—Review—

Damage Control Surgery and Open Abdominal Management: Recent Advances and Our Approach

Shigeki Kushimoto, Masato Miyauchi, Hiroyuki Yokota and Makoto Kawai

Department of Emergency and Critical Care Medicine, Graduate School of Medicine, Nippon Medical School

Abstract

The concept of damage control and improved understanding of the pathophysiology of abdominal compartment syndrome (ACS) have been proven to be great advances in the management of both traumatic and nontraumatic surgical conditions. The practice of damage control surgery includes 3 components: 1) abbreviated resuscitative surgery for rapid control of hemorrhage and abdominal contamination by gastrointestinal contents, followed by temporary abdominal wall closure for planned reoperation and prevention of ACS; 2) restoration of physiologic function, including rewarming and correction of coagulopathy and hemodynamic stabilization in the intensive care unit; and 3) re-exploration for the definitive management of injuries and abdominal wall closure. Although this new approach can decrease the mortality rate of patients with severe physiological derangement, the establishment of clearly defined indications is necessary. For patients who require damage control surgery, interventional radiology should be integrated into the strategy for achieving hemostasis. Angiographic evaluation and embolization should be considered immediately after initial operation, especially for patients with combined intraperitoneal and retroperitoneal hemorrhage, severe hepatic injury, or ongoing hemorrhage after damage control surgery.

In many patients who require conventional open abdominal management following damage control surgery or decompressive laparotomy for ACS, the granulating abdominal contents are covered with only a skin graft, which is associated with a risk of enterocutaneous fistula. These patients will ultimately require complex abdominal wall reconstruction at a later stage. We have performed early fascial closure using an anterior rectus abdominis sheath turnover flap method. This technique may reduce the need for skin grafting and subsequent reconstruction and can be considered as an alternative method for the early management of patients with open abdomen.

(J Nippon Med Sch 2009; 76: 280–290)

Key words: damage control surgery, severe trauma, abdominal compartment syndrome, open abdomen, anterior rectus abdominis sheath turnover flap

Correspondence to Shigeki Kushimoto, MD, Department of Emergency and Critical Care Medicine, Nippon Medical School, 1–1–5 Sendagi, Bunkyo-ku, Tokyo 113–8603, Japan
E-mail: kussie@nms.ac.jp
Journal Website (http://www.nms.ac.jp/jnms/)

Introduction

The concept of damage control and improved understanding of the pathophysiology of the abdominal compartment syndrome (ACS) have been great advances in the management of traumatic[1–3] and nontraumatic surgical conditions[4]. Although damage control surgery is widely performed for the management of these conditions, this approach frequently requires the peritoneal cavity to be left open (open abdomen) for a considerable period in patients who cannot undergo early abdominal wall closure because of visceral edema.

Stone et al. have been credited with popularizing the technique of abbreviated laparotomy in 1983[5]. They rapidly terminated the surgical procedure at the onset of coagulopathy by employing packing for nonsurgical bleeding, along with selective ligation of vessels and rapid bowel resection without anastomosis or stoma formation. Definitive surgery was performed after correction of physiological derangements, including coagulopathy. Compared with 1 of 14 patients who survived after being treated with the traditional approach, 11 of 17 patients after abbreviated laparotomy. To describe such truncated surgery for trauma patients with massive hemorrhage and shock, acidosis, and hypothermia, the term "damage control" was coined in 1993 by Rotondo et al.[1].

We have previously reported on the important role of angiographic embolization in patients requiring damage control surgery[6]. The goal of angiography in severely injured patients is to identify and treat arterial hemorrhage in a minimally invasive fashion while preserving organ function. Although transcatheter arterial embolization (TAE) has been reported to rapidly and effectively control arterial pelvic bleeding and bleeding from hepatic injury[7,8], it is generally held that TAE should not be chosen for control of hemorrhage in patients who are hemodynamically unstable. However, we have integrated TAE with damage control surgery as a multimodal strategy to achieve hemostasis[8,9].

Over the past decade intra-abdominal hypertension (IAH) and ACS have been increasingly recognized in critically ill patients[10]. ACS refers to decreased blood flow to the abdominal wall and organs, as well as secondary pressure effects on the respiratory and cardiovascular systems, when the intra-abdominal pressure rises above a critical level. Edema and distension of intraperitoneal and retroperitoneal contents are commonly noted at laparotomy when trauma patients have required resuscitation with large volumes of fluid in addition to blood, especially patients undergoing prolonged laparotomy. The volume of the abdominal contents increases significantly, so that formal closure of a midline abdominal incision carries a high risk of excessively increasing the intra-abdominal pressure, especially if perihepatic or intra-abdominal packing with surgical towels has been done for nonsurgical hemorrhage as part of damage control. To prevent ACS, leaving the abdominal incision open is an easy and definitive choice. However, an open abdomen can be required for a considerable period in patients who cannot undergo early abdominal wall closure because of prolonged visceral edema[11].

We developed the anterior rectus abdominis sheath turnover flap method for early fascial closure in patients requiring open abdominal management who cannot undergo standard abdominal wall closure[12]. This method has never been reported as a technique for early abdominal wall reconstruction. It may reduce the need for creating a planned ventral hernia, in which the abdominal contents are covered with only a skin graft, and subsequent abdominal wall reconstruction is required.

