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Effect of Smoke Inhalation Injury on Fluid Requirement in Burn Resuscitation

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ABSTRACT

The effect of smoke inhalation injury on fluid requirement was assessed retrospectively. A total of 131 burn patients were classified into two groups: burn patients with smoke inhalation injury (Group IB: 73 patients) and burn patients without inhalation injury (Group B: 58 patients). Fluid resuscitation was commenced according to the Parkland formula and the infusion rate was modified to meet the main resuscitation goal of an hourly urine output of 1.0 to 2.0 ml/kg. Regression analyses were performed on the volume of fluid administered during the initial 24 hours after injury by burn size for each group. The linear equations obtained were Y (ml/kg/24 hrs) = 71.0 + 5.08 × %TBSA (Group IB) and Y = 39.7 + 5.14 × %TBSA (Group B). A substantial effect of inhalation injury on fluid requirement was speculated to be reflected in a y intercept difference of about 30 ml/kg/24 hrs. Thus, an increase in the fluid requirement related to the presence of inhalation injury was found to be independent and additional to burn injury.

Key words: *Smoke inhalation injury, Burn resuscitation, Fluid requirement, Resuscitation formula*

Intravascular volume depletion, derived from the increased permeability of the capillary bed accompanying substantial interstitial fluid accumulation, is the prime critical condition in burns. This critical problem has been well treated with volume restoration formulas. The most commonly used burn resuscitation regimen is the Parkland formula, which prescribes 4 ml of lactated Ringer's solution per kilogram of body weight of the patient per percent of burn to be administered during the first 24 hours after burn injury[2,19].

However, with advances in burn management, the magnitude of the problem caused by smoke inhalation injury has become apparent. Many authors have reported that the combination of smoke inhalation injury and burn injury produces a marked increase in mortality and morbidity compared with either injury alone[1,2,7,10]. Also, in addition to direct injury to the respiratory system, an indirect but serious systemic effect of smoke inhalation injury, namely an increase in initial fluid requirement and hemodynamic instability in early burn resuscitation has been reported[3,6,13,16,17]. The need to establish a formula for smoke inhalation injury has been proposed, but the need has not yet been fulfilled. In order to elucidate the effect of the smoke inhalation on fluid requirement, a retrospective analysis was conducted.

PATIENTS AND METHODS

From January 1989 through June 2001, 242 burn patients were treated at the Intensive Care Unit (ICU) in Hiroshima University Medical Hospital. Of these 242 patients, 131 patients were enrolled in this study while 111 patients were excluded for the following reasons:

1. They were younger than 14 years of age: 46 patients were excluded.
2. Admission later than 2 hours after injury: 23 patients were excluded.
3. Imprecise or imperfect information regarding administered fluid volume and urine volume during the 24 hours after injury: 16 patients were excluded.
4. Concomitant complications that affect urine output or fluid demand: 3 patients were excluded, with 2 suffering electrical injury and 1 heat stroke.

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5. Resuscitation resigned within 24 hours: 23 patients were excluded.

Admission to any hospital before transfer to our institute was accepted if initial treatment such as fluid administration had been commenced. Of 131 patients, 68 were admitted directly to our institute while 63 patients were transferred from 31 regional hospitals in and around Hiroshima prefecture.

Treatment was conducted by ICU staff and dermatologists. The depth and extent of burn were assessed and recorded according to Lund and Browder's diagram[5]. Initial fluid requirement was estimated according to the Parkland formula and the rate of fluid administration was flexibly modified according to the clinical response of blood pressure, heart rate and urine output of the patient[5]: an hourly urine output of 1.0 to 2.0 ml/kg was used as the principal resuscitation guideline. Lactated or acetated Ringer's solution was mainly used for replacement. Maintenance fluid was also employed in minor burn patients who did not develop systemic edema. Colloids were commenced at about 8 hours after injury when indicated. Corticosteroids were not administered in initial treatment for burn injury or inhalation injury.

