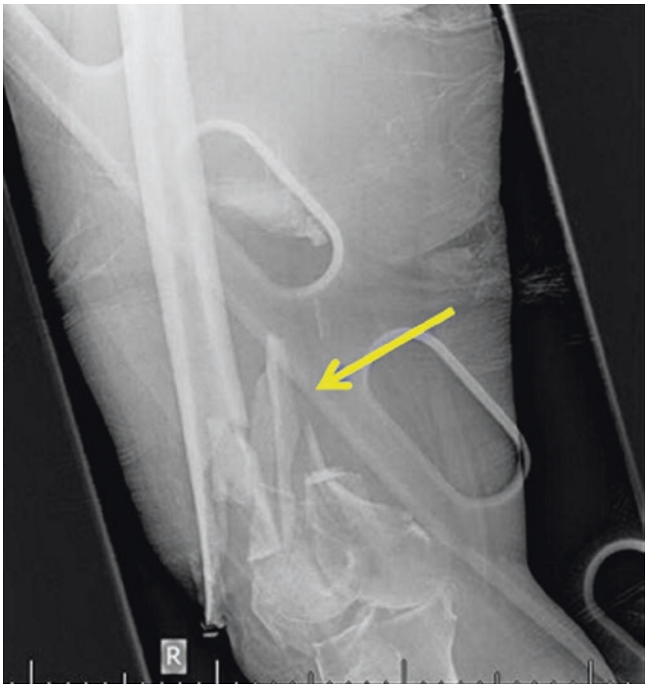

Fig. 89.2 Extremity radiograph with distal comminuted femur fracture

partment fasciotomy was performed at the bedside. Muscle swelling without muscle necrosis was noted at the completion of the fasciotomy. Her fasciotomy wounds were initially managed with wet-to-dry gauze wraps with normal saline but were changed to a NPT dressing after 48 hours. Her subsequent hospital course was notable only for a temporary abdominal coverage with a prosthetic mesh on postinjury day 10, followed by skin grafting on postinjury day 14. Delayed primary closure of her fasciotomy wound was achieved after 5 days of NPT.

Principles of Management

Diagnosis

Compartment syndrome is a state of decreased tissue perfusion in a specific body compartment due to increased intracompartmental pressures from either interstitial edema, or increased intracompartmental contents or fluid. Early diagnosis is the key to successful management. Clinical exam alone has been shown to be inadequate for diagnosis of an acute compartment syndrome [1, 2]. Surveillance with a combination of serial clinical exams and intra-compartmental pressure monitoring is the most efficient approach to diagnosis in both the abdomen and extremity [3, 4].

Abdomen

Abdominal surgery, fluid resuscitation >3500 mL/24 h, ileus, pulmonary, renal, or liver dysfunction, hypothermia, acidosis, anemia, oliguria, and elevated GAP CO_2 (gastric mucosal CO_2 minus end-tidal CO_2 tension) have been identified as risk factors for abdominal compartment syndrome in three prospective trials [5–7]. Patients with at least 2 risk factors should be surveyed with intra-abdominal pressure measurements taken via transbladder catheter. The measurements should be taken by instilling 25 cc of normal saline through the catheter and connecting the catheter to a pressure monitor. The patient should be supine and the monitor should be zeroed at the midaxillary line at the iliac crest. Patients sometimes require sedation and neuromuscular blockade to obtain an accurate intra-abdominal pressure reading via urinary catheter, as activity and abdominal muscle tensing will falsely elevate bladder pressures.

Organ dysfunction has been detected with IAPs as low as 10–15 mmHg [8]. The World Society of the Abdominal Compartment Syndrome (WSACS) has defined intra-abdominal hypertension (IAH) as a pathological state where the IAP is persistently greater than 12 mmHg. The spectrum of IAH is broken into 4 categories of increasing severity (Table 89.1).

Abdominal compartment syndrome is defined as an abdominal compartment pressure of greater than 20 mmHg (class 3 or greater) that is associated with new organ dysfunction [8]. Common organ dysfunction associated with abdominal compartment syndrome include respiratory (high peak and plateau airway pressures, hypercarbia and hypoxemia) and renal (oliguria, increasing serum creatinine, acute kidney injury).

Extremity

Risk factors for extremity compartment syndrome can be separated into fracture vs. non-fracture factors. Fracture-related risk factors include tibial diaphyseal fractures, soft tissue injury, crush injury and distal radial fractures [9]. Non-fracture risk factors include older age, greater number of comorbidities, presence of a coagulopathy such as

Table 89.1 Intra-abdominal hypertension grading scale

Grade	IAP (mmHg)
1	12–15
2	16–20
3	21–25
4	25+

Adapted from Malbrain et al. [8]

hemophilia A or anticoagulant therapy, an increased base deficit, lactate and blood product transfusion [10, 11]. Patients with at least two risk factors should undergo surveillance via serial clinical exams and intracompartmental pressure monitoring.