What is Damage Control Surgery?

In the conventional management of trauma, definitive repair of all injuries is accomplished in the immediate postinjury setting. However, physiologic derangement due to severe shock often leads to successful repair but also patient death[1–3,11]. In response to this challenge, the concept of "damage control" was developed, as a method of controlling but not definitively repairing a patient's injuries. Damage control was introduced as a temporary measure to save the lives of moribund trauma

patients. It has since become an alternative method for patients with nontraumatic conditions when physiologic derangements do not allow completion of the scheduled surgical procedure[4]. The term "damage control" originates from the United States Navy and refers to the ability of a ship to absorb damage while maintaining mission integrity. Damage to the ship's hull is rapidly assessed, and adequate repairs are performed to allow the ship to return to the controlled environment of port[13].

1) Rationale for Damage Control Surgery

Patients are more likely to die from intraoperative metabolic failure than from the failure to complete organ repair[1–3,11]; therefore, the rationale behind this paradigm shift in operative strategy is simple and compelling. Although control of hemorrhage and intestinal contamination is mandatory, the time required to complete formal surgery may aggravate the vicious cycle of coagulopathy, acidosis, and hypothermia[1–3]. The onset of this cycle heralds a state of physiological exhaustion from which recovery is nearly impossible during surgery despite vigorous attempts at correction. To break this vicious cycle, it is necessary to terminate the surgical procedure and close the abdomen.

Studies have confirmed the linear relationship between mortality rate and degree of hypothermia, with few survivors among patients with a core temperature less than 32℃[14,15]. The detrimental effects of hypothermia on coagulopathy were reviewed by Reed et al.[16], who noted significant prolongation of the clotting time at temperatures less than 35℃. Platelet dysfunction (measured with the bleeding time) has also been linked to hypothermia[17]. Temperature-dependent enzyme reactions that form the coagulation cascade are blocked by hypothermia. This negative effect is exacerbated by acidosis, which most often results from overproduction of lactate due to hypovolemic shock[18].

Acute coagulopathy, which cannot be explained as traditional dilutional coagulopathy, has recently been identified in 1 of 4 trauma patients on admission and is associated with a 4-fold increase in the mortality rate[19–21]. This coagulopathy of trauma results from multiple independent but interacting mechanisms, including tissue damage, shock, hemodilution, hypothermia, acidemia, and inflammation. A new concept of "acute coagulopathy of trauma-shock" has been proposed, in which initiation of coagulation occurs along with the activation of anticoagulation and the fibrinolysis pathway. These mechanisms may contribute to traumatic coagulopathy[19,21].

2) Operative Approach and Resuscitation for Damage Control

The intraoperative detection of coagulopathy represents an absolute indication for damage control surgery. However, the decision may be made too late, because it can be difficult to control nonsurgical hemorrhage by packing once coagulopathy has become manifest. Therefore, it would be ideal to predict the patients who are close to a state of coagulopathy early after admission[18]. Morris et al. have proposed a temperature less than 35℃, base deficit greater than 14, and the presence of coagulopathy as indicators[22]. Cosgriff et al. have suggested that predictors of the onset of coagulopathy include hypotension (systolic blood pressure <70 mmHg), pH less than 7.10, temperature less than 34℃, and an Injury Severity Score of at least 25[23]. Johnson et al. have described the following factors as 'classic' triggers: pH less than 7.30, transfusion of 10 or more units of packed red cells with an estimated blood loss greater than 4 L, and temperature less than 35℃[24]. In 2001, Asensio et al. proposed the following criteria: pH of 7.2 or less, intraoperative temperature less than 34℃, blood replacement greater than 4 L, and total intraoperative fluid replacement greater than 10 L[25].

Damage control has 3 separate components, which are: 1) abbreviated resuscitative surgery for rapid control of hemorrhage and intestinal contamination, followed by temporary abdominal wall closure; 2) ongoing core rewarming, correction of coagulopathy, and hemodynamics in the intensive care unit; and 3) re-exploration for definitive management of injuries and abdominal wall closure[1–3].

(1) Primary operative approach to damage control

Scalea has summarized the principles of damage control as follows: only blood loss kills early;

gastrointestinal injury causes problems later; everything takes longer than you think; an injury may be missed during hasty operation in an unstable patient; hypothermia, acidosis, and coagulopathy lead to more of the same; and the best setting for a critically ill patient is the intensive care unit[26].

The primary goal of damage control surgery is to control active hemorrhage, followed by limitation of contamination and temporary abdominal wall closure. While packing with surgical towels may seem to have a leading role in damage control, packing is only the technique of choice for nonarterial bleeding (venous bleeding, oozing, and coagulopathy). In contrast, arterial bleeding must be controlled at the time of initial exploration before packing (by direct ligation, repair, or intraluminal shunting if organs cannot tolerate ligation). Limiting gastrointestinal contamination is another objective of the initial operation, by stapling, simple oversewing, or clamping of enteric injuries.

