Pulmonary mechanics and diffusion after ‘shock lung’

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Yernault, J. C., Englert, M., Sergysels, R., and de Coster, A. (1975). *Thorax*, 30, 252–257. Pulmonary mechanics and diffusion after ‘shock lung’. Pulmonary function studies performed in seven patients who had recovered from ‘shock lung’ showed a highly significant decrease of diffusing properties of the lung, a slight loss of lung recoil pressure, and a borderline increase of residual volume with normal vital capacity and total lung capacity. Pulmonary compliance was normal. The interpretation of these findings is discussed.

‘Shock lung’ (Proctor, Ballantine, and Broussard, 1970) is a syndrome of severe respiratory insufficiency accompanying shock of several aetiologies (trauma, hypovolaemia, haemorrhage, sepsis, etc.). The clinical evolution of the acute period can be roughly divided into four stages (Moore et al., 1969; Gay and Campan, 1972; de Coster et al., 1974):

1. Shock is treated by massive intravenous infusion. Hyperventilation with hypocapnia is sometimes present.
2. Moderate hypoxaemia appears some hours or days after haemodynamics have returned to normal; it resolves or progresses to stage 3.
3. Distress, tachypnoea, and cyanosis develop. Radiography shows mottled opacities which progressively opacify the entire lung. In spite of artificial ventilation with pure oxygen, arterial oxygen pressure remains low.
4. Severe hypoxaemia persists and eventually hypercapnia, loss of consciousness, and death.

The pathophysiology of this syndrome is still debated. Functional studies made during the acute period have shown a lowered pulmonary compliance (Henry et al., 1967; Cahill et al., 1965; Wilson et al., 1969; Proctor et al., 1970); diffusing properties of the lung have not been studied.

The aim of the present study was to evaluate the physiological sequelae in patients who had completely recovered from the acute syndrome.

 MATERIAL AND METHODS

Of 12 patients hospitalized in the medical intensive care unit of our hospital for shock lung syndrome from 1971 to 1973 eight have completely recovered. Seven of them have been studied after recovery one to 20 months after the acute period.

The clinical and therapeutic problems have been reported elsewhere (de Coster et al., 1974) and are summarized in Table I. It should be emphasized that none of the patients had a history of previous pulmonary disease. At the time of the study physical examination and chest radiography were normal in all patients and all were symptom free except case 6, who complained of slight exertional dyspnoea.

The biometric characteristics of the subjects studied are reported in Table I, together with the time, in months, after the acute phase before the physiological studies were performed.

Vital capacity (VC) and one-second forced expiratory volume (FEV₁) were measured with a conventional spirometer. Functional residual capacity (FRC) was measured by the helium dilution method. Predicted values for lung volumes were calculated according to Grimby and Söderholm (1963), Berglund et al. (1963), and Birath, Kjellmer, and Sandqvist (1963).

Airway resistance (Raw) was determined by constant volume body plethysmography; the predicted values are those of Amrein et al. (1970).

Diffusing properties of the lung were studied by the carbon monoxide single-breath method; the
normal values are those of Englert (1967). The transfer factor was calculated using both the effective alveolar volume measured using the dilution of helium during breath-holding (TF') and the alveolar volume measured by adding the inspired volume to the residual volume previously determined by the multiple-breath helium dilution method (TF).

Oesophageal pressure was measured with a Latex balloon (length 10 cm, perimeter 5 cm) containing 1 ml of air. With the balloon in the lower third of the oesophagus, the subject breathed into a bag containing air at 37°C and saturated with water vapour. After a few normal breaths, during which the end expiratory level and the zero pressure were carefully noted, the subject took a full inspiration, then expired slowly to or slightly under the FRC level; during the next very slow deep inspiratory and expiratory manoeuvres (to or near residual volume level), transpulmonary pressure and volume were directly recorded on an X-Y recorder. At least two correct measurements were obtained for each subject (i.e., measurements with total lung volume very close to previously determined total lung capacity (TLC) and without evident artefact of pressure). From these tracings, static inspiratory (CLI) and expiratory (CLE) compliances were calculated from the transpulmonary pressure variation between FRC and FRC+0.5 litre. The normal values for compliance were determined in a group of 22 young adults (Yernault and Englert, 1974). Maximal inspiratory pressure (Pi max) and elastic recoil at various levels of total lung capacity (Pst) were compared to the normal values established by Turner, Mead, and Wohl (1968). Finally, the coefficient of retraction (CR), according to Schluter, Immekus, and Stead (1967), was calculated by dividing Pst at 100% TLC by TLC.