Clinical presentation of acute extremity compartment syndrome is most notably characterized by pain out of proportion to exam and pain with passive stretch [4]. Paresthesias, loss of pulses, pallor and paralysis are late signs of a compartment syndrome. These clinical signs have a sensitivity of 14–16% but a specificity of 97% [2]. Intracompartmental pressures can be obtained via commercial monitoring devices or an arterial blood pressure assembly. The threshold for diagnosing an acute compartment syndrome is defined as the difference between the diastolic blood pressure and the intracompartmental pressure. A threshold of less than 30 mmHg has generally been accepted as an indication for fasciotomy [12]. The sensitivity and specificity of continuous compartmental monitoring with a value of less than 30 mmHg is 94% and 98%, respectively [12].

Management

Definitive treatment of compartment syndrome involves surgical decompression of the compartment.

Abdomen

The gold standard for treatment of acute abdominal compartment syndrome is a decompressive laparotomy. Laparotomy is associated with a decrease in intra-abdominal pressure with improvement in cardiac, pulmonary and renal indices. However, despite these improvements, mortality still remains high at 46% [13]. Temporizing measures have been developed to decrease intra-abdominal pressure in hopes of preventing an abdominal compartment syndrome such as sedation, supine positioning, and neuromuscular blockade [3]. Etiologies due to increased luminal or abdominal fluid collections benefit from evacuation through nasogastric/orogastric suctioning and/or drainage of the fluid collections [3]. These measures should be implemented early before the development of ACS [3].

Extremity

Upon diagnosis of acute extremity compartment syndrome, emergent fasciotomy to release the compartment should be performed. The one exception is when there is suspicion that the compartment syndrome may have been ongoing for greater than 24 h. In a retrospective review of 336 combat veterans, delayed fasciotomy was associated with greater rates of muscle excision (25 vs. 11%), amputation (31 vs. 15%) and mortality (19 vs. 5%) [14]. These results supported the findings of Finkelstein et al. who described the clinical course in 5 patients who underwent delayed fasciotomy after 35 h of acute extremity compartment syndrome [15]. One patient died from multiorgan failure and septicemia, and the remaining four patients required amputations to treat refractory infections, multiorgan failure and sepsis. They speculated that after 24 h most of the tissues in the leg had died and by exposing that dead tissue to the open air, it provided a substrate for bacterial infection [15]. Thus, after 24 h, fasciotomy provides no benefit and definitive treatment may involve amputation.

Wound Management

Once the compartment is released, it should remain open until the acute compartment syndrome has resolved. The patient then has an open wound that will require closure. Negative pressure therapy has been shown to help with wound closure in both the abdomen and extremity.

Abdomen

The WSACS has recommended negative pressure therapy (NPT) to help manage the open abdomen [3]. NPT has been shown to decrease bowel wall edema, remove cytokines, and reduce the incidence of intra-abdominal abscesses [16]. In their review of the literature, the WSACS showed that NPT significantly decreased mortality by 298 deaths per 1000 patients and increased primary closure by 350 per 1000 patients [3]. One potential complication of NPT is development of an entero-atmospheric fistula (EAF). With NPT, EAF incidence ranges in the literature from 2 to 20%, as compared to the rate of EAF formation with planned ventral hernia repair, 5–9% [17, 18]. As per the WSACS analysis, the calculated relative risk of EAF with NPT is 3.57 [3]. Following NPT, delayed primary closure should be attempted; but if that is unable to be achieved, a prosthetic mesh can be sewn in place, followed by skin grafting. The resulting ventral hernia can then be repaired electively after 6–12 months [19].

Extremity

Delayed primary closure is the goal for all fasciotomy wounds. If a fasciotomy cannot be closed primarily, a skin graft may be necessary for coverage. Negative pressure therapy has been studied as an adjunct to attain delayed primary closure. Zannis et al. retrospectively compared 458 patients who underwent fasciotomy in a 10-year period. They looked at rates of primary closure between NPT use and regular dressing changes and found that NPT use was associated with a greater percentage of primary closure as compared to traditional dressings changes (78.8 vs. 50.8%). Additionally, the fasciotomy wounds closed in fewer days with NPT use (7.1 vs. 9.6 days for primary closure; 8.5 vs. 11.5 for secondary intention) [20].

Evidence Contour

Compartment syndrome is still being actively studied, and new management strategies for all aspects of acute compartment syndrome are still being discussed.