Lastly, temporary abdominal wall closure is performed, without formal closure of the abdominal fascia. The key objectives of temporary closure are containment of the abdominal viscera, control of abdominal fluid loss, maintenance of pressure on tamponaded areas, and increasing the likelihood of subsequent complete abdominal wall closure[27]. Various techniques for temporary abdominal closure will be described later.

(2) Resuscitation in the intensive care unit

The immediate goal after damage control surgery is correction of physiologic abnormalities, including vigorous rewarming, restoration of normal cardiovascular function by the infusion of fluid/blood, the use of inotropes and other drugs, correction of residual coagulopathy after hypothermia has resolved, and supportive care for the lungs and kidneys.

(3) Re-exploration for definitive management and abdominal wall closure

While there are no scientific data regarding the timing of re-exploration, it should be performed after the patient has been completely resuscitated, and the lethal triad has been reversed. However, it has been shown that the rates of morbidity and mortality increase if the interval from initial damage control surgery to reoperation is more than 72 hours[28]. Early reoperation may be necessary if there is evidence of continued hemorrhage (>10 units of packed red blood cells during the early postoperative period or ongoing loss of $\geq$2 units/hour), uncorrectable acidosis, or ACS[29].

The goals of reoperation are to achieve definitive organ repair and complete fascial closure. Accordingly, gastrointestinal continuity is reestablished, a stoma is created if necessary, and solid organ debridement is performed as needed. Although persistent visceral edema may prevent formal fascial closure, it is successful in over 85% of patients[1,30].

3) Does Cumulative Experience Support Damage Control?

Rotondo et al. have reviewed the literature and identified 961 patients who underwent damage control surgery: among these patients the mortality rate was 50%, and among survivors the morbidity rate was 40%[1]. Shapiro et al. have expanded the review to more than 1,000 patients and found a mortality rate of 50% (503 of 1,001 patients) and morbidity rate among survivors of 40% (193 of 480 patients)[3].

The fact that the mortality rate of extremely ill trauma patients may approach 100% without damage control should be taken into consideration when this very high mortality rate is assessed. The fundamental premise of damage control surgery is to prevent impending death. This change in treatment strategy has higher complication rate, which is also unexpected if patients do not survive.

Our Multidisciplinary Approach Combining Angiographic Embolization and Damage Control Surgery

While damage control surgery is now widely accepted as a standard strategy for the management of patients with severe abdominal trauma and coagulopathy, acidosis, and hypothermia[1–4], TAE has been positioned as strategy to identify and treat arterial hemorrhage in a minimally invasive fashion

in patients with less severe trauma and stable hemodynamics while preserving organ function. However, it is generally thought that TAE should not be chosen to control hemorrhage in patients who are hypotensive or hemodynamically unstable[31,32].

Before our report[6], few papers had been published regarding the role of interventional radiology in patients who required damage control surgery, and interventional radiology had never been cohesively integrated into the management of patients with such severe trauma. We retrospectively analyzed 20 patients who had undergone damage control laparotomy[6], 8 of whom had also undergone angiographic evaluation and treatment before or after damage control surgery. Three patients had undergone angiography before damage control surgery, because a large pelvic retroperitoneal hematoma had been seen on computed tomography and the volume of intraperitoneal blood had seemed insufficient to account for the severity of hemodynamic instability. The other five patients had undergone angiography after damage control laparotomy. The indications were a nonexpanding retroperitoneal hematoma in 3 patients, a nonexpanding hepatic hilar hematoma in 1 patient, and hepatic injury associated with cirrhosis in 1 patient. Lumbar artery injuries were identified and treated with embolization in 3 patients. We proposed that angiography may be indicated before damage control laparotomy to control retroperitoneal pelvic hemorrhage in patients who have insufficient intraperitoneal blood loss to account for hemodynamic instability. Angiography should be considered after damage control laparotomy when a nonexpanding, inaccessible hematoma is found at operation in a patient with coagulopathy.

We have previously reported on a patient with blunt hepatic injury requiring damage control surgery because of inaccessible major venous injury and the onset of coagulopathy[33]. The decision to perform immediate postoperative angiography was based on the hemorrhagic response to Pringle's maneuver and its release after perihepatic packing during surgery. Hepatic angiography revealed extravasation from a branch of the middle hepatic artery, which was embolized successfully. We suggested that a hemorrhagic response to Pringle's maneuver and its release after perihepatic packing during damage control surgery is an indication for immediate postoperative angiography/embolization.

On the basis of our clinical experience and a literature review, we have integrated interventional radiology into damage control surgery as follows:

(1) In patients with blunt trauma and persistent hemodynamic instability despite resuscitation because of combined intraperitoneal and retroperitoneal hemorrhage, laparotomy (damage control surgery in most patients) should be performed first, followed immediately by TAE to complement surgical hemostasis.

(2) In patients with hepatic injury requiring damage control surgery, immediate postoperative angiography/embolization should be considered (irrespective of the hemodynamic status at the end of surgery) in patients with severe parenchymal injury and apparent arterial bleeding after release of Pringle's maneuver during perihepatic packing.

(3) When there is evidence of continuing hemorrhage (>10 units of packed red blood cells in the early postoperative period or $\geq$2 units/hour ongoing) or uncorrectable acidosis, re-exploration or angiographic evaluation and embolization should be considered, depending on the intraoperative findings.

