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Outcomes of Damage Control Surgery for Abdominal Trauma Evaluated Using the Trauma and Injury Severity Score and Lethal Triad in a Single Institution

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ABSTRACT

In trauma management, damage control surgery is an effective approach to decrease the incidence of preventable trauma death. In this study, we aimed to investigate the survival outcomes and clinical factors in patients undergoing damage control surgery for severe abdominal trauma, in relation to trauma severity based on the trauma and injury severity score and lethal triad (hypothermia, metabolic acidosis, and coagulopathy), to assess the indicators of mortality and criteria for performing damage control surgery. Fifteen patients with severe abdominal trauma underwent damage control surgery from January 2011 to September 2017. We compared the short-term outcomes and perioperative factors associated with the trauma and injury severity score and the lethal triad between survivors and non-survivors. Of the 15 included patients, eight (53.3%) survived and seven (46.7%) died. No preventable deaths occurred. The patient characteristics, including age, sex, and mechanism of injury were not related to survival. The injury severity score ($p = 0.035$) and abbreviated injury scale score of the head ($p = 0.005$) were significantly higher among the non-survivors than among the survivors. Of the lethal triad, the incidence of metabolic acidosis was significantly higher in the non-survivors ($p < 0.050$). This study found that head injury and metabolic acidosis are predictors of mortality. These indications provide a practical basis for determining whether to use damage control surgery and postoperative management.

Key words: *Abdominal trauma, damage control surgery, lethal triad, trauma and injury severity score*

INTRODUCTION

Among the recent advances in severe abdominal trauma treatment, damage control surgery (DCS) has led to reduction in mortality and has become a standard approach. Many surgeons have reported that patients who underwent DCS had a survival advantage compared with those not managed with DCS[7,13,21)]. In the management of abdominal trauma, both criteria should be defined to evaluate injury severity associated with mortality and to determine whether to perform DCS. The trauma and injury severity score (TRISS) has commonly been used to evaluate injury severity, and the probability of survival (PS) calculated using the TRISS has been used as a predictor of mortality[2,4)]. Deaths in trauma patients with a PS score of 0.5 or higher are defined as preventable trauma deaths (PTDs), which accounted for approximately 40% of all trauma deaths in Japan according to the Ministry of Health[23)]. Decreasing the incidence of PTDs is considered important for the quality control of the treatment of trauma patients[22,26)].

The TRISS is calculated using the injury severity score (ISS) as an anatomic index, revised trauma score (RTS) as a physiologic index, patient age, and mechanism of injury. Although the abbreviated injury scale (AIS) assesses injury severity on a scale from 1 (minor) to 6 (fatal) in each of six body systems (i.e., head, face, chest, abdomen, limbs and pelvis, and skin surface), along with the ISS, only a few studies have focused on the association of other injury sites with abdominal trauma even if multiple organs are often injured[11)].

Hypothermia, metabolic acidosis, and coagulopathy with hemostatic disorder have been reported as indications for DCS; these elements comprise the lethal triad[1,8)]. The concept of the lethal triad was described by Feliciano et al. in 1981; it is known worldwide as a predictor of mortality in trauma patients[9)]. Although the lethal triad is a utility predictor of mortality and is often used to determine the need to perform DCS, its standards remain unclear. Thus, this study aimed to retrospectively compare the outcomes and clinical factors

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Table 1 Characteristics of survivors group

