The Use of Diuretics in the Treatment of Early Wet Lung Syndrome

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WET LUNG syndrome (WLS) has been described in three consecutive wars, and in civilian practice as well.[1, 2, 3, 6, 9, 10, 13] All of the patients so classified have suffered major insults of some sort, either traumatic or surgical. Whatever the nature of the injury and regardless of the postulated mechanism, clinical, isogravimetric, and isotopic technics have confirmed the apparent increase in pulmonary interstitial fluid in all cases studied.[7, 8, 11, 14, 15]

Doty and Moseley,[5] studying combat casualties in Vietnam, reached the conclusion that in many instances WLS may be the result of excessive fluid given during resuscitation. Certainly, most patients who develop WLS have received large volumes of fluid and/or colloid,[7] and it may be difficult or impossible to determine the volume of fluid lost.

Materials and Methods

During the period 1 January 1970–1 July 1970, the 24th Evacuation Hospital, Long Binh, Vietnam, performed 2,602 major operations on more than 2,000 patients, of whom 128 received postoperative ventilatory assistance for more than 24 hours. As part of another study, all patients on respirators were monitored with determinations of arterial gases, minute ventilatory volume, tidal volume, and peak inspiratory pressure. From these values, effective pulmonary compliance was routinely calculated.[6A, 12] All determinations were performed twice daily for 2 days, then daily for 3 days, then every other day.

Patients were selected for study when a diagnosis of WLS was made based upon the presence of all of the following criteria:

A. A significant decline in arterial Po_2.

B. A significant decline in pulmonary compliance.

C. X-ray evidence of increased interstitial pulmonary fluid bilaterally.

D. No thoracic injury.

E. No other apparent cause for the changes noted such as fat embolism or respirator changes.

All 10 patients in this study were receiving long-term ventilatory support via tracheostomy, and all had positive tracheostomy cultures, usually *Klebsiella aerobacter* and/or *Pseudomonas aeruginosa*. All were receiving antibiotics, including penicillin. The Emerson volume-limited respirator was used for eight patients; and the Bennett PR-2, a pressure limited model, was used for two patients.

All 10 patients had audible rales and two patients were in pulmonary edema. Peripheral edema was not seen. Because the mag-

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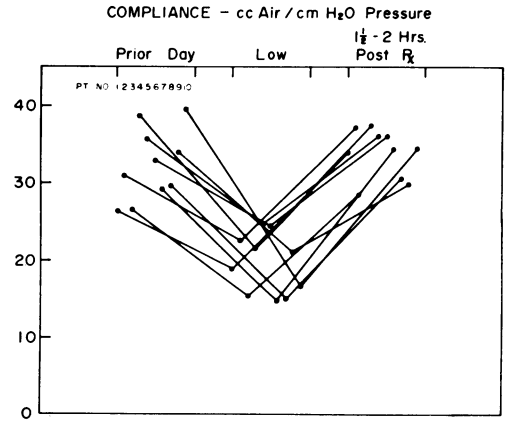

FIG. 1. Pulmonary compliance is shown on the day prior to diagnosis of WLS, at the time of diagnosis of WLS (low), and 1½–2 hours after WLS, apy. All ten patients show a decrease with WLS, and all show a rise following therapy. Normal for adult males is 40–50 cc./cm. H_2O.

nitude of loss could only be crudely estimated, fluid balance in these patients was difficult to assess. The large total fluid volumes used in resuscitation and initial operation for five of the 10 patients plus fluid balance from the time of operation until the onset of WLS, are shown in Figure 5. The figure shows that the volume used in resuscitation ranged from 6,500 to 16,000 cc., averaging just over 11,000 cc. Thereafter, four of the five patients were in positive fluid balance each day until onset of WLS.

The onset of WLS occurred 2–15 days after injury with a median of 4.5 days. Upon diagnosis of WLS all but one patient had CVP measured. Furosemide 40–80 mg. was then administered intravenously. One patient received 40 mg. Furosemide plus 25 mg. ethacrynic acid. Urine volume was measured over the next 2 hours and all determinations were repeated 1½–2 hours following therapy.

Respirator settings and inspired gas mixture, previously selected by the responsible surgeon according to the needs of the individual patient, remained constant for each patient throughout the study.

Results

Every patient treated responded with a dramatic increase in compliance within 1½ to 2 hours, as shown in Figure 1. This improvement was accompanied in every instance by an increase in arterial oxygenation without adjustment of the respirator or O_2 concentration. These changes are shown in Figures 2 and 3.

