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# The Volume Limit in Fluid Resuscitation to Prevent Respiratory Failure in Massively Burned Children without Inhalation Injury

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## ABSTRACT

We evaluated the accurate fluid requirement to prevent respiratory failure during the postresuscitation period in the resuscitation of massively burned children without inhalation injury. Forty-nine children were treated by similar fluid resuscitation and physiologic support protocols. Using a retrospective chart review, the children were divided into three groups as follows: Group N (no lung injury, n = 33, 41.4 ± 18.7%TBSA burned), Group M (mild-to-moderate lung injury, n = 11, 73.7 ± 17.1%TBSA burned) and Group S (severe lung injury, n = 5, 67.2 ± 16.6%TBSA burned). Information about fluid resuscitation during the first 24 hr post-injury was collected and compared among the three groups. There was no significant difference in the hourly urine output and the resuscitation volume estimated by body weight and burn size among the groups. The volumes estimated by ml/kg/%TBSA burned were 7.0 ml/kg/%TBSA burned, 8.0 ml/kg/%TBSA burned, and 9.4 ml/kg/%TBSA burned in Groups N, M, and S, respectively. According to the fluid volume estimated by the burn index (BI; 1/2 of % second-degree burns plus % third-degree burns), the volumes were 13.8 ± 4.0ml/kg/BI, 14.4 ± 4.4ml/kg/BI, 18.8 ± 3.7ml/kg/BI in Groups N, M, and S, respectively (Group N < Group S, $p < 0.05$). There was a significant positive correlation between the maximum respiratory index ($AaDO_2/PaO_2$) during the first week and the initial total volume administered (ml/kg/BI). These findings indicated that the fluid requirements to prevent postresuscitation respiratory failure in massively burned children might be estimated according to the depth of burned area in addition to body weight and burn size.

***Key words:*** *Pediatric thermal injury, Respiratory failure, Fluid resuscitation*

It is well known that young children require a prescribed amount of fluid resuscitation for smaller burns, and more fluid for resuscitation than adults[7]. Compared to adults, children have high rates of water exchange in relation to total body water. Children also require relatively larger volumes of urine for the excretion of waste products and insensible water losses. The volume necessary to resuscitate burned children depends on injury severity, age, physiologic status, and associated injury. Consequently, the volume predicted by a resuscitation formula for burns must commonly be modified according to the individual's response to therapy. However, most fluid resuscitation formulas have been designed to estimate volume based on body weight and the percentage of body surface burned. These formulas do not take into consideration the fluid needed to replace burn-depth-related losses. They tend to underhydrate deep burned children and to overestimate fluid requirements for the massively superficial dermal-burned children. Underhydration can prolong the state of shock and induce renal failure, while overhydration fosters pulmonary congestion.

In general, the postresuscitation period is the ideal time to initiate aggressive wound excision and closure[10,16]. For this purpose, the patient must be hemodynamically stable and safe from hypovolemia or uncontrolled respiratory dysfunction in this period. Respiratory dysfunction is a common early complication of smoke inhalation, but pulmonary problems are also common in the absence of smoke inhalation injury. Major fluid balance problems develop during the postresuscitation period and fluids shifting back into the circulatory system from tissue edema can lead to hypervolemia, which can aggravate pulmonary edema.

In this study we made an accurate prediction of

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resuscitation fluid volume based on body weight, burn size and burn depth in massively burned children without smoke inhalation injury in order to prevent pulmonary congestion during the postresuscitation period after injury.

## SUBJECTS AND METHODS

Forty-nine children less than 12 years of age having greater than 30% total body surface area (TBSA) second-degree burns and/or with greater than 10% of TBSA third-degree burns were studied. They were admitted to the Division of Emergency and Critical Care Medicine of Hiroshima University Medical Hospital in Japan from January 1979 through December 1997 on the first day of their injuries. Patients with smoke inhalation injuries were excluded from this study. Inhalation injury was diagnosed by the presence of facial burns with a history of a closed space injury, sooty sputum, bronchoscopic evidence of airway erythema, or blisters in the trachea or bronchus. All children survived the first four weeks after sustaining injuries. Two patients subsequently died. Death was caused by sepsis and multiple organ dysfunction syndrome.