Patient No.	Age	Sex	Injuries	ISS	PS	DCS	Definitive surgery
1	64	F	Pancreas, Hemopneumothorax	33	0.113	Packing	Pancreaticoduodenectomy
2	22	F	Liver, Spleen, Rib fracture	51	0.406	Packing	Splenectomy, Cholecystectomy
3	77	F	Liver, Rib fracture Hemopneumothorax	32	0.672	Packing	Hepatorrhaphy, Cholecystectomy
4	22	M	Liver, Spleen, Lung, Rib fracture	42	0.768	Packing	Hepatorrhaphy, Partial splenectomy
5	47	F	Liver, Small intestine Transverse colon, Kidney, Diaphragm, Hemopneumothorax	16	0.823	Packing, Small intestine transection Enterorrhaphy	Partial colectomy, Partial enterectomy, Ileostomy, Gastrostomy, Nephrectomy, Adrenalectomy
6	79	M	Pancreas, Liver, Extrahepatic bile duct	16	0.879	Packing, Cholecystectomy, External drainage of bile duct	Choledochojejunostomy Pancreatorrhaphy, Enterostomy
7	57	M	Small intestine, Mesentery	17	0.939	Small intestine transection	Ileocolic resection
8	51	M	Liver	17	0.989	Packing, Hepatorrhaphy	Left lobectomy

DCS, damage control surgery; ISS, injury severity score; PS, probability of survival

based on the TRISS and lethal triad between survivors and non-survivors to assess the indicators of mortality and criteria for performing DCS in patients undergoing such a surgical procedure for severe abdominal trauma.

MATERIALS AND METHODS

From January 2011 to September 2017, 83 patients underwent an emergency laparotomy for abdominal organ and pelvic injuries at a single tertiary hospital in Japan (Hiroshima Prefectural Hospital). Of these 83 patients, 15 underwent DCS without undergoing a temporary surgery. DCS includes three main steps: initial surgery with hemostasis and packing, intensive care unit (ICU) resuscitation, and later definitive repair of all temporized injuries. Clinical data were retrospectively collected from the 15 patients who underwent DCS.

In our hospital, the treatment of patients with severe abdominal trauma is managed using the Japan Advanced Trauma Evaluation and Care system[12). Patients with hemorrhagic shock were categorized into three groups according to initial fluid resuscitation: responders, transient responders, and non-responders. Responders were defined as patients who responded to the initial infusion and had a maintained systolic blood pressure of above 90 mmHg. Transient responders were defined as those who first achieved adequate blood pressure after an initial infusion but required an additional infusion to maintain a blood pressure above 90 mmHg. Non-responders were defined as those who did not achieve an adequate blood pressure after the infusion and had a maintained systolic blood pressure below 90 mmHg[18)]. Generally, DCS was used for the responders and non-responders, whereas total-body computed tomography (CT) was performed in the responders to determine the need to perform DCS based on the damaged organs and structures, severity of damage, and presence of coagulopathy and metabolic acidosis.

In the initial surgery, a rapid midline incision was created; the hemoperitoneum and clots were removed; and the abdominal cavity was quickly assessed. Bleeding was controlled with either ligation or suturing of the vessels and gauze packing, and contamination was controlled with transection of the damaged bowels. Once bleeding and contamination were controlled, the fascia was left open, and vacuum packing closure was used to prevent abdominal compartment syndrome. Subsequently, the patients underwent continued resuscitation, stabilization of vital signs, and aggressive correction of their hypothermia, metabolic acidosis, and coagulopathy in the ICU. After the patients regained their physiologic reserve in the ICU (approximately 24 to 48 hr), definitive repair was performed, including damaged solid organ resection or bowel reconstruction.

Of the 15 patients who underwent DCS, eight survived, while the remaining seven died. The patient demographics, injury characteristics, pre-hospital vital signs, preoperative laboratory findings, AIS score, RTS, ISS, PS score, and surgical details and outcomes are shown in Tables 1 and 2. Consent to participate was obtained from the patients, and ethical approval was obtained from the ethical committee of Hiroshima Prefectural Hospital.

Statistical analysis

Data were compared between survivors and non-survivors using Student's *t*-test and chi-squared analysis. Differences with a p-value of < 0.050 were considered statistically significant. All statistical analyses were conducted using the JMP software (version 14.2.0; SAS Institute, Inc., Cary, NC, USA). Data were summarized as mean ± standard deviation.