The CVP averaged 6.4 cm. saline pretreatment, with a range of 3.5–8.5. There was no significant change in CVP following therapy. Two patients had pulmonary edema with superior caval pressures of 7.5 and 8.0 cm. of saline.

The urine output for the 2 hours after administration of the diuretic averaged 2,165 cc. with a range of 1,155–3,800 as

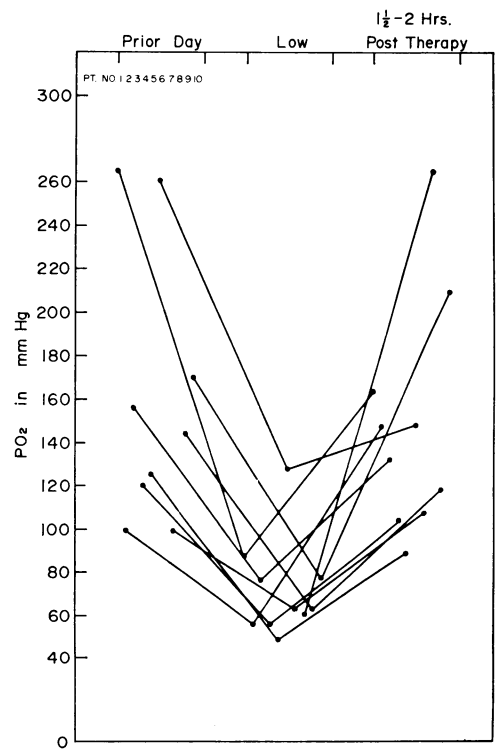

FIG. 2. Arterial P_{O_2} is shown to have the same pattern as compliance. All 10 patients show a decreased P_{O_2} with WLS and an increase after therapy.

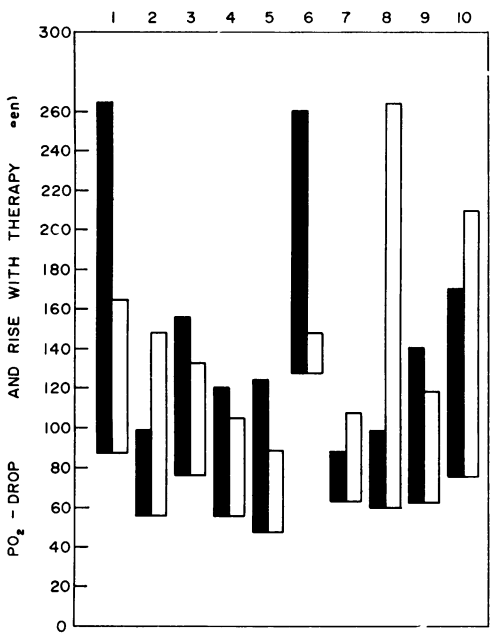

FIG. 3. The magnitude of the decrease in Po_2 with WLS is shown in black, and the increase after therapy is shown in white. Eight of ten patients had Po_2 below 80 mm. Hg. with WLS, and nine of ten rose to greater than 100 after therapy.

shown in Figure 4. Both of the patients in pulmonary edema cleared their edema and in seven of the remaining eight patients the rales decreased. The patient in whom no change in rales was noted had considerable superimposed pneumonitis, and the rales persisted at a moderate level in this patient. Two patients were retreated for similar problems 1 and 4 days later, again with similar results.

Figure 5 shows the fluid balance for the five patients on whom accurate figures could be obtained. The large volume of fluid required for resuscitation and operation precluded accurate knowledge of the state of hydration of these patients. Nevertheless, it is evident in Figure 5 that the daily intake of over 3,000 cc., much of it as Ringer's solution, produced a steadily increasing fluid load in at least four of the five patients. Since these patients were located in airconditioned wards, insensible loss should not be abnormally high.

Seven patients treated for WLS in this study were long-term survivors. Each was alive and well 1 week following removal of the tracheostomy tube, and was breathing spontaneously on room air alone with arterial Po_2 greater than 80 mm. Hg. Several had incompletely healed extremity wounds when lost to follow-up, but these were well past their respiratory problems.

Three of the patients in this study died. One died 12 days after therapy for WLS of his severe head injury and bleeding stress ulcer. One died 5 days after therapy of necrotizing pneumonitis due to staphylococcus. The third death occurred 1 day after therapy of generalized sepsis due to *Pseudonomas aeruginosa.* Autopsies of these latter two patients showed severe pneumonitis and negative fat stains.

At the 24th Evacuation Hospital prior to this study, there had been an average of just over 2 deaths per month attributed to WLS. During the 6 months of this study, and the 3 months following, there were no deaths in this hospital attributed to WLS.