The presence of smoke inhalation injury was suspected if they were involved in a closed space accident, or if facial burns, singed nasal hair, soot in sputum, hoarseness and/or stridor were present. Reference was also made to other information such as orolaryngeal observation, arterial blood gas analysis and chest roentgenologic findings. A final diagnosis was established by bronchoscopic findings such as mucosal erythema, edema, ulceration and/or deposition of carbon particles on the tracheobronchial wall. Tracheal intubation and mechanical ventilatory support were indicated when the burn exceeded 60% of the total body surface area (%TBSA) or when the existence of smoke inhalation injury was suspected. Often prophylactic intubation was also established when the development of airway and cardiopulmonary complications were feared[14]. Wounds were treated with topical antimicrobial creams and cleansed daily by a dermatological team. Escharotomy was performed on admission if dangerous thoracic constriction or malperfusion in peripherals was observed. The selected 131 patients were divided into two groups according to the diagnosis of inhalation injury: burn patients with inhalation injury (Group IB) and burn patients without inhalation injury (Group B).

To compare the characteristics of the patients in the two groups, the following information was scanned from medical records: age, gender, height, weight and body surface area. To compare the severity of the burn, %TBSA burned recorded in the diagram was also extracted, and the burn index (half of second degree burn + third degree burn) and prognostic burn index (burn index + age) were calculated for each patient. Elapsed time to admission to any hospital after injury was also sought because a time delay in treatment has been reported to affect the fluid requirement[14,16]. The amount of fluid administered and the urine output within 24 hours after injury were extracted from ICU flow sheets and compared between the two groups. The obtained fluid volume was plotted on a scatter diagram against %TBSA burned, and regression analysis was performed for each group. The mortality rate and the incidence of acute lung injury or acute adult respiratory distress syndrome (ALI-ARDS) were also compared.

Statistical analysis

Differences in parametrical values such as height, weight and body surface area were analyzed by Student's unpaired t-tests. Differences in non-parametrical values such as age, %TBSA burned, burn index, prognostic burn index and elapsed time to treatment were analyzed by Mann-Whitney U-tests. Significant differences in gender ratio, mortality and incidence of ALI-ARDS were tested by Chi-square tests. Statistical significance was defined as $p < 0.05$. All values are given as means ± standard deviation (Table 1). The range and median of chief non-parametrical values such as age, %TBSA burned and elapsed times to admission are given in Table 1.

RESULTS

Of the 131 patients, 73 belonged to Group IB and 58 to Group B. The demographics and clinical characteristics of the patients in the two groups are shown in Table 1. There was no significant difference in age, gender ratio and physical status such as height, weight and body surface area between Group IB and Group B. Percent of TBSA burned ranged from 0 to 86.0% in Group IB and from 3.0 to 96.5% in Group B; mean and standard deviation were 28.9 ± 23.9% and 37.0 ± 24.3%, and the median was 21.0% and 34.0% in Group IB and Group B, respectively. These distributions of %TBSA burned were skewed (right tailed) and there was statistically significant difference between the two groups ($p = 0.035$). No difference in burn index and prognostic burn index was demonstrated. The elapsed time to admission to any hospital was similar. Hourly urine output obtained during the initial 24 hours after injury was 1.8 ± 0.7 ml/kg and 1.6 ± 0.9 ml/kg in Group IB and Group B, respectively, with no significant difference between the two. Differences in mortality rate did not reach statistical significance, but the incidence of ALI-ARDS was higher in Group IB compared with Group B. The criterion of ALI-ARDS applied in this report is a rapidly deteriorating pulmonary complication where the ratio of arterial oxygen pressure to fraction of inspired oxygen (PaO_2/FiO_2 ratio) decreases below 200 with