Definition of ACS and Open Abdominal Management

ACS is an increasingly recognized clinical entity that occurs when the intra-abdominal pressure is abnormally high and is associated with organ dysfunction. Although the most common cause of ACS is blunt abdominal trauma associated with massive hemorrhage, ACS can also arise in patients who have burns and other nontraumatic conditions, such as complex major abdominal surgery and severe acute pancreatitis requiring extensive resuscitation[4,11,34]. Recently, both IAH and ACS were defined by the World Society of Abdominal Compartment Syndrome[10]. IAH was defined as an intraabdominal pressure (IAP) of at least 12 mmHg, and ACS was defined as an IAP of at least 20 mmHg with evidence of organ dysfunction or failure.

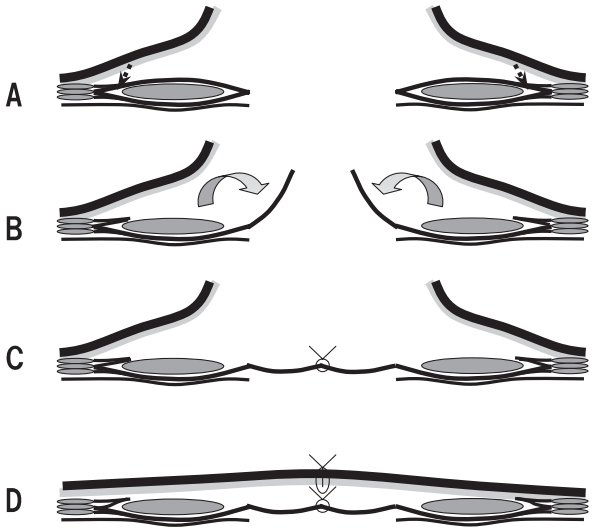

Fig. 1 Cross-sectional diagram of the technique for turnover flap creation from the anterior rectus abdominis sheath.
The procedure is started by separating the skin and underlying adipose tissue from the anterior rectus sheath, with a base several centimeters beyond the lateral border of the rectus sheath (A). The turnover flap then is fashioned from the anterior sheath by longitudinally incising it along the entire lateral border. The site of this incision must be carefully selected to avoid entering the junction of the internal oblique aponeurosis and the external oblique aponeurosis (B). The anterior sheath is then dissected from the lateral to medial direction to free it from the rectus muscle. The linea alba is kept intact to serve as a medial hinge. The turnover flap is approximated with interrupted sutures (C), and the skin is closed primarily (D) (from reference 12).

Standard methods for IAP monitoring were also provided. When a sustained increase in IAP is observed despite medical management (i.e., sedation, neuromuscular blockade, and evacuation of abdominal fluid collections), decompressive laparotomy is required to reduce IAP and improve visceral perfusion and systemic cardiovascular and respiratory function[34]. Patients with severe trauma who require extensive resuscitation almost always show increased IAP due to visceral edema, intraperitoneal and retroperitoneal blood collections, accumulation of fluid, and abdominal packing. The definitive procedure for decreasing IAP and preventing IAH/ACS is to leave the abdominal wound open. However, prolonged open abdominal management might be required if visceral edema persists for more than several days after damage control surgery.

Conventional Approach to Open Abdomen

Patients requiring open abdominal management who cannot undergo early standard fascial closure often have a prolonged open abdomen. During this time, the musculofascial structures of the abdominal wall contract laterally, leaving a large midline defect for which standard fascial closure is impossible. Many patients temporarily have a large ventral hernia in which the granulating abdominal contents are only covered with a skin graft, requiring subsequent complex abdominal wall reconstruction. To reduce the need for an intermediate period with a large ventral hernia and later abdominal wall reconstruction, several techniques, such as vacuum-assisted wound closure and application of a Wittmann patch, have been employed for temporary closure[35–37].

Risk of Enterocutaneous Fistula

Enterocutaneous fistula is a devastating complication of open abdomen that has been reported to occur in 5% to 25% of patients[36,38–40], with lower fistula rates reported after vacuum-assisted wound closure[35,36,41]. If a fistula develops, mesh application is significantly prolonged. The risk of enterocutaneous fistula increases with the duration of open abdominal management[38]. In another series, 3 of 14 fistulae developed even after skin grafting for the granulating open wound[36], suggesting the importance of early definitive wound closure to prevent fistula formation.

Reconstruction of the Abdominal Wall after Planned Ventral Hernia

To achieve late reconstruction of the abdominal wall after a period with a planned ventral hernia following open abdominal management, several methods have been proposed, including component