Abdomen

Abdominal Perfusion Pressure

Abdominal perfusion pressure (APP) has been suggested as a preferable means (APP) of diagnosing compartment syndrome over absolute pressure alone. Abdominal perfusion pressure is defined as the difference between the mean arterial pressure (MAP) and the IAP. In a retrospective study by Cheatham et al., they examined 149 patients with IAH or ACS who underwent IAP monitoring in a 25 month period [21]. Using ROC curve analysis, they found that APP was a better predictor of patient survival than either MAP or IAP alone.

Fluid Management

The WSACS has suggested that a damage control resuscitation (DCR) protocol, ie. permissive hypotension, limited crystalloids and increased FFP:RBC ratio, may be beneficial during the initial resuscitation. This is supported by a prospective series of 141 trauma patients by Cotton et al. who looked at providing blood products early in exsanguinating trauma. They found a decreased incidence of abdominal compartment syndrome and increased survival [22]. This was subsequently supported by another retrospective series of 390 patients who either received DCR or not [23]. Both studies found that giving a greater FFP:RBC ratio earlier in a patient's resuscitation significantly reduces the amount of crystalloid administered and the incidence of ACS [22, 23]. However, both studies are criticized for their use of historical controls and relatively small sample sizes. The WSACS has also recommended implementation of a fluid management protocol for at-risk patients to achieve an even or negative fluid balance once resuscitation is completed [3]. Currently, many ICU's use a combination of diuresis, albumin and continuous renal replacement therapies (CRRT) to achieve that balance. These modalities have not been studied specifically in the context of their effects on IAP. A Belgium study is currently examining the effects of CRRT on intra-abdominal pressure.

Percutaneous Drainage

Percutaneous drainage has been studied as a possible alternative means of decompressing the abdomen in order to avoid the complications of decompressive laparotomy such as lateralization of the fascia, EAF and non-closure of the abdomen. The evidence for this practice lies mainly in case reports in burn patients and secondary ACS where there is a buildup of intraperitoneal fluid from massive resuscitation. A case control study of 62 patients by Cheatham et al. comparing percutaneous drainage vs. open decompression for all etiologies showed that percutaneous drainage was not inferior to open decompression in regards to hospital stay (40 vs. 49, P = 0.4) and mortality (58 vs. 39%, P = 0.2). They did see a non-statistically significant trend in recurrent ACS with percutaneous drainage (64 vs 48%; $P = 0.39$) [24]. Several ongoing trials are looking at percutaneous drainage in the setting of acute pancreatitis, severe sepsis and managing IAH.

Extremity

Hyperbaric Oxygen Hyperbaric oxygen therapy (HBO) has been used as an adjunct to compartment release for the treatment of acute compartment syndrome. Further research is needed to evaluate the overall benefit and cost effectiveness of the therapy [25]

Infrared Spectroscopy

Near-infrared spectroscopy (NIS) is an optical technique that measures the oxygenated state of hemoglobin within a tissue. It has been proposed as more direct means of assessing tissue perfusion in the context of extremity compartment syndrome. There are no clinical studies to support the use of near-infrared spectroscopy in diagnosing an acute extremity compartment syndrome at this time, but an animal model of extremity compartment syndrome has shown a strong correlation between compartment pressures and spectroscopy readings [26]. There are currently 9 ongoing clinical trials at different stages of completion that are looking at near-infrared spectroscopy as a diagnostic tool for extremity compartment syndrome.

Dermotraction

Split thickness skin grafts (STSG) are the gold standard for fasciotomy closure if delayed primary closure cannot be achieved. STSGs create a second wound, can cause pain at the donor site, cause numbness at the graft site, and is associated with weakness in the underlying muscle due to the lack of fascia [27]. For these reasons, many surgeons have explored other means of achieving delayed primary closure. Using either sutures or a commercial device, the concept is to apply gradual mechanical traction to the fascia over time to achieve closure. Most dermatotraction techniques are based on the "shoelace" technique [28] where vessel loops are criss-crossed from both sides of the wound and then stapled to the skin edge. The vessels are tightened every 48 h until closure is achieved. The evidence behind this technique and the devices are all reported in small case series ranging from 2 to 56 patients [27]. Larger comparative studies will have to be performed to assess non-inferiority of this technique with negative pressure therapy.