Table 1. Demographics and clinical characteristics of Group IB and Group B

	Group IB	Group B	P values
Number of patients	73	58	
Age mean ± SD	49.1 ± 19.8	53.6 ± 21.6	
range (median)	15–91 (49)	15–91 (50.5)	n.s.
Gender (male/female)	48/25	33/25	n.s.
Physical status			
Height (cm)	162.6 ± 8.2	160.1 ± 9.6	n.s.
Weight (kg)	59.4 ± 11.0	57.7 ± 10.9	n.s.
Body surface area (m^2)	1.65 ± 0.18	1.60 ± 0.20	n.s.
Severity of burn			
%TBSA burned (%) mean ± SD	28.9 ± 23.9	37.0 ± 24.3	
range (median)	0–86.0 (21.0)	3.0–96.5 (34.0)	0.035
Burn index*	31.6 ± 21.0	24.6 ± 19.7	n.s.
Prognostic burn index†	70.4 ± 28.8	77.8 ± 29.2	n.s.
Time to admission (min) mean ± SD	44.0 ± 23.0	48.4 ± 30.4	
range (median)	10–114 (35)	10–110 (42.5)	n.s.
Urine output in first 24hrs (ml/kg/hr)	1.8 ± 0.7	1.6 ± 0.9	n.s.
Deaths (mortality rate)	13 (17.8%)	9 (15.5%)	n.s.
ALI-ARDS	12 (16.4%)	3 (5.2%)	0.044

* Burn index = second degree burn (%) × 1/2 + third degree burn (%)
† Prognostic burn index = burn index +age

emerging consolidation in the chest roentogenogram[4].

Each set of data pairs of %TBSA burned and amount of fluid administered was represented as points on a scatter diagram with the extent of TBSA burned as independent variables on the x-axis and the amount of fluid requirement as dependent variables on the y-axis (Fig. 1). The linear equations obtained by regression analysis with the least square method were as follows:

Group IB:

Fluid administered (ml/kg)
= 71.0 + 5.08 × % TBSA burned (r = 0.859)
... (1)

Group B:

Fluid administered (ml/kg)
= 39.7 + 5.14 × % TBSA burned (r = 0.902)
... (2)

DISCUSSION

The optimal volume of fluid resuscitation in the presence of smoke inhalation injury is still being debated. The proceedings of the National Institute of Health (NIH) Workshop on Burn Management stated that the ideal volume of fluid for burn resuscitation would be normalizing circulatory variables while minimizing organ dysfunction such as pulmonary edema[14]. This guideline recommended fluid restriction in the face of combined burn and smoke inhalation injury. However, the uniform experience in burn centers is that inhalation injury significantly increases fluid requirements for adequate resuscitation compared with patients with burn injury alone[13,17].

Two linear equations (1) and (2) obtained by regression analysis were geometrically parallel with a y intercept difference of about 30 ml/kg. It is suggested that this difference is derived from a single different condition in grouping: whether inhalation injury is present or not. Then, 30 ml × kilograms of body weight was the additional fluid required for the initial 24 hours accompanying inhalation injury.

The proportional effect of smoke inhalation injury and that of cutaneous injury on fluid requirement can be explained by these equations.

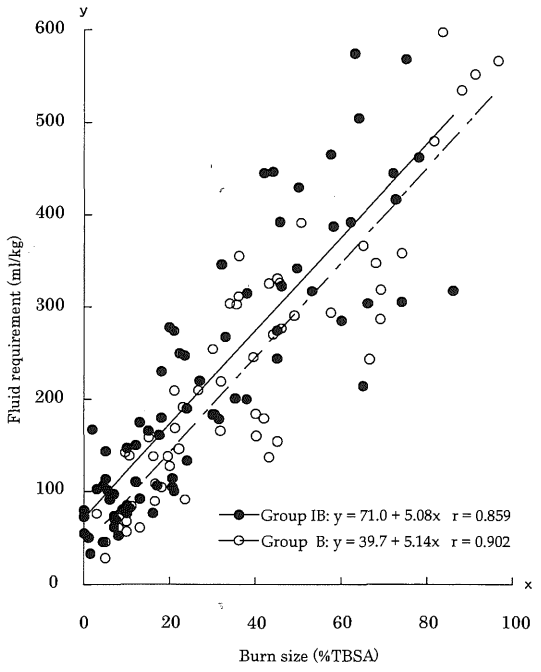

Fig. 1. Scatter diagram of fluid requirement by burn size during the first 24 hours after burn. The solid circle represents a patient in Group IB. The open circle represents one in Group B. The two regression lines obtained are also depicted in the diagram.