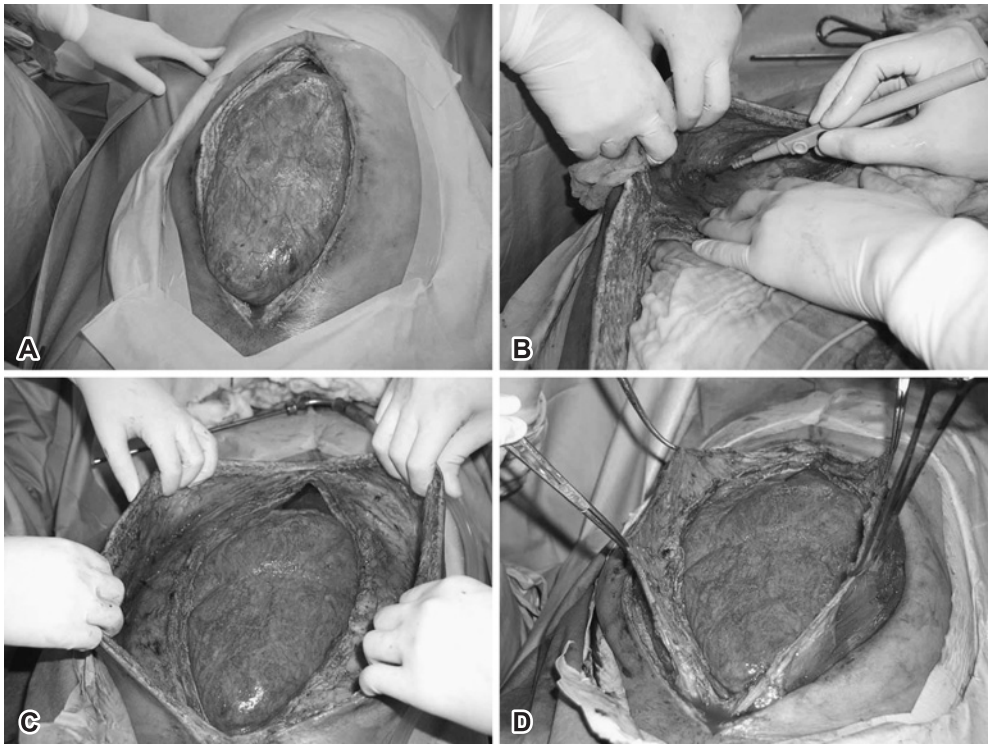

Fig. 2 Intraoperative view of the anterior rectus abdominis sheath turnover flap method (initial steps).
A: View just after removal of the vacuum pack (11 days of open abdomen). **B**: Skin and underlying adipose tissue are initially separated from the anterior rectus sheath as a flap. **C**: The skin and adipose tissue have been completely dissected from the anterior sheath bilaterally beyond the lateral border of the rectus sheath. **D**: The anterior rectus sheath flap is reflected medially by dissection from the lateral to medial direction to free it from the rectus muscle. The linea alba is kept intact as a medial hinge (from reference 12).

separation[42], a rectus turnover flap[43], and the modified component separation technique[38]. Although the "open-book" variation of component separation has been reported as a technique for abdominal wall reconstruction 6 to 12 months after the initial operation[44], application of these techniques in the early period of open abdomen has never been evaluated.

Bilateral Anterior Rectus Abdominis Sheath Turnover Flap Method for Early Fascial Closure and Prevention of Enterocutaneous Fistula

Management of Open Abdomen

At our institution, patients who require temporary abdominal wall closure undergo either Bogota bag closure (suturing of a sterile opened intravenous fluid bag to the skin) or vacuum pack closure using the modified method described by Garner et al[12,45]. Recently, the latter has been the preferred technique, except for initial damage control surgery where aggressive resuscitation is ongoing and visceral edema may increase after the operation. These dressings are changed every 48 to 72 hours until fascial closure or the decision to perform skin grafting over an intentional ventral hernia. If the abdominal fascia can be fully approximated without tension, standard fascial closure is performed. Ten to 14 days after initial laparotomy, the anterior rectus abdominis sheath turnover flap method is considered if the distance to be closed with fascia is less than 15 cm in patients for whom standard fascial closure is inappropriate because of prolonged visceral edema. Formation of a planned ventral hernia by skin grafting over granulating abdominal contents is chosen for patients in whom edema has not resolved by 3 weeks or more after the initial laparotomy and who are not candidates for either method of fascial