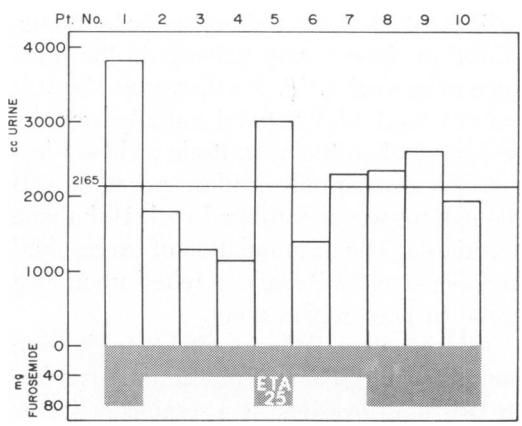

FIG. 4. The urine output is shown for each patient during the 2 hours following therapy. All outputs exceed 1,000 ml., and the mean is 2,165 ml. The doses of Furosemide are shown at the bottom of the figure. Patient 5 received 40 mg. Furosemide plus 25 mg. ethacrynic acid.

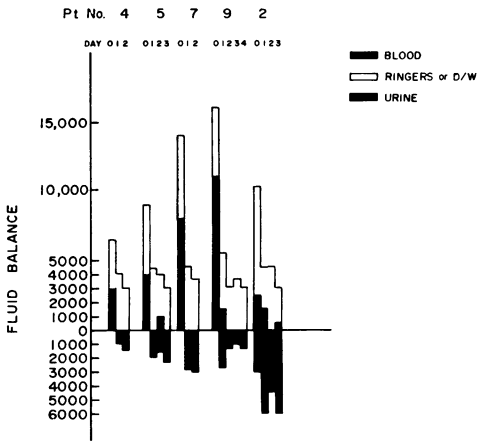

FIG. 5. The fluid balance from admission until diagnosis of WLS is shown for the five patients on whom data are available. The large volumes of fluid used in resuscitation are shown. The markedly positive fluid balance for four of the five is also apparent.

Strong diuretic therapy had been previously applied in 2 cases of "pump lung" following open-heart surgery, with similarly beneficial results.

Diuretic therapy was used in three cases of blast injury of the lung, an interstitial hemorrhage caused by the overpressure associated with a large blast, without demonstrable benefit to the patient.

Discussion

Both WLS and pulmonary edema occurred in these young patients in the presence of normal CVP. Furthermore, the volume of fluid administered initially was determined when the magnitude of blood loss was unknown or only crudely estimated and the patient was vasodilated with Halothane anesthesia. The accumulation of excess fluid may occur if CVP alone is relied upon as a guide to fluid replacement.

The response of these patients to diuretic therapy would seem to confirm the hypothesis that fluid overload is a significant factor in WLS. The median interval of 4.5 days between resuscitation and the onset of WLS suggests that WLS is not a simple fluid overload problem. The other factors in the etiology remain to be clarified. Fluid and electrolyte shifts seem likely as vascular tone is regained following anesthesia. Changes in capillary permeability have been suggested,[4] and left ventricular failure is a possible factor. Prolonged shock, sepsis, and toxins associated with massive tissue destruction are all potential causes of such changes. Pressure measurements in the pulmonary artery and left atrium would help to distinguish between various possible mechanisms. However, these were not found feasible in a combat zone. Antidiuretic hormone, pulmonary extravascular water, and transthoracic impedance were not measured in these patients, though such measurements might prove helpful in defining the mechanism of WLS.

For clinical use, the routine measurement of effective pulmonary compliance was found to be rapid, simple, safe, and highly effective in the early detection of WLS. Strong diuretics were found to be both rapid and effective in treating WLS, producing prompt improvement in both compliance and arterial oxygenation.

Conclusions

1. Ten patients showed a marked decrease in pulmonary compliance and arterial Po_2 with the onset of WLS.

2. The CVP may remain normal in WLS, even in the presence of frank pulmonary edema.

3. Treatment with Furosemide resulted in a marked increase in both pulmonary compliance and arterial Po_2 within 1½–2 hours in all patients.

4. The fluid balances and urinary responses to Furosemide suggest that overhydration may be the etiology, or at least a necessary component, of WLS.

5. Therapy with Furosemide is probably beneficial in "pump lung," but is not beneficial in blast injury of the lung.

6. The routine measurement of pulmonary compliance is suggested as a simple,

inexpensive, and non-invasive method of detecting the early onset of WLS and other problems in patients requiring ventilatory assistance.

7. Deaths due to WLS can be prevented by avoiding overhydration, recognizing the early onset of WLS by measuring compliance, and treating vigorously with fluid restriction and strong diuretics.

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