Abstract
Secondary abdominal compartment syndrome (s-ACS) is a serious complication with high mortality in patients with extensive burns requiring extensive fluid therapy to maintain the hemodynamic state. This report presents 2 cases of extensive burn patients complicated with s-ACS requiring surgical decompression. Fluid resuscitation was administered according to Parkland formula, using urinary output as the primary parameter to assess the volume status and tissue perfusion. The first case had a scald burn with an 80% total burn surface area (TBSA) requiring 28 L over 17 h. The second case was scald burn with a 77% TBSA requiring 31 L over 20 h. These cases required a revision of the institutional fluid resuscitation protocol for burn patients during the initial 24 h after the injury. The revised protocol divided burn patients into ≥ 60% TBSA or < 60%, according to the risk for the development of s-ACS following fluid resuscitation using crystalloids. In addition, the protocol provide mandatory sequential monitoring of intra-abdominal pressure (IAP) by measuring intra-bladder pressure (IBP) and aggressive intervention from the early post-burn period, when the patients required more than 250cc/kg during the first 24 h post-burn period. The revised protocol may reduce the development of s-ACS.

Key words: fluid resuscitation, intra-abdominal pressure, secondary abdominal compartment syndrome, Parkland formula

Introduction
Fluid resuscitation is a critical treatment component for severe burn patients in the early phase after injury, because increased vascular permeability is one of the most significant pathophysiological changes in the early phase after burn injury. There are multiple formulae for fluid resuscitation in burn patients with no clear international consensus. Severe burns are a devastating injury that induces profound systemic inflammation, requiring a large volume of resuscitative fluids. The consequent generalized severe soft tissue edema and peritoneal ascites raises the intra-abdominal pressure (IAP) well above the normal physiological levels commensurate with intra-abdominal hypertension (IAH), secondary abdominal compartment syndrome (s-ACS) associated with an IAP > 20mmHg and is associated with subsequent organ failure.

Although routine monitoring of IAP is recommended in patients with extensive burns, because of the high risk of s-ACS, IAP monitoring is not routinely performed in clinical practice. The development of s-ACS significantly worsens the prognosis of severe burn patients. This report presents 2 cases of s-ACS with different etiology, and introduces a revised institutional fluid resuscitation protocol for burn patients during the initial 24 h after injury designed to reduce the risk and predict the onset of s-ACS associated with poor prognosis.

Case Reports
This study reviewed the medical records of two pa-
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Patients with extensive scald burns that developed secondary ACS. The pre-decompression resuscitation data are summarized in Table 1. Comparisons of the pre- and post-decompression clinical parameters are shown in Table 2.

Case 1
A 47-year-old male with no past medical history was brought to our emergency room with scald burns due to exposure to boiling water following consumption of excess alcohol. The total burn surface area (TBSA) was 80% including 3.5% superficial dermal burns (SDB), 42% deep dermal burns (DDB), and 34.5% deep burns (DB) with no inhalational injuries (Fig. 1). The burn index (BI) was 57.25 and the prognostic burn index (PBI) was 104.25. He was intubated upon arrival and started on mechanical ventilation. His initial examination revealed a Glasgow Coma Scale of 13 (E4V4M5), re-
spiratory rate of 30 breaths per minute, heart rate of 97 regular beats per minute, blood pressure of 117/60 mmHg, and O₂ saturation 95% without oxygen inhalation. He was admitted to the intensive care unit (ICU) with severe hemolysis, hemoconcentration, and metabolic acidosis (pH 7.294, HCO₃⁻ 17.4 mmol/L, BE -8.1 mmol/L, Lactate 5.0 mmol/L). He should have received a total of 19,200 ml of crystalloids solution over the first 24 h, according to the Parkland formula. Urine output and global end diastolic volume (GEDV) were monitored for hemodynamic evaluation using PiCCO plus® (Pulsion Medical Systems) with a goal of 0.5 to 1.0 ml/kg/h and 680 to 800 ml/m², respectively. However, approximately 28 liters of intravenous fluid was administered over 17 h after the injury. The dosage was 1.86 times greater than the value estimated by the Parkland formula. The IAP and peak inspiratory pressure (PIP) was 20 mmHg and 37 cmH₂O, respectively, indicating s-ACS. He underwent escharotomies of the chest and abdominal surface into the fascial layer for decompression at the bedside. Although his respiratory condition was improved by decreasing the IAP and PIP to 15 mmHg and 21 cmH₂O, respectively, he was anuric and incapable of recovering from acute kidney injury (AKI), in spite of the induction of continuous hemodiafiltration (CHDF). The patient received albumin and fresh frozen plasma 6h after the burn injury, but fluid volume over the initial 24 h was approximately 31.7 liters, equal to 6.6 ml/kg/%TBSA, which was significantly greater than predicted.