All children were treated with similar fluid resuscitation and physiologic support protocols. The ICU staff directed the acute treatment of all patients with thermal injuries using conventional therapeutic approaches. The percent body surface area of the burn and its distribution were recorded with a Lund and Browder diagram. Fluid resuscitation was accomplished using 5 to 7 ml/kg/%TBSA burned of lactated Ringer's solution during the first 24 hr post-injury. Colloid solution using heated human plasma or fresh frozen plasma was given after three hours following burns and 0.5 to 1 ml/kg/%TBSA burned of colloid was administered during the first 24 hr post-injury. Additional modifications of fluid administration were made by the ICU staff and were guided by the patient's hemodynamic status and urine output. 2 to 3 ml/kg of hourly urine output was used as the principle resuscitation guideline. Wounds were initially debrided and treated with alternating topical antimicrobial creams and cleansed daily. Surgical excision and autografting were carried out from the first week when indicated and when the patient's condition was stable enough to allow general anesthesia and surgery. Since 1989, prophylactic tracheal intubation and mechanical ventilatory support have been indicated when burns exceed 60%TBSA, and there are facial burns, even if there is no evidence of inhalation injury. Corticosteroids were not administered for treatment of burn injury.

Using a retrospective chart review, the children were divided into three groups according to the evidence of respiratory dysfunction from days 2 through 7 post-burn injuries. Criteria for the diagnosis of respiratory dysfunction were determined from lung injury scores[15)] based on radiographic appearance, degree of hypoxemia and level of positive end-expiratory pressure. Group N (no lung injury) consisted of thirty-three children with zero lung injury scores. Group M (mild-to-moderate lung injury), eleven children with mild-to moderate lung injury, whose score ranged from 0.1 through 2.5. Group S (severe lung injury) consisted of five children with scores greater than 2.5.

In order to detect the causes of respiratory failure, the following information was collected from each group and then compared among the three groups. 1) age in years, 2) percentage of TBSA burned, 3) burn index (BI; a half of the second-degree burns of TBSA plus the third-degree burns of TBSA), 4) the maximum respiratory index (A-aDO$_2$/PaO$_2$) during the first week, 5) total fluid volume administered (ml/kg/%TBSA burned and ml/kg/burn index) during the first 24 hr after the burn, 6) total amount of colloid replacement (ml/kg/%TBSA burned/24 hr), and 7) the minimum value of serum protein and albumin concentration during the first week after injuries.

All values in the tables and figures were given as means ± standard deviation. Non-parametric Student T-test analysis was used where appropriate to evaluate the statistical significance of the differences. P values less than 0.05 were considered to indicate statistical significance.

## RESULTS

Patient characteristics are listed in Table 1. There was no difference in age among the three groups. Although Group M and Group S had greater burn sizes than Group N, there was no sig-

**Table 1.** Characteristics of total patients ingroups

| | Group N (no lung injury) n = 33 | Group M (mild-to-moderate lung injury) n = 11 | Group S (severe lung injury) n = 5 |
|---|---|---|---|
| Age (years) | 4.9 ± 3.9 | 3.9 ± 3.5 | 4.8 ± 3.9 |
| %TBSA burned | 41.4 ± 18.7 | 73.4 ± 17.1* | 67.2 ± 16.6* |
| Burn index † | 22.2 ± 12.5 | 44.5 ± 20.0* | 33.7 ± 8.1 |

All values are mean ± standard deviation
* vs Group N, $p < 0.05$
† Burn index: 1.2% TBSA II° burn + % TBSA III° burn

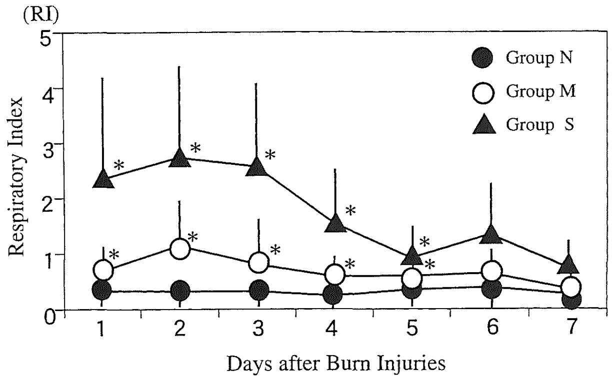

**Fig.1.** Respiratory index (RI; $AaDO_2/PaO_2$) during the first week after burns. The results of RI in Group N were within the normal range during this period. The RI in groups M and S increased significantly until 5 days postinjuries.

nificant difference in the burn size between Group M and Group S. The burn index in Group M was greater than in Group N. In contrast, there was no difference in the burn index between Group N and Group S.

The respiratory index during the first week following burns in each group is shown in Fig. 1. The respiratory index in Group N was within the normal range during this period. The respiratory index in both Group M and Group S increased significantly until 5 days following burns, as compared with those in Group N.