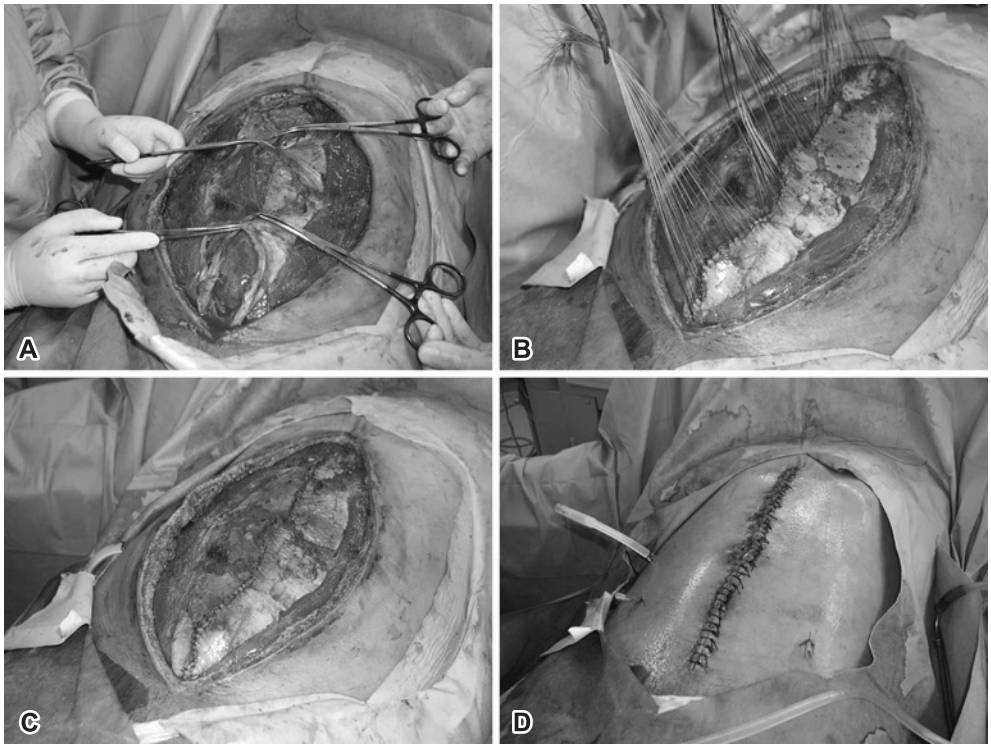

Fig. 3 Intraoperative view of the anterior rectus abdominis sheath turnover flap method (later steps).
A: Approximating the bilateral turnover flaps. **B** and **C**: Turnover flaps from the anterior rectus sheaths are approximated with interrupted sutures. **D**: The skin and subcutaneous tissue are sutured primarily (from reference 12).

Fig. 4 Open abdominal management in a pediatric patient with severe torso trauma.
An 8-year-old girl with lung contusion, left diaphragmatic rupture, mesenteric injury, pelvic fracture, and bilateral femoral fractures. **A**: The abdomen was covered temporarily with a Silo closure (3 days after the initial laparotomy). **B**: Vacuum pack closure at 10 days after the initial surgery. **C**: The abdomen was covered with a vacuum pack 30 days after laparotomy.

closure[12].

Surgical Procedure for the Anterior Rectus Abdominis Sheath Turnover Flap

The procedure is started by separating the skin and underlying adipose tissue from the anterior rectus sheath. Next, a turnover flap is created from the anterior sheath by incising the sheath along the entire length of its lateral border. The anterior sheath is then dissected from the lateral to medial aspect, freeing it from the rectus muscle. The linea alba is kept intact as a medial hinge to mobilize the flap **(Fig. 1)**. The fascial flap is then reflected medially while taking care not to damage the anterior sheath.

After the bilateral turnover flaps are created, they are approximated to cover the abdominal contents using interrupted sutures. Finally, the skin and

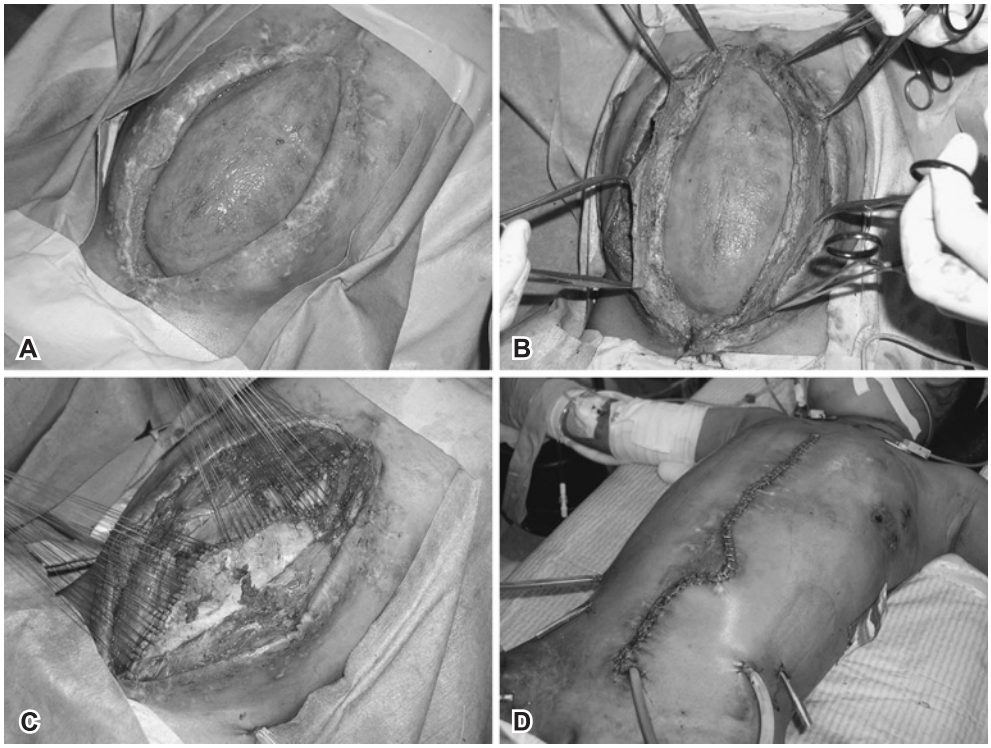

Fig. 5 Intraoperative view of the anterior rectus abdominis sheath turnover flap method 30 days after initial laparotomy.
A: View just after removal of the vacuum pack (30 days of open abdomen) showing the granulated abdominal contents and retracted musculofascial structures of the anterior abdomen. **B**: The anterior rectus sheath flap is reflected medially and dissected from the lateral to medial direction to free it from the rectus muscle. **C**: Bilateral turnover flaps are approximated with interrupted sutures. **D**: Skin and subcutaneous tissue are sutured primarily (from reference 12).

adipose tissue are approximated **(Fig. 2–5)**.

