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EDITORIAL OFFICE
Dr. Sandhya Talekar
Chief Editor, IJCCM
Shree Medical Foundation, Prayag Hospital, 1247, Deccan Gymkhana, Pune 411004, India.
Tel: 91 20 553 2812 /553 2490
Fax: 91 20 553 4448
E-mail: editor@ijccm.org

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CONTENTS

Original Article

An increase in weight worsens the respiratory state and leads to intensive care unit re-admission

Yoshinori Matsuoka, Akinori Zaitsu

Abstract

We investigated the reasons for intensive care unit (ICU) readmission of patients with acute respiratory failure. Of 88 patients re-admitted to our ICU over a 15-month period, 16 were suffering from acute respiratory failure. Body weight, blood gases, time without food during the initial ICU stay and excess extracellular fluid (ΔECF) were determined. The interval until ICU readmission (D) was defined as the time between the last day of the first admission and the first day of the second admission. Significant correlations were found among the values for D, ΔECF and P/F ratio; a patient with a P/F ratio below 200 on the day of release from ICU and a ΔECF over 3 kg was likely to return to the ICU within four days. Hence, we conclude that fluid-management failure may be associated with ICU readmission in acute respiratory failure patients.

Key words: intensive care unit readmission

Introduction

The inflammatory response in humans leads to significant cytokine release[1] and subsequently to cytokine stimulation of adherence of leukocytes and monocytes to the endothelial cells of blood vessels.[2] Leukocytes then cause damage to these endothelial cells through release of elastase and oxygen radicals, leading to circulatory failure and blood-vessel permeability.[3] The lungs are particularly vulnerable to leukocyte damage through various mechanisms.[4-6] Following damage to blood-vessel endothelial cells by leukocyte activation in the acute phase, increased blood-vessel permeability in the lungs allows plasma to move into the alveolar space from outside the lung blood vessels. The relative increase in the amount of fluid outside the lung blood vessels caused by movement of the plasma causes alveolar collapse, a fall in lung compliance and atelectasis.[7] These events all occur in the initial stage of lung failure.

Extensive transfusion can be performed to compensate for the insufficient amount of plasma produced by increased blood-vessel permeability in the acute phase and this treatment may stabilize the circulation dynamics. Hence, transfusion is indicated for patients with increased blood-vessel permeability in the lungs and may lead to restoration of the blood-vessel endothelium and reduction permeability. Once the circulation is stabilized this procedure should enter the refilling stage. At this point, it is important to normalize the amount of fluid outside the lung blood vessel by quickly reducing the transfusion volume, performing full diuresis and promptly eliminating extracellular fluid from the body. However, since judgment of the correct time to begin this process is not easy in practice, extracellular fluid is often not normalized because of continuation of superfluous transfusion and inadequate diuresis. As a result, the respiratory state may worsen and respiratory failure patients may require readmission into the intensive care unit (ICU) soon after

From:
Department of Emergency and Critical Care Medicine, School of Medicine, University of Tokyo, Japan

Correspondence:
Dr. Yoshinori Matsuoka, 7-3-1 Hongo Bunkyo-ku, 113-8655 Japan.
E-mail: yoshinori216@h2.dion.ne.jp

initial ICU discharge. Hence, we assumed that lung failure patients whose conditions arose because of superfluous transfusion would be intermingled among the readmission cases in this study.

For 16 respiratory failure patients who were readmitted into the ICU, we examined body weight, blood gases, inspiratory oxygen function and starvation period during the initial ICU stay. Correlations between these factors and the interval to ICU readmission (D), defined as the time between the last day of the first admission and the first day of the second admission, were then examined.

Materials and Methods

During the 15-month period from January 1, 2003 to March 31, 2004, we admitted 1,147 patients into our ICU. Of these patients, 88 (7.7% of the total number of admissions) were readmittance cases and 16 of the 88 patients suffered from acute respiratory failure. Thus, acute respiratory failure patients comprised 18.2% of readmittance patients and 1.4% of the total number of ICU patients. During the first ICU admission period, initial body weight, final body weight, excess extracellular fluid (ΔECF) and P/F ratio (P/F) on the first day and the last day were measured for the 16 acute respiratory failure patients. Correlations between these factors and the interval to ICU readmission (D) were investigated.