Hourly urine outputs and the total amount of colloid replacement (ml/kg/%TBSA burned/24hr) were compared among the three groups (Table 2). There was no apparent difference among the groups. The total fluid volume administered during the first 24 hr after the burn was estimated by ml/kg/%TBSA burned and ml/kg/burn index, and was compared among the three groups (Table 2). The volumes estimated by ml/kg/%TBSA burned were 7.0 ml/kg/%TBSA burned, 8.0 ml/kg/%TBSA burned, and 9.4 ml/kg/%TBSA burned in Groups N, M, and S, respectively. No significant difference could be shown among the three groups in the total fluid volume estimated by ml/kg/%TBSA burned. In contrast, the volume estimated by ml/kg /burn index in Group S was larger than that in Group N. There were no significant differences in the volumes estimated by ml/kg /burn index either between Group N and Group M or between Group M and Group S. The averages of the volume estimated by ml/kg/burn index were 13.8 ml/kg/burn index, 14.4 ml/kg/burn index, and 18.8 ml/kg/burn index in Groups N, M, and S, respectively.

Figure 2 shows a correlation between the maximum respiratory index during the first week and the initial total fluid volume administered (ml/kg/burn index) for patients. There was a significant positive correlation between the maximum respiratory index and the initial total volume.

The minimum values of serum protein and albumin concentration during the first week after injury in Group S were significantly lower than those in Group N (Table 3).

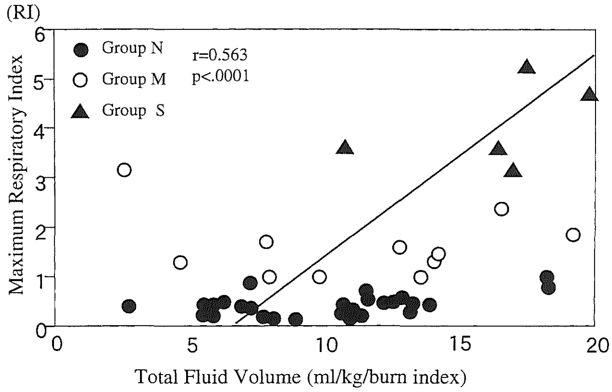

**Fig. 2.** Comparison of the maximum respiratory index during the first week postinjuries versus the initial total fluid volume administered (ml/kg/burn index). There was a significant correlation between the maximum respiratory index and the initial total fluid volume.

**Table 2.** Comparison of volumes of hourly urine output, colloid solution and total fluid administered in the 24 hours postinjury

| | Group N<br>(no lung injury)<br>n = 33 | Group M<br>(mild-to-moderate lung injury)<br>n = 11 | Group S<br>(severe lung injury)<br>n = 5 |
|---|---|---|---|
| Hourly urine volme (ml/kg) | 2.68 ± 1.55 | 3.83 ± 2.40 | 3.27 ± 1.38 |
| Colloid volme (ml/kg/%TBSA burned) | 0.73 ± 0.72 | 1.04 ± 0.41 | 1.19 ± 0.41 |
| Total fluid volme (ml/kg/TBSA burned) | 7.01 ± 2.57 | 8.03 ± 1.81 | 9.43 ± 1.88 |
| Total fluid volume (ml/kg/burn index) | 13.77 ± 3.99 | 14.38 ± 4.63 | 18.77 ± 3.66* |

All values are mean ± standard deviation
* vs Group N, $p < 0.05$

**Table 3.** Comparison of minimum concentration for serum total protein and albumin during the first week postinjury

| Substance | Group N<br>(no lung injury)<br>n = 33 | Group M<br>(mild-to-moderate lung injury)<br>n = 11 | Group S<br>(severe lung injury)<br>n = 5 |
|---|---|---|---|
| Total protein (g/dl) | 3.66 ± 1.15 | 4.35 ± 0.97 | 2.56 ± 0.42* |
| Albumin (g/dl) | 2.37 ± 0.75 | 2.71 ± 0.77 | 1.92 ± 0.42* |