In many patients requiring conventional open abdominal management, the granulated abdominal contents are covered with only a skin graft, and there is a risk of enterocutaneous fistula. These patients ultimately require complex reconstruction. Early abdominal wall reconstruction in patients for whom standard closure is inappropriate has received little attention. Early fascial closure with an anterior rectus abdominis sheath turnover flap may reduce the need for skin grafting and subsequent reconstruction. This approach can be considered as an alternative technique for early management of patients with open abdomen.

Conclusions

Damage control surgery has been widely used to manage severe trauma associated with massive hemorrhage, as well as for nontraumatic surgical conditions requiring extensive resuscitation. If physiologic derangement does not permit the completion of formal surgery or the scheduled procedure, temporary measures to save the life of a critically ill patient are required. Although this new approach may decrease the mortality rate of patients with severe physiological derangements, especially coagulopathy, excessive application of damage control could result in a high morbidity rate. Establishment of clearly defined indications is necessary for appropriate use of the damage control approach. In patients who require damage control surgery to control hemorrhage, interventional radiology should be integrated into the strategy for achieving hemostasis. Angiography and embolization can be considered immediately after the initial operation if arterial bleeding is thought to be ongoing. A combination of interventional radiology and damage control may improve outcomes for critically ill trauma and nontrauma patients.

In many patients requiring conventional open abdominal management after damage control surgery or decompressive laparotomy for ACS, the granulated abdominal contents are covered with only a skin graft, and there is a risk of enterocutaneous fistula. These patients ultimately require complex abdominal wall reconstruction. Early fascial closure with an anterior rectus abdominis sheath turnover flap may reduce the need for skin grafting over a ventral hernia and subsequent reconstruction. This can be considered as an alternative approach for the early management of patients with open abdomen.

References

1. Rotondo MF, Schwab CW, McGonigal MD, et al.: "Damage control": An approach for improved survival in exsanguinating penetrating abdominal injury. J Trauma 1993; 35: 375–383.
2. Moore EE, Burch JM, Franciose RJ, et al.: Staged physiologic restoration and damage control surgery. World J Surg 1998; 22: 1184–1191.
3. Shapiro MB, Jenkins DH, Schwab CW, et al.: Damage control: Collective review. J Trauma 2000; 49: 969–978.
4. Mcnelis J, Soffer S, Marini CP, et al.: Abdominal compartment syndrome in the surgical intensive care unit. Am Surg 2002; 68: 18–23.
5. Stone H, Strom P, Mullins R: Management of the major coagulopathy with onset during laparotomy. Ann Surg 1983; 197: 532–535.
6. Kushimoto S, Arai M, Aiboshi J, et al.: The role of interventional radiology in patients requiring damage control laparotomy. J Trauma 2003; 54: 171–176.
7. Bassam D, Cephas GA, Ferguson KA, Beard LN, Yong JS: Protocol for the initial management of unstable pelvic fractures. Am Surg 1998; 64: 862–867.
8. Claridge JA, Young JS: A successful multimodality strategy for management of liver injuries. Am Surg 2000; 66: 920–926.
9. Hoffer EK, Borsa JJ, Bloch RD, Fontaine AB: Endovascular techniques in the damage control setting. Radiographics 1999; 19: 1340–1348.
10. Malbrain MLNG, Cheatham ML, Kirkpatrick A, et al.: Results from the international conference of experts on intra-abdominal hypertension and abdominal compartment syndrome. I. Definition. Intensive Care Med 2006; 32: 1722–1732.
11. Wyrzykowski AM, Feliciano DV: Trauma damage control. In Trauma (Feliciano DV, Mattox KL, Moore EE, eds), Sixth edition. 2008; pp 851–870, McGrraw-Hill, New York.
12. Kushimoto S, Yamamoto Y, Aiboshi J, et al.: Usefulness of the bilateral anterior rectus abdominis sheath turnover flap method for early fascial closure in patients requiring open abdominal management. World J Surg 2007; 31: 2–8.
13. Department of Defense: Surface ship survivalility. In Naval War Publication 3-20.31, 1996; Department of Defense, Washington DC.
14. Jurkovich GJ, Greiser WB, Luterman A, et al.: Hypothermia in trauma victims: an ominous predictor of survival. J Trauma 1987; 27: 1019–1024.
15. Luna GK, Maier RV, Pavlin EG, et al.: Incidence and effect of hypothermia in seriously injured patients. J Trauma 1987; 27: 1014–1107.
16. Reed RL, Bracey AW, Hudson JD, et al.: Hypothermia and blood coagulation: dissociation between enzyme activity and clotting factor levels. Circ Shock 1990; 32: 141–152.
17. Czer L, Bateman T, Gray R, et al.: Prospective trial of DDAVP in treatment of severe platelet dysfunction and hemorrhage after cardiopulmonary bypass. Circulation 1985; 72: 111–130.
18. Lee JC, Peitzman AB: Damage-control laparotomy. Curr Opin Crit Care 2006; 12: 346–350.
19. Hess JR, Brohi K, Dutton RP, et al.: The coagulopathy of trauma: A review of mechanisms. J Trauma 2008; 65: 748–754.
20. Maegele M, Lefering R, Yucel N, et al.: Early coagulopathy in multiple injury: an analysis from German Trauma Registry on 8724 patients. Injury 2007; 38: 298–304.
21. Brohi K, Singh J, Heron M, et al.: Acute traumatic coagulopathy. J Trauma 2003; 54: 1127–1130.
22. Morris JA Jr, Eddy VA, Blinman TA, et al.: The staged celiotomy for trauma. Ann Surg 1993; 217: 576–586.
23. Cosgriff N, Moore EE, Sanaia A, et al.: Predicting life-threatening coagulopathy in the massively transfused trauma patient: hypothermia and acidosis revisited. J Trauma 1997; 42: 857–862.
24. Johnson JW, Gracias VH, Schwab W, et al.: Evolution in damage control for exsanguinating penetrating abdominal injury. J Trauma 2001; 51: 261–271.
25. Asensio JA, McDuffie L, Petrone P, et al.: Reliable variables in the exsanguinated patient which indicate damage control and predict outcome. Am J Surg 2001; 182: 743–756.
26. Scalea T: What's new in trauma in the past 10 years. Int Anesthesiol Clin 2001; 40: 1–7.
27. Schreiber MA: Damage control surgery. Crit Care Clin 2004; 20: 101–118.
28. Abikhaled JA, Granchi TS, Wall MJ, et al.: Prolonged abdominal packing for trauma is associated with increased morbidity and mortality. Am Surg 1997; 63: 1109–1112.
29. Loveland JA, Boffard KD: Damage control in the abdomen and beyond. Br J Surg 2004; 91: 1095–1101.
30. Hirshberg A, Wall MJ, Mattox KL: Planned reoperation for trauma: a two-year experience with 124 consecutive patients. J Trauma 1994; 37: 365–369.
31. Claridge JA, Young JS: A successful multimodality strategy for management of liver injuries. Am Surg 2000; 66: 920–926.
32. Hoffer EK, Borsa JJ, Bloch RD, Fontaine AB: Endovascular techniques in the damage control setting. Radiographics 1999; 19: 1340–1348.
33. Kushimoto S, Koido Y, Omoto Y, et al.: Immediate postoperative angiographic embolization after