All of the burned tissue deteriorated to deep burns soon after his admission. Although he underwent extensive debridement and skin grafting using five courses of autografts and allografts over the course of his hospital stay, he died on day 60 due to multiple organ dysfunction syndrome (MODS).

Case 2
A 72-year-old male with a past medical history of hyperlipidemia was transferred to the emergency department with a scald burn except for the back and left foot due to falling into a hot spring that was about 90℃. The %TBSA was 77 and the depth was only second degree burn including SDB 15% and DDB 62% without inhalation injury. The BI was 38.5 and PBI was 110.5 (Fig. 2). He had fairly clear consciousness on admission, a body temperature of 38.5℃, respiratory rate of 21 breaths per minute, heart rate of 77 regular beats per minute, blood pressure of 166/102 mmHg, and O₂ saturation of 100% under 100% oxygen. His laboratory analysis showed mild hemolysis, hemoconcentration and high lactate (pH 7.414, HCO₃⁻ 21.6 mmol/L, BE -1.7 mmol/L, Lactate 7.2 mmol/L). He was intubated after admission to the ICU, because the Parkland formula indicated that he required infusion of 17 liters fluid during the initial 24 h after the injury. He had difficulty in maintaining his hemodynamic status several hours after admission, and his urine output was 0.5 to 1.0 ml/kg/h. Administration of approximately 31 liters of intravenous fluid over the 20 h after the injury resulted in an IAP of 99 mmHg and PIP of 48 cmH₂O, and progression to s-ACS. The infused volume for resuscitation was about twice as much as the value estimated by the Parkland formula. Emergency decompression by laparotomy was required due to cardiopulmonary failure, and renal impairment, or lactic acidosis. Decompressive laparotomy allowed the patients to temporarily recover from cardiopulmonary and renal dysfunction or lactic acidosis. The resuscitation volume during the initial 24 h was approximately 37.4 liters of intravenous fluid, and equivalent to 8.8 ml/kg/% Table 3 The revision of institutional fluid resuscitation protocol

<table>
<thead>
<tr>
<th>Is the total burn surface area more than 60%?</th>
<th>Parkland formula 4 ml/kg/%TBSA; crystalloid alone</th>
<th>Original formula 2 ml/kg/%TBSA; colloid: crystalloid = 1:1</th>
</tr>
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<tbody>
<tr>
<td>No</td>
<td>Yes</td>
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Strict IAP monitoring if the volume of fluid resuscitation ≥ 250 ml/kg/24h.
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TBSA. However, his condition continued to deteriorate and he died four days after the injury due to septic shock.

Revision of the institutional fluid resuscitation protocol

Each burn case had a different etiology and pathophysiology. s-ACS resulted from massive fluid resuscitation in the first case, in addition to diminishing abdominal wall compliance due to the extensive deep burn. The second case led to s-ACS due to the large volume of fluid resuscitation using crystalloid.

There is a high mortality rate in extensive burn patients if complicated with s-ACS, and the prevention and early recognition of s-ACS is extremely important. Therefore, a new institutional strategy was established to prevent s-ACS in extensive burn patients with high risk of s-ACS, which required an estimated fluid resuscitation in excess of 250 ml/kg/24h or those with more than 60% TBSA. The revised protocol may reduce the risk for the onset of s-ACS by using colloid from the early post-burn period. In addition, there was strict monitoring of IAP for high risk of s-ACS and an original formula for those with more than 60% TBSA (Table 3).