All values are mean ± standard deviation
* vs Group N, $p < 0.05$

## DISCUSSION

Although the mortality rates for burned patients have improved in recent years, infants and young children do not tolerate thermal injuries as well as adults[7)]. Many investigators have reported that pediatric burned patients required more fluid (per kilogram per percent burn) for resuscitation than adults for comparable injuries and that the formulas for adults were not optimal for hydration in children[4,8,13)]. A number of explanations have been proposed to explain the difference. Estimation of fluid volume on the basis of body weight in adults might be inaccurate in burned children because the surface area to weight ratio in children is larger than that in adults. Another problem with using formulas for adults stems from the fact that the formulas in adult patients made no separate allowances for maintenance fluid requirements. For these reasons, the formulas used for adult burned patients should be changed for pediatric patients. Some investigators proposed the use of fluid requirements based on body surface area in burned children[2)]. Our fluid resuscitation protocols for burned children follow the modified Parkland formula (Baxter formula). The estimates of the fluid volume for the first 24 hr post-injury were based on the weight of patient, the percent of TBSA burned and the maintenance fluid requirements. According to these protocols, total fluid requirements for the first 24 hr postburn can be calculated on the basis 4 ml/kg/%TBSA burned, plus the volume of maintenance fluid requirements, 1500 ml/m$^2$ BSA per 24 hr. This is similar to the formula used at the Shriners Burns Institute in the Cincinnati Unit[17)].

According to the Parkland formula, protein replacement is not begun until the second day of postburn. However, in pediatric patients, adding plasma or albumin to resuscitation fluids has been recommended by many investigators[3,5)]. Colloid-containing fluids during the first 24 hr post-injury restore hemodynamics with lower infusion volumes, which minimize edema formation and maintain cardiac, pulmonary, renal, and gastrointestinal functions. Some investigators recommend that albumin be added to resuscitation fluids from the onset of resuscitation[3)]. However, in our protocol, albumin or plasma was withheld during the first 3 hr after the burn because extravasation and water accumulation occur most rapidly within the first 3 hr postburn and the portion of albumin that leaks into the tissues might be detrimental to the patients.

With regard to the choice of resuscitation guideline, some investigators have used hourly urine volume while others[9)] have recommended frequent measurements of hematocrit to determine hemoconcentration. Invasive monitoring, such as measurement of the central venous pressure, cardiac index, and ventricular stroke work index, were used at some institutions[12)]. However, this type of monitoring may introduce additional morbidity for burned children. We used hourly urine volume output to determine hydration. In adult patients, 0.5 ml /kg to 1 ml/kg of hourly urine output has been used as the principle resuscitation guideline. However, children normally produce larger volumes of urine for excretion of waste products. Moreover, the surface area to weight ratio is greater in children than in adults, and the lower the age of the patients the greater the quantities of hourly urine per kilogram of body weight[14)]. The guide used for adults is inadequate for children. We used 2 ml/kg/hr to 3 ml/kg /hr of urine output as a guide for pediatric patients.

The present study demonstrated that some burned children without inhalation injuries might experience severe respiratory failure after fluid resuscitation using current fluid resuscitation protocols. This may be explained in part by the difference in burn size of the children who developed severe respiratory failure (Group S) and those with no evidence of respiratory failure (Group N). According to many formulas of fluid resuscitation for burn patients, including our protocols, average fluid requirements (ml/kg/%TBSA burned) are estimated only by body weight and burn size, and do not differentiate between second-degree burns or third-degree burns. There was no significant difference in resuscitation volumes between Group S (67.2%TBSA burned) and Group M (73.7% TBSA burned) as estimated burn size. However, Group S (severe respiratory failure) had less third-degree burns than Group M (mild respiratory dysfunction). According to the total fluid volume estimated by the burn index, children in Group S received an average of 18.8 ml/kg/burn index for the first 24 hr post-injury and developed severe respiratory failure. This volume was larger than that in

Group N. In contrast, Group M, children with massive third-degree burns, received an average of 14.4 ml/kg/burn index for the first 24 hr post-injury, which was similar to that in Group N, and suffered only mild respiratory dysfunction. These data indicate that when the estimates of fluid volume for the first 24 hr post-injury were based exclusively on the size of the burn, some patients with massive second-degree burns had a risk of developing severe respiratory failure. This was supported by the fact that there was a significant positive correlation between the maximum respiratory index during the first week and the initial total volume administered (ml/kg/burn index).

The severity of burn injury is dependent not only on the extent of tissue damage but also on the depth of burns. The development of hemoglobinemia in third-degree burns may obstruct the renal tubules and lead to severe oliguria, and patients with massive third-degree burns require much more fluid[1,11]. On the other hand, when children with massive second-degree burns received fluids based only on burn size, they may receive too much crystalloid solution and develop severe hypoproteinemia and pulmonary edema[6].