damage control surgery for liver injury: report of a case. Surg Today 2006; 36: 566–569.
34. Cheatham ML, Malbrain MLNG, Kirkpatrick A, et al.: Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome. II. Recommendations. Intensive Care Med 2007; 33: 951–962.
35. Garner GB, Ware DN, Cocanour CS, et al.: Vacuum-assisted wound closure provides early fascial reapproximation in trauma patients with open abdomen. Am J Surg 2001; 182: 630–638.
36. Miller PR, Thompson JT, Faler BJ, Meredith JW, Chang MC: Late fascial closure in lieu of ventral hernia: The next step in open abdomen management. J Trauma 2002; 53: 843–849.
37. Wittmann DH, Aprahamian C, Bergstein JM: Etappenlavage: advanced peritonitis managed by planned multiple laparotomies utilizing zippers, slide fastener, and Velcro analogue for temporary abdominal closure. World J Surg 1990; 14: 218–226.
38. Jernigan TW, Fabian TC, Croce MA, et al.: Staged management of giant abdominal wall defect. Acute and long-term results. Ann Surg 2003; 238: 349–357.
39. Fabian TC, Croce MA, Pritchard FE, et al.: Planned ventral hernia: Staged management for acute abdominal wall defects. Ann Surg 1994; 219: 643–653.
40. Nagy KK, Filder JJ, Mahr C, et al.: Experience with three prosthetic materials in temporary abdominal wall closure. Am Surg 1996; 62: 331–338.
41. Suliburk JW, Ware DN, Balogh Z, et al.: Vacuum-assisted wound closure achieves early facial closure of open abdomens after severe trauma. J Trauma 2003; 55: 1155–1160.
42. Ramirez OM, Ruas E, Dellon AL: "Components separation" method for closure of abdominal-wall defects: An anatomic and clinical study. Plast Reconstr Surg 1990; 86: 519–526.
43. DeFranzo AJ, Kingman GJ, Sterchi JM, Marks MW, Thorne M: Recus turnover flaps for the reconstruction of large midline abdominal wall defects. Ann Plast Surg 1996; 37: 18–23.
44. Ennis LS, Young JS, Gampper TJ, Drake DB: The "Open-Book" variation of component separation for repair of massive midline abdominal wall hernia. Am Surgeon 2003; 69: 733–743.
45. Garner GB, Ware DN, Cocanour CS, et al.: Vacuum-assisted wound closure provides early fascial reapproximation in trauma patients with open abdomen. Am J Surg 2001; 182: 630–638.

(Received, September 7, 2009)
(Accepted, October 9, 2009)