Excess extracellular fluid is caused by transfer of fluid from intracellular to extracellular environments and exchange of moisture and electrolytes from outside the body. In the acute phase, the muscle weight of bed-rest patients is thought to decrease by 0.0 to 0.5 kg per day, depending on the inflammatory condition and this leads to increase of extracellular fluid.[8] For an average withering of the muscles of an adult patient of 300 g/day, which will cause an increase in the extracellular fluid volume, the target weight at the time of ICU discharge is given by the initial body weight − 0.3 × the number of starvation days. Furthermore, assuming that there is no change in the nature of the fluid and especially in the Na concentration, it is thought that the rapid increase in weight is based on an increase in extracellular fluid volume in the acute phase.[9-11] Therefore, the excess extracellular fluid (ΔECF) = body weight at ICU discharge − target weight at ICU discharge = body weight at ICU discharge − initial body weight + 0.3 × the number of starvation days. The P/F ratio (P/F) was used as an index of lung oxygenation: $P/F = PaO_2 \div F_IO_2$, where P/F > 400 is normal, P/F < 300 reflects some difficulty with breathing and P/F < 200 reflects a serious difficulty.

Results

Clinical management during the first period in the ICU is shown for the 16 re-admitted acute respiratory failure patients in Table 1. At the time of re-admission, eight patients were diagnosed with pneumonia, since lung consolidation was seen, their respiratory state had worsened and WBC and CRP levels were high. However, no bacterium was identified in expectorant from any of these patients and candida infection in catheter urine was only detected in one patient. Among the 16 acute respiratory failure patients who were readmitted to the ICU, shorter intervals to ICU readmission (D) were seen for patients who had a weight above the target weight at the time of initial ICU discharge; that is, patients with a large excess of extracellular fluid (ΔECF) and patients with a low P/F ratio (P/F) [Table 1].

A significant correlation was found between the interval to ICU readmission (D), excess extracellular fluid (ΔECF) and the P/F ratio (P/F). A negative linear correlation (D=−2.8228×ΔECF+12.549, R=0.9411) was found between excess extracellular fluid (ΔECF) and the interval to ICU readmission (D), indicating that the period to re-admission shortens with increased weight [Graph 1]. A negative linear correlation (ΔECF=−1.4707×(P/F)+5.9191, R=0.8101) was also found between the excessive extracellular fluid (ΔECF) and the P/F ratio (P/F) [Graph 2] and a positive linear correlation (D=4.3255×(P/F)−4.6588, R=0.7944) was found between the P/F ratio (P/F) and the interval to ICU readmission (D) [Graph 3]. A P/F ratio (P/F) 200 makes it likely that a patient will need to be readmitted into the ICU within four days of initial ICU discharge. Furthermore, even if the body weight at ICU discharge was the same as the initial body weight, a large ΔECF led to a low P/F ratio [Table 1].

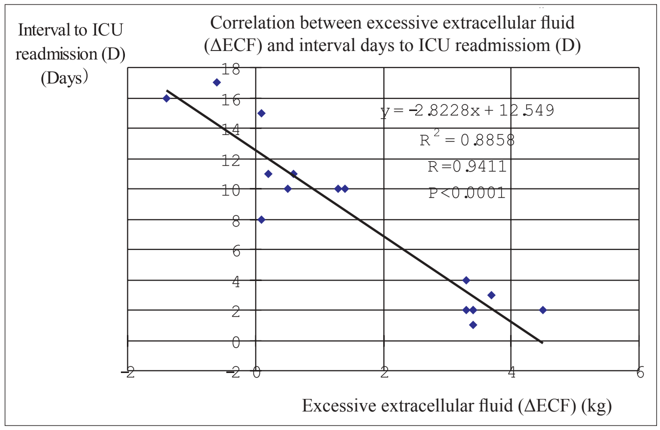
Discussion

Respiratory failure is frequently seen in the ICU and can be divided roughly into ventilation insufficiency and lung failure.[12] Ventilation insufficiency does not reflect a problem with the lungs themselves, but occurs when the effective alveolar ventilation is decreased and it becomes impossible to take in O_2 due to checking of breathing movements, leading to a failure to discharge