A previously described partially computerized program (Yernault et al., 1972) was used for the calculations and presentation of results.

Pulmonary scanning was performed in three patients (cases 1, 2, and 3) with a gamma camera after intravenous injection of technetium-99m labelled microspheres.

### RESULTS

Table II shows the results of measurements of lung volumes: vital capacity is slightly lowered, but functional residual capacity, measured either

<table>
<thead>
<tr>
<th>Patient</th>
<th>Vital Capacity (l)</th>
<th>Total Lung Capacity (l)</th>
<th>RV/TLC (%)</th>
<th>FEV1 (l)</th>
<th>FEV1/VC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.71(3.84)</td>
<td>5.76(5.26)</td>
<td>36(27)</td>
<td>3.05(3.19)</td>
<td>82(83)</td>
</tr>
<tr>
<td>2</td>
<td>2.25(2.95)</td>
<td>3.70(3.90)</td>
<td>37(24)</td>
<td>1.35(1.40)</td>
<td>88(81)</td>
</tr>
<tr>
<td>3</td>
<td>2.17(1.1)</td>
<td>4.83(4.82)</td>
<td>32(23)</td>
<td>1.97(1.40)</td>
<td>97(85)</td>
</tr>
<tr>
<td>4</td>
<td>1.56(1.1)</td>
<td>6.35(4.40)</td>
<td>34(25)</td>
<td>1.65(1.40)</td>
<td>87(85)</td>
</tr>
<tr>
<td>5</td>
<td>1.73(1.38)</td>
<td>4.68(4.25)</td>
<td>34(25)</td>
<td>2.11(2.37)</td>
<td>82(79)</td>
</tr>
<tr>
<td>6</td>
<td>1.99(1.23)</td>
<td>4.91(5.18)</td>
<td>27(22)</td>
<td>2.30(3.90)</td>
<td>85(86)</td>
</tr>
<tr>
<td>7</td>
<td>1.71(1.80)</td>
<td>4.96(6.81)</td>
<td>34(26)</td>
<td>2.30(3.90)</td>
<td>71(78)</td>
</tr>
</tbody>
</table>

Mean observed: 3.17, 3.07, 1.68, 4.85, 34.7, 2.66, 84
Mean predicted: 3.0, 0.28, 0.28, 0.4, 0.49, 7.7, 82.4

Predicted values are shown in parentheses. The mean value of the group studied is compared to the mean predicted value. The significance of the difference between the two groups is also reported (NS = not significant).
by helium dilution or by body plethysmography, and residual volume (RV) are significantly increased; total lung capacity remains normal. The increase of the RV/TLC ratio is highly significant, but the ratio FEV1/VC is normal.

In Table III are recorded the diffusing properties of the lung. When calculated by the classical method, TF is slightly greater than when calculated using effective alveolar volume, but whatever the method used there is a highly significant reduction of TF. The Krogh constant (k) is also significantly lowered.

The mechanical properties are presented in Table IV. Airways resistance is normal, as are both CLI and CLE. A moderate loss of lung recoil is apparent in five patients, as shown by a low P1 max and low Pst at different lung volumes (Figure). It is of interest that the only subject with normal lung recoil had been ventilated with residual positive expiratory pressure of 30 mmHg.

Pulmonary scanning was normal in two patients (cases 1 and 3) and showed heterogeneity of perfusion in one (case 2).

**DISCUSSION**

The diagnosis of shock lung was firmly established in all the cases reported on clinical, radiological, and physiological bases. Aetiology was, however, not uniform and the severity of the disease varied as could be judged from the varying duration of artificial ventilation needed (de Coster et al., 1974).

Nevertheless the physiological findings are remarkably constant. Total lung capacity is normal, but the ratio RV/TLC tends to be high; there is no sign of airway obstruction, airway resistance, and the FEV1/VC ratio being normal in all cases. Compliance is normal but there is a slight loss of lung recoil in most patients; transfer factor is strikingly reduced. Interpretation of the increases in FRC, RV, and RV/TLC must be cautious since in absolute values it is only slight and depends on the normal values used. For example, if RV is predicted according to Needham, Rogan, and McDonald (1954) or to Goldman and Becklake (1959), there is no significant variation from normal. Previous reports from our laboratory have drawn attention to these problems (de Coster and Schmitz-Cusnier, 1970; de Coster, Messin and Degré, 