If a patient suffered severe burn injury, the effect of y intercepts is relatively small in the calculation; whether smoke inhalation exists or not is of relatively little concern. Thus these y intercepts can be neglected if utilization of the equations is limited only to severe burns; this is the *Parkland formula*. On the other hand, if the burn size is small, the relative effect of y intercepts is more prominent. For example, when a patient weighing 60 kg suffers smoke inhalation injury without cutaneous burn, according to equation (1), the fluid required for initial resuscitation is calculated to be 4,200 ml for the initial 24 hours. At the same time, when the patient is free from inhalation injury and free from cutaneous burn, according to equation (2), it is calculated to be 2,400 ml for the initial 24 hours, which coincides with the daily maintenance fluid requirement of a healthy adult of the same weight. Thus twice as much fluid is required during the first 24 hours for patients with inhalation injury and without cutaneous burns. These equations are applicable to any burn size.

Another interpretation of the equation revealed the nature of insults. The effects of smoke inhalation injury and that of cutaneous burn on the fluid requirement are clearly divided in the equation. Smoke inhalation injury can be regarded as an independent and additional insult to cutaneous burn.

The coefficient of about 5 in the equations is slightly greater than that of 4 in the Parkland formula; the larger coefficient is supposedly due to a higher resuscitation endpoint of 1.0 to 2.0 ml/kg/hr urine output, which is recommended to be 0.5 to 1.0 ml/kg/hr in the formula. We have never experienced a resuscitation failure that results in acute renal failure or liver failure with this regimen, and the incidence of complicating ALI-ARDS was similar to that of other reports[17]. These coefficients can alter if the applied resuscitation regimen and resuscitation endpoint are different, probably with simultaneous alteration in y intercepts.

Scheulen and Munster reported that a group of burn patients with inhalation injury required a 31.4% increase in their fluid requirement compared to the non-inhalation group[17]. However, this rate of increase in the fluid requirement was calculated throughout all the participants. Their result simply showed the total increase in fluid requirement, but did not fully document the relationship between the amount of fluid administered and the size of the accompanying burn with smoke inhalation injury. Navar et al reported a total 44% increase in the fluid requirement with a detailed description according to the patient's age and burn size[13]. There is a similar tendency found in their result that the greater the burn size, the smaller the proportion of fluid increase compared with the total fluid administered with the existence of smoke inhalation injury. However, they did not refer to this tendency and the reason for it is explained by the pair of equations in this report, as described above.

What are the most reliable techniques for determining the extent of inhalation injury was the first question asked at the Smoke Inhalation Section in the Second Conference on Supportive Therapy in Burn Care[8]. We made our diagnosis of smoke inhalation injury by physical examination and by bronchoscopic findings. The diagnostic accuracy of these methods is now being debated[11,12,15]. With these methods, it is difficult to make a clear distinction between simple upper airway injury and smoke alveolar injury, or the ratio of their coexistence[8]. Thus, we treated these two types of airway injury together in this report as smoke inhalation injury. In our clinical experience, alveolar injury produces enough harm to cause a systemic response, while upper airway injury resolves itself within a local edema. Lalonde, Demling and their associates clearly demonstrated in a sheep model that smoke inhalation can cause an increase in the degree of burn edema[9] and that graded increases in smoke inhalation injury can cause proportional increases in fluid requirement and oxygen consumption[6]. It is essential to distinguish these two types of airway injury and to estimate the extent of each injury in making a precise assessment of the effect of inhalation injury on the modification of systemic response. If a new method evaluating the magnitude of smoke inhalation should become available, further precise study would be possible.

In conclusion, there is clearly an increase in fluid requirement in patients with smoke inhalation injury compared to those without inhalation injury. The proportion of the increase in fluid requirement can be given by a pair of linear equations with the same coefficient of slope and different and larger y intercepts with smoke inhalation injury.

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