References

1. Kirkpatrick AW, Brenneman FD, McLean RF, Rapanos T. Boulanger BR. Is clinical examination an accurate indicator of raised intra-abdominal pressure in critically injured patients? Can J Surg. 2000;43:207–11.
2. Ulmer T. The clinical diagnosis of compartment syndrome of the lower leg: are clinical findings predictive of the disorder? J Orthop Trauma. 2002;16:572–7.
3. Kirkpatrick AW, et al. Intra-abdominal hypertension and the abdominal compartment syndrome: updated consensus definitions and clinical practice guidelines from the World Society of the Abdominal Compartment Syndrome. Intensive Care Med. 2013;39:1190–206.
4. Garner MR, Taylor SA, Gausden E, Lyden JP. Compartment syndrome: diagnosis, management, and unique concerns in the twenty-first century. HSS J. 2014;10:143–52.
5. Balogh Z, et al. Both primary and secondary abdominal compartment syndrome can be predicted early and are harbingers of multiple organ failure. J Trauma. 2003;54:848–59. discussion 859–61
6. Malbrain ML, et al. Prevalence of intra-abdominal hypertension in critically ill patients: a multicentre epidemiological study. Intensive Care Med. 2004;30:822–9.
7. Malbrain ML, et al. Incidence and prognosis of intraabdominal hypertension in a mixed population of critically ill patients: a multiple-center epidemiological study. Crit Care Med. 2005;33:315–22.
8. Malbrain ML, et al. Results from the international conference of experts on intra-abdominal hypertension and abdominal compartment syndrome. I definitions. Intensive Care Med. 2006;32:1722–32.
9. McQueen MM, Gaston P, Court-Brown CM. Acute compartment syndrome. Who is at risk? J Bone Joint Surg Br. 2000;82:200–3.
10. Hope MJ, McQueen MM. Acute compartment syndrome in the absence of fracture. J Orthop Trauma. 2004;18:220–4.
11. Kosir R, et al. Acute lower extremity compartment syndrome (ALECS) screening protocol in critically ill trauma patients. J Trauma. 2007;63:268–75.
12. McQueen MM, Duckworth AD, Aitken SA, Court-Brown CM. The estimated sensitivity and specificity of compartment pressure monitoring for acute compartment syndrome. J Bone Joint Surg Am. 2013;95:673–7.
13. De Waele J, et al. Abdominal decompression for abdominal compartment syndrome in critically ill patients: a retrospective study. Acta Clin Belg. 2010;65:399–403.
14. Ritenour AE, et al. Complications after fasciotomy revision and delayed compartment release in combat patients. J Trauma. 2008;64:S153–61. discussion S161–152
15. Finkelstein JA, Hunter GA, Hu RW. Lower limb compartment syndrome: course after delayed fasciotomy. J Trauma. 1996;40:342–4.
16. Batacchi S, et al. Vacuum-assisted closure device enhances recovery of critically ill patients following emergency surgical procedures. Crit Care. 2009;13:R194.
17. Bee TK, et al. Temporary abdominal closure techniques: a prospective randomized trial comparing polyglactin 910 mesh and vacuum-assisted closure. J Trauma. 2008;65:337–42. discussion 342–34
18. Dubose JJ, Lundy JB. Enterocutaneous fistulas in the setting of trauma and critical illness. Clin Colon Rectal Surg. 2010;23:182–9.
19. Fabian TC, et al. Planned ventral hernia. Staged management for acute abdominal wall defects. Ann Surg. 1994;219:643–50. discussion 651–43
20. Zannis J, et al. Comparison of fasciotomy wound closures using traditional dressing changes and the vacuum-assisted closure device. Ann Plast Surg. 2009;62:407–9.
21. Cheatham ML, White MW, Sagraves SG, Johnson JL, Block EF. Abdominal perfusion pressure: a superior parameter in the assessment of intra-abdominal hypertension. J Trauma. 2000;49:621–6. discussion 626–7
22. Cotton BA, et al. Damage control hematology: the impact of a trauma exsanguination protocol on survival and blood product utilization. J Trauma. 2008;64:1177–82. discussion 1182–73
23. Cotton BA, et al. Damage control resuscitation is associated with a reduction in resuscitation volumes and improvement in survival in 390 damage control laparotomy patients. Ann Surg. 2011;254:598–605.
24. Cheatham ML, Safcsak K. Percutaneous catheter decompression in the treatment of elevated intraabdominal pressure. Chest. 2011;140:1428–35.
25. Wattel F, Mathieu D, Nevière R, Bocquillon N. Acute peripheral ischaemia and compartment syndromes: a role for hyperbaric oxygenation. Anaesthesia 1998;53(S2):63–5.
26. Cathcart CC, Shuler MS, Freedman BA, Reno LR, Budsberg SC. Correlation of near-infrared spectroscopy and direct pressure monitoring in an acute porcine compartmental syndrome model. J Orthop Trauma. 2014;28:365–9.
27. Kakagia D. How to close a limb fasciotomy wound: an overview of current techniques. Int J Low Extrem Wounds. 2015;14(3):268–76.
28. Kakagia D, et al. Wound closure of leg fasciotomy: comparison of vacuum-assisted closure versus shoelace technique. A randomised study. Injury. 2014;45:890–3.