During the resuscitation period, errors in fluid therapy may have grave consequences. Underhydration can prolong the state of shock and induce organ dysfunction, while overhydration fosters edema formation and pulmonary congestion. Accurate prediction of fluid requirements is particularly difficult in burned children because most fluid resuscitation formulas have been designed for adults and are based solely on body weight and percentage of body surface burned. In addition, these formulas do not take into account depth-related burns, thus they tend to underestimate fluid requirements for children with massive third-degree burns and overestimate them for massive second-degree burns. These findings suggest that fluid requirements should be estimated according to depth of burned area in addition to body weight and burn size in order to reduce overhydration and respiratory failure after resuscitation in massively burned children.

In conclusion, we recommend that the estimation of the fluid requirement is based on the depth of burned area in addition to body weight and burn size in order to reduce overhydration and pulmonary congestion after resuscitation in massively burned children.

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## REFERENCES

1. **Aikawa, N., Ishibiki, K., Okusawa, S., Yamamoto, S., Motegi, M., Sudo, M. and Abe, O.** 1984. Use of haptoglobin to prevent renal damage due to hemolysis in extensive third-degree burns. J. Burn. Care. Rehabil. **5:** 20–24.
2. **Carvajal, H.F.** 1977. Fluid therapy for the acutely burned child. Compr.Ther. **3:** 17–24.
3. **Carvajal, H.F.** 1985. Management of severely burned patients: Sorting out the controversies. Emerg. Med. Rep. **6:** 89–96.
4. **Carvajal, H.F.** 1988. Controversies in fluid resuscitation and their impact on pediatric populations, p.51–77. *In* H. R. Carvajal and D. H. Parks (eds.), Burns in children; Pediatric burn management, Year Book Medical Publishers, Chicago.
5. **Demling, R.H., Kramer, G.C. and Harms, B.** 1984. Role of thermal injury-induced hypoproteinemia on edema formation in burned and non-burned tissue. Surgery **95:** 136–144.
6. **Demling, R.H., Wong, C., Jin, L., Hechtman, H.H., Lalonde, C. and West, K.** 1985. Early lung dysfunction after major burns.: role of edema and vasoactive mediators. J. Trauma **25:** 959–966.
7. **Erickson, B.E. J., Merrell, S.W., Saffle, J.R. and Sullivan, J.J.** 1991. Differences in mortality from thermal injury between pediatric and adult patients. J. Pediatr. Surg. **26:** 821–825.
8. **Graves, T.A., Cioffi, W.G., McManus, W.F., Mason, A.D. Jr. and Pruitte, B.A. Jr.** 1988. Fluid resuscitation of infants and children with massive thermal injury. J. Trauma **28:** 1656–1659.
9. **Haynes, B.W. Jr.** 1968. Early fluid treatment of severe burns: Hemodynamic alternations and the use of dextran and blood. Ann. NY. Acad. Sci. **150:** 907–911.
10. **Herndon, D.N. and Parks, D.H.** 1986. Comparison of serial debridement and autografting and early massive excision with cadaver skin overlay in the treatment of large burns in children. J. Trauma **26:** 149–152.
11. **Herndon, D.N., Barrow, R.E., Traber, D.L., Rutan, T.C., Rutan, R.L. and Abston, S.** 1987. Extravascular lung water changes following smoke inhalation and massive burn injury. Surgery **102:** 341–349.
12. **Martyn, J.A., Snider, M.T., Farago, L.F. and Burke, J.F.** 1981. Thermodilution right ventricular volume; A novel and better predictor of volume replacement in acute thermal injury. J. Trauma **21:** 619–626.
13. **Merrel, S.W., Saffle, J.R., Sullivan, J.J., Navar, P.D., Kravitz, M. and Warden, G.D.** 1986. Fluid resuscitation in thermally injured children. Am. J. Surg. **152:** 664–669.
14. **Mlcak, R.P., Dimick, A.R. and Malcak, G.** 1996. Pre-hospital management, transportation and emergency care, p.33–43. *In* D. N. Herndon (ed.), Total Burn Care, Saunders, London.
15. **Murray, F., Matthay, M.A., Luce, J.M. and Flick, M.R.** 1988. An expanded definition of the adult respiratory distress syndrome. Am. Rev. Respir. Dis. **138:** 720–723.
16. **Thompson, P., Herndon, D.N., Abston, S. and Rutan, T.** 1987. Effect of early excision on patients with major thermal injury. J. Trauma **27:** 205–207.
17. **Warden, G.D.** 1996. Fluid resuscitation and early management, p.53–60. *In* D. N. Herndon (ed.), Total Burn Care. Saunders, London.