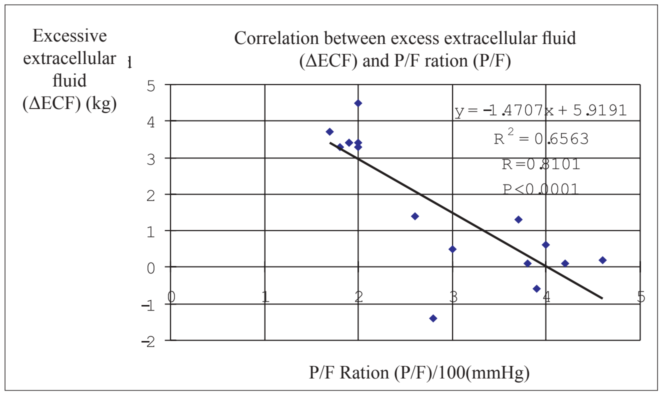
Table 1: Data for 16 acute respiratory failure patients who were readmitted to the ICU: Management during the first ICU admission period

Department in charge	Diagnosis at readmission	Initial body weight (kg)	Final body weight (kg)	Target weight at the time of ICU discharge (kg)	Excess extracellular fluid (ΔECF) (kg)	P/F ratio on the first day	P/F ratio on the last day	Interval to ICU readmission (D) (days)
GS	LE	49.3	48.2	44.8	+3.4	334	200	1
GS	RF	47.7	47.7	44.4	+3.3	322	182	2
GS	Pneumonia	52.4	45.6	42.2	+3.4	378	193	2
GS	RF	60.5	58.5	55.1	+3.4	280	189	2
GS	RF	50.2	48.7	44.2	+4.5	266	201	2
GS	Pneumonia	49.2	48.7	45	+3.7	335	169	3
GS	Pneumonia	55.5	54.5	54.4	+0.1	399	381	8
GS	Pneumonia	49.6	51.7	48.4	+3.3	301	199	4
HS	Pneumonia	57.3	57.1	55.8	+1.3	406	374	10
HS	RF	57.0	55.4	54.9	+5.0	295	300	10
GS	RF	48.6	49.1	47.7	+1.4	378	262	10
BS	Pneumonia	45.3	44.6	44.4	+0.2	417	464	11
BS	LE	44.9	39.5	38.9	+0.6	411	403	11
CS	Atelectasis	30.6	29.6	29.7	+0.1	420	422	15
GS	Pneumonia	48.6	46.3	47.7	-1.4	387	284	16
BS	Pneumonia	41.3	38.3	38.9	-0.6	406	393	17

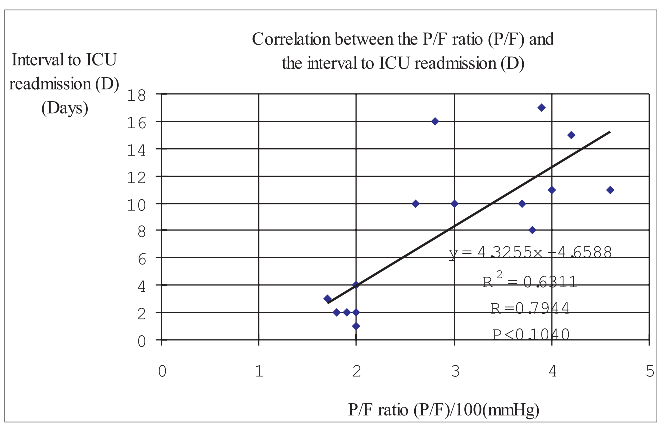
Department in charge: GS=General surgery; BS=Brain surgery; CS=Child surgery; HS=Heart surgery. Diagnosis at readmission: RF=Respiratory failure; LE=lung edema.