RESULTS

Between January 2011 and September 2017, 15 patients with abdominal trauma were admitted to our institution and subsequently underwent DCS. Among them, eight survived, and seven died. The patient characteristics, including age, sex, mechanism of injury, severity of injuries calculated using the TRISS, and

Table 2 Characteristics of non-survivors group

Patient No.	Age	Sex	Injuries	ISS	PS	DCS	Definitive surgery	Cause of death
9	69	M	Mesentery, T-SAH, Hematothorax	50	0.008	Packing	—	Hemorrhage (Post-injury day 0)
10	22	M	Liver, T-SAH	57	0.020	Packing	—	Hemorrhage (Post-injury day 0)
11	47	M	Liver, Mesentery, T-SAH, Hematothorax	41	0.082	Packing	—	Hemorrhage (Post-injury day 0)
12	19	M	Spleen, Common iliac vein Pelvic fracture	57	0.163	Packing, Splenectomy, Vascular sutures	—	Hemorrhage (Post-injury day 0)
13	20	F	Liver, Spleen	57	0.201	Packing	Depacking, Gastrostomy, Splenectomy Cholecystectomy	Hemorrhagic cerebral infarction (Post-injury day 21)
14	71	M	Liver	29	0.350	Packing, Hepatorrhaphy Right portal vein ligation	Right lobectomy	Liver failure, Sepsis (Post-injury day 49)
15	52	M	Mesentery, IVC, Common iliac artery	26	0.460	Packing, Vascular sutures	—	Hemorrhage (Post-injury day 1)

DCS, damage control surgery; ISS, injury severity score; PS, probability of survival; T-SAH; traumatic subarachnoid hemorrhage; IVC, inferior vena cava

Table 3 Patients' characteristics and physiological parameters.

	All (n = 15)	Survivor group (n = 8)	Non-survivor group (n = 7)	p value
Age	47.9 ± 22.0	52.4 ± 7.9	42.9 ± 8.4	0.424
Sex (M/F)	10/5	4/4	6/1	0.143
Mechanism of injury (Blunt/Penetrate)	13/2	7/1	6/1	0.919
AIS Head	1.20 ± 1.93	0.00 ± 0.00	2.57 ± 0.55	0.005
AIS Face	0.27 ± 1.03	0.00 ± 0.00	0.57 ± 0.39	0.302
AIS Chest	2.33 ± 1.95	2.25 ± 0.72	2.43 ± 0.76	0.867
AIS Abdomen	4.47 ± 0.52	4.25 ± 0.17	4.71 ± 0.18	0.081
AIS Limbs and pelvis	0.60 ± 1.23	0.13 ± 0.39	1.14 ± 0.42	0.097
AIS Surface	0.27 ± 0.46	0.38 ± 0.16	0.14 ± 0.17	0.346
RTS	4.909 ± 2.031	6.231 ± 0.517	3.399 ± 0.552	0.003
ISS	35.5 ± 15.1	28.0 ± 4.65	44.0 ± 5.00	0.035
PS	0.460 ± 0.355	0.698 ± 0.087	0.188 ± 0.03	0.002
BT (°C)	36.3 ± 1.3	36.7 ± 0.5	35.8 ± 0.5	0.232
pH	7.17 ± 0.15	7.27 ± 0.01	7.05 ± 0.04	0.002
BE	−10.1 ± 7.1	−5.9 ± 2.0	−14.8 ± 2.1	0.009
PT activity (%)	60.3 ± 22.8	68.0 ± 7.8	51.6 ± 8.3	0.174

AIS, abbreviated injury scale; RTS, revised trauma score; ISS, injury severity score; PS, probabiliry of survival, BT, body temprature; BE, base excess; PT, prothrombin time.

physiologic parameters of the lethal triad, were evaluated using medical records and summarized thereafter (Table 3). The patients who underwent DCS included 10 men and 5 women, with age ranging from 19 to 79 (47.9 ± 22.0) years. Injury was caused by blunt trauma in 13 patients and stabbing in 2 patients. The patient characteristics, including age, sex, and mechanism of injury, were not related to the survival outcome. The mean ISS was 35.5 (range, 16–57), and the mean PS score was 0.460 (range, 0.008–0.989). Only the mean AIS score for the head was significantly higher in the non-survivors than in the survivors (p = 0.005). No other significant differences were found. However, the ISS was significantly higher (p = 0.035), and the PS score was significantly lower among the non-survivors than among the survivors (p = 0.002).