Discussion

Although the Parkland formula is utilized in practically every burn center, extensive burn patients often receive far more fluid than the volume predicted by the Parkland formula. This phenomenon is termed fluid creep.

How can "fluid creep" be avoided? It is important to consider the timing of colloid use in fluid resuscitation. Recent studies demonstrate that the appropriate early use of colloids for burn patients reduce the incidence of significant adverse outcomes. Dulhunty et al. reported that the protective effect of colloid for the reduction of edema is associated with protection against extremity compartment syndrome and renal system failure in major burned patients. In addition, O'Mara et al. reported the results of prospective and randomized trial demonstrating that a larger volume of fluid resuscitation would elevate IAP proportionally in burn patients with greater than 50% TBSA and the rate of the increase in the IAP is lower in the plasma group that was resuscitated using a combined crystalloid and colloid regimen, than in the crystalloid group that was resuscitated using Ringer's solution alone. They also reported that there is an increase in the IAP above 25 mmHg in patients requiring 600 ml/kg in the plasma and 350 ml/kg in the crystalloid.

In addition, it is necessary to conduct close monitoring of the IAP for early diagnosis of IAH. Oda et al. demonstrated that the administration of a fluid volume of more than 300 ml/kg crystalloid during the first 24 h to maintain urine output at 0.5 to 1.0 ml/kg/h might risk the development of s-ACS in patients with a burn injury of 63-99% TBSA. Another report recommended the serial measurement of IAP in any burn patients that receives 250 ml/kg or more of fluid resuscitation, since the critical volume associated with progression to s-ACS is approximately 300 ml/kg over a 24 h period. Therefore, the administration of 4 ml/kg/%TBSA according to the Parkland formula assumes a %TBSA of 62.5%.

A wide variety of fluid protocols are employed to resuscitate burn patients in individual burn units, thus the concept of a permissive hypovolemic approach for severe burns should be widely accepted. Arlati et al. compared the outcome of 12 patients resuscitated according to the Parkland formula, with that of 12 patients resuscitated using permissive hypovolemia. They concluded that the permissive hypovolemia allowed for infusion of a lower volume infusion in the initial 24 h (4.6 ± 0.3 ml/kg/%TBSA vs. 3.2 ± 0.7 ml/kg/%TBSA) and significantly lower multiple organ dysfunction scores.

Chung et al. developed an impressive protocol for severe burn in Operation Iraqi Freedom that makes early use of albumin soon after admission if the projected 24 h resuscitation requirements exceed 6 ml/kg/%TBSA to prevent the adverse effects of overresuscitation. In addition, monitoring IAP or hemodynamic parameters frequently decreased the percentage of patients with greater than 20% TBSA requiring decompressive laparotomies for s-ACS from 13% to 0. The UK and US protocols have moved away from the Parkland formula towards formulas with lower fluid volume requirements in the initial 24 h, using of 2 ml/kg/%TBSA as a starting point.

The current study introduced an original formula for fluid resuscitation within the first 24 h for those
with a high-risk of progression to s-ACS.

The protocol classified the patients using the following criteria: 1) patients received crystalloid alone at 4 ml/kg/%TBSA according to the Parkland formula if the %TBSA was less than 60%, 2) patients received a one-to-one combination with colloid and crystalloid at 2 ml/kg/%TBSA if the %TBSA was more than 60%, as it was called the original formula.

The revised protocol requires strict monitoring of the IAP, since early recognition and intervention are essential in burn patients with high risk of s-ACS requiring large volume of fluid resuscitation, especially in excess of 250 ml/kg/24h.

In addition, urgent decompression should be performed to prevent the development of s-ACS, if diminishment abdominal wall compliance due to all-round deep burn is recognized on admission.

Conclusion

The revision of fluid resuscitation protocol may contribute to early diagnosis and prevention of s-ACS. A multicenter prospective randomized trial would be beneficial to definitively establish the efficacy of the protocol for extensive burn patients.

References

6) Dulhunty JM, Boots RJ, Rudd MJ, et al.: Increased fluid resuscitation can lead to adverse outcomes in major-burn injured patients, but low mortality is achievable. BURNS 34: 1090–1097, 2008