Graph 1: A negative linear relationship (D= -2.8228xΔECF+12.549 R=0.9411) was obtained between excess extracellular fluid (ΔECF) and the interval to ICU readmission (D), indicating that the period to readmission becomes shorter with an increase in weight



Graph 2: A negative linear relationship (ΔECF=-1.4707×(P/F) +5.9191 R=0.8101) was found between excess extracellular fluid (ΔECF) and the P/F ratio (P/F), indicating that lung failure advances in proportion to the volume of excess extracellular fluid (ΔECF)



Graph 3: A positive linear relationship (D=4.3255×(P/F)+4.6588 R=0.7944) was found between the P/F ratio (P/F) and the interval to ICU readmission (D), indicating that readmission to the ICU within four days is likely for P/F < 200

CO_2 and accumulation of CO_2. This situation may arise due to ①suppression of the respiratory center caused by anesthetics, analgesics or sedatives, ②paralysis of respiratory muscles caused by muscle relaxants, ③respiratory-muscle fatigue caused by airway constriction or reduced lung compliance and ④reduction of the ventilation area caused by lung excision or lung infarction.

Since the ability of the lungs to take in oxygen is satisfactory, hypoxemia caused by ventilation insufficiency can be improved if gas exchange is performed by artificial ventilation. However, hypoxemia is a problem in the ICU and lung failure due to hypoxemia does not improve with artificial ventilation. This kind of lung failure reflects a state in which alveolar regions with poor ventilation are formed locally. Even if breathing movement is satisfactory and alveolar ventilation is maintained, inspiration of oxygen cannot occur fully because a blood-flow shunt has arisen in the lungs. This may be due to ①alveolar collapse (atelectasis), ②ventilation-perfusion disequilibrium and ③lung edema. In the ICU, lung failure caused by atelectasis or lung edema occurs frequently, because ①lungs are internal organs that are particularly sensitive to leukocyte-induced damage and ②superfluous transfusion is often continued after circulatory stabilization is achieved.

In the acute phase, blood-vessel permeability increases in the lungs. Transfusion can be performed to compensate for insufficient plasma due to the increased blood-vessel permeability and this may stabilize the circulation dynamics. Transfusion is generally indicated for patients with increased permeability of blood vessels in the lungs, but once the blood-vessel endothelium is restored, the permeability is reduced and the circulation is stabilized, the transfusion procedure should enter the refilling stage. Since extracellular fluid has now returned to the lung blood vessels, diuresis is performed to normalize the amount of fluid outside the blood vessels. This requires immediate reduction of transfusion, performance of diuresis and prompt discharge of the extracellular fluid from the body. However, judgment of the timing of this procedure is not easy in practice and often there is a failure to normalize the extracellular fluid because of continuation of superfluous transfusion and inadequate diuresis. Lung edema or atelectasis may therefore arise and this kind of lung failure might be viewed as iatrogenic respiratory failure.

The fundamental clinical approach to lung failure is normalization of the superfluous extracellular fluid outside the lung blood vessel. PEEP is effective for atelectasis caused by lung edema, because it increases the lung expiratory volume, widens the peripheral respiratory tract and re-expands the collapsed alveolar space.[13] As a result, oxygenation ability appears to improve, but if PEEP is stopped the respiratory state worsens; hence, this procedure does not address the fundamental causes of lung failure. Extubation by PEEP (which widens the peripheral respiratory tract) before the extracellular fluid is normalized does allow oxygenation to be maintained with a high concentration of oxygen, but the alveolar space opened by PEEP collapses in a short time and this causes lung consolidation in this region. Patients in whom this occurs will often be diagnosed with pneumonia, aspiration pneumonia or acute respiratory failure and will be readmitted into the ICU.