Significant differences in the lethal triad elements were found between the survivors and non-survivors. The mean pH (7.27 ± 0.01 versus 7.05 ± 0.04; p = 0.002) and mean levels of base excess (−5.9 ± 2.0 versus −14.8 ± 2.1; p = 0.009) also differed significantly between them. On the contrary, no significant differences in the body temperature (BT) (p = 0.232) and prothrombin time (PT) activity (p = 0.174) were observed.

The overall survival rate was 53.3%; all patients with a PS score above 0.5 survived, and no PTD occurred. Furthermore, two patients with a PS score below 0.5 also survived. In contrast, two patients who underwent surgery for definitive repair died during their hospital stay. The first patient was a 20-year-old woman who was injured in a traffic accident and had liver and splenic injury and pelvic fracture. An initial emergency laparotomy with gauze packing was performed. Splenectomy and cholecystectomy were performed the day after the initial laparotomy. Although bleeding was controlled, metabolic acidosis and coagulopathy did not improve.

On post-injury day 21, she died suddenly owing to a wide hemorrhagic cerebral infarction. The second patient was a 71-year-old man who was injured due to a fall. This patient had a severe right hepatic lobe injury and massive intra-abdominal bleeding. Ligation of the right branch of the portal vein and gauze packing were used to control bleeding. After resuscitation, right lobe hepatectomy was performed. Despite the control of surgical bleeding, the patient developed liver failure and required massive transfusion of fresh frozen plasma. Eventually, coagulopathy led to intestinal bleeding and death due to liver failure on post-injury day 49.

DISCUSSION

In the present study, 8 of the 15 patients survived after DCS, and the overall survival rate was 53.3%. All patients with a PS score above 0.5 and two of the nine patients with a PS score below 0.5 responded to the treatment. Rotondo et al. first reported DCS as a treatment approach to prevent failure of homeostasis before it becomes irreversible in severe trauma patients with massive bleeding or serious contamination[25]. This approach has been shown to lead to better than expected survival rates for severe abdominal trauma.

In evaluating trauma severity, the ISS can also be used as a predictor of mortality. Liberman et al. reported that the mortality rate of patients with an ISS above 25 exceeded 20%[15]. This study also showed that the ISS was significantly higher, and the PS score was significantly lower in the non-survivors than in the survivors. Multiple organs and structures were often damaged in patients with a high ISS; the present study revealed that the AIS score for head injuries was significantly higher in the non-survivors. No patients required surgery for or died of a head injury. Although the presence of coagulopathy is a prognostic factor in patients with head injury only, head injury alone also affects the coagulation system via the release of tissue thromboplastin and other biomarkers. MacLeod et al. reported that 81% of patients were coagulopathic when their Glasgow coma scale (GCS) score was ≤ 6, and 100% were coagulopathic when their GCS score was 3 or 4, with a trend toward a higher mortality in the coagulopathic patients[17]. Bleeding could not be controlled owing to the prolonged coagulopathy in the patients with head injury in our study. Because head injury is a key factor in exacerbating coagulopathy, which is one element of the lethal triad, in cases with complicated head injury, careful observation in cooperation with neurosurgeons is needed to monitor coagulability and aggravation of intra-abdominal or intracranial bleeding.

The lethal triad has been used as an indicator of mortality when DCS is performed. In our study, the patients with at least one element of the lethal triad were more likely to die, and the lethal triad was an impressive indicator for mortality. These signs were commonly defined in the literature as a BT of ≤ 35°C, pH of ≤ 7.2, and PT international normalized ratio of ≥ 1.50[20,24].