As the respiratory state worsens, pneumonia may be diagnosed at the time of ICU readmission and lung consolidation may have appeared after initial ICU discharge. Although WBC and CRP levels may be high, these data cannot be used as indicative of pneumonia, since they are often high postoperatively. In addition, a negative expectorant culture after readmission into the ICU may suggest that pneumonia is not present. Although recognition of a new consolidation on a chest X-ray is most important for clinical diagnosis of pneumonia, this is also seen with lung edema or atelectasis and differential diagnosis is a problem. There is a report of a 40% failure rate in recognition of infection in ICU patients with lung consolidation[14] and clinical diagnosis of pneumonia may have many errors; this is also supported by a report suggesting that upon dissection at autopsy 60% of patients diagnosed with pneumonia may have been misdiagnosed.[15] In our hospital, there was one candida cystitis case among eight patients for whom pneumonia was considered as a possible diagnosis at the time of ICU readmission, but bacteria was not detected in the lungs of any of these patients and none satisfied the diagnostic standards for pneumonia. Hence, lung edema due to fluid management failure may be intermingled in patients diagnosed with pneumonia.

In [Table 1], P/F ratio appears to have got worse during the initial ICU stay. We considered this as follows. PO_2 is maintained using a high oxygen density mask after extubation and this gives an apparently worse calculated P/F ratio. Such patients did not lose weight that was increased by the perioperative surplus intravenous drip.

If they responded to the respirator and were extubated without removal of surplus water in the body and lungs, atelectasis and lung edema were not fundamentally improved. The apparent respiratory state can be improved by positive pressure ventilation and a high PO_2 is maintained with high density oxygen after extubation, which leads to a high P/F ratio.

Patients who could not reach the target weight at the time of ICU discharge and patients with low P/F ratios (P/F) had shorter intervals to ICU readmission (D) [Table 1] and lung failure advanced in proportion to excess extracellular fluid (ΔECF) [Graph 2]. Patients with a large excess of extracellular fluid (ΔECF) had shorter intervals to ICU readmission (D) [Graph 1] and patients with P/F ratios (P/F) below 200 were likely to be readmitted to the ICU within four days [Graph 3]. A weight increase over the target weight is caused by extracellular fluid outside the lung blood vessels, including fluid present due to superfluous transfusion. Once atelectasis and lung edema arise in lungs due to the increase in fluid outside the lung blood vessels, lung failure will occur and the P/F ratio will subsequently worsen. Therefore, if the target weight is not achieved, the respiratory state is likely to worsen quickly after extubation and the probability of ICU readmission increases. If the P/F ratio of the patient is below 200 upon discharge from the ICU and excess extracellular fluid (ΔECF) is three kg higher than the ECF on the initial ICU day, it is likely that the patient will be readmitted to the ICU within four days and in such cases strict fluid management must be performed.

Complete remission of lung failure during the first ICU stay is the key for prevention of ICU readmission. For this purpose, it is necessary to perform strict fluid management after the refilling stage. Since the interval to ICU readmission (D) becomes shorter as ΔECF increases, daily weight measurements are needed and fluid management should be performed such that the weight remains close to the target weight. Moreover, estimation of the blood-flow shunt in the lungs using the P/F ratio (P/F) and improvement of lung failure before extubation are of importance. Normalization of ΔECF may be used to treat lung failure and this may prevent ICU readmission. Moreover, careful consideration should be given to superfluous transfusions carried out to improve the heart and kidney functions of patients readmitted into ICU, despite having normal or only slightly low P/F ratios (P/F).

Conclusion

Complete resolution of lung failure during the first ICU admission period may be important for prevention of ICU readmission. To achieve this, it is necessary to perform strict fluid management after the refilling stage. Since the interval to ICU readmission (D) becomes shorter as ΔECF increases, daily weight measurement is required and fluid management is needed to maintain a weight close to the target weight. Moreover, estimation of the blood-flow shunt in the lungs is necessary using the P/F ratio (P/F) and lung failure must be completely resolved before extubation. Surplus ΔECF at ICU discharge may be associated with an increased chance of readmission, but a causative link cannot be proved from this study. Normalization of ΔECF may be useful in treatment of lung failure and this approach may prevent ICU readmission.

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