Hypothermia, which can have marked physiologic effects on various organs and hemostatic systems, is associated with high mortality. In trauma patients, tissue hypoperfusion and resuscitation may elicit hypothermia, which leads to cardiac depression, decreased respiratory drive, decreased cerebral blood flow, platelet dysfunction, and impaired clotting enzyme function[27]. Jurkovich et al. reported a mortality rate of 100% among trauma patients with a BT of ≤ 32.8°C[14]. However, no significant difference in the BT between the survivors and non-survivors was found in the present study, and only one patient with a BT of ≤ 35.0°C survived.

Metabolic acidosis is the predominant physiologic dysfunction resulting from persistent hypoperfusion. Acidosis at a pH of ≤ 7.2 is associated with decreased contractility and cardiac output, vasodilation, hypotension, bradycardia, increased dysrhythmias, and decreased blood flow to the liver and kidneys[19]. Furthermore, acidosis can affect coagulopathy synergistically with hypothermia. Davis and Kaups reported that a base deficit of −6 or less is a marker of severe injury and significantly predicts mortality in all trauma patients; it is particularly ominous in patients aged 55 years and older[6].

Although acidosis is defined by the pH of the arterial blood, the pH and base excess level were used in this study because acidosis is difficult to determine accurately owing to respiratory compensation or the response to infusion. In this study, the pH and base excess level in the non-survivors were significantly lower than those in the survivors, indicating the utility of the pH and base excess level, as these results can be obtained more rapidly than any other laboratory data.

Coagulopathy is very common in trauma and is one of the single most important factors of prognosis. The incidence of an abnormal first PT or partial thromboplastin time is independently associated with mortality[3,5,10]. MacLeod et al. reported that an initial abnormal PT increases the adjusted odds of dying by 35% and that an initial abnormal partial thromboplastin time increases the adjusted odds of dying by 326%[17]. Coagulopathy is also the most preventable cause of trauma-related death.

Many surgeons believe that prognosis is improved if DCS is performed before a patient develops the lethal triad[16,28]. Matsumoto et al. suggested that the indications for DCS are systolic blood pressure of ≤ 90 mmHg, base excess level of ≤ −7.5 mmol/L, and BT of ≤ 35.5°C at the start of surgery[18]. Several reports have shown that the survival rate is lower after DCS once coagulopathy or a metabolic disorder has developed. Therefore, it is important to evaluate hemodynamics and trauma severity easily and quickly for rapid decision-making on whether DCS should be performed. We determined the following criteria for performing DCS: 1) non-response or transient response to fluid infusion, 2) BT of ≤ 35°C, and 3) severe metabolic acidosis.

Furthermore, it is often difficult to evaluate images, such as CT images, in determining whether DCS should be performed. When a complication of head injury is suspected or the lethal triad is presented, DCS should be performed instead of primary definitive repair. During resuscitation in the ICU after the initial surgery, the severity of abdominal and head injuries should be evaluated accurately using CT. When a head injury is complicated, coagulopathy can worsen; hence, we should follow up laboratory data carefully and improve coagulopathy aggressively.

The limitations of our study include its retrospective and single-center design and the small number of subjects. Further investigations with larger numbers of patients are necessary.

In conclusion, this study indicated that head injury complications and metabolic acidosis are predictors of mortality. In addition, all patients with a PS score above 0.5 survived, and no PTD occurred in our study; therefore, DCS was considered an effective approach for severe abdominal trauma. Although the criteria for performing DCS are controversial and should be examined further, we proposed a set of criteria for its implementation. It is difficult to establish a uniform treatment strategy for multiple injuries owing to differences in the injured organs, severity of damage, and patient background; nevertheless, we believe that appropriate and rapid decision-making regarding the performance of DCS by evaluating the severity of trauma and multidisciplinary treatment, including surgery and resuscitation, can decrease the incidence of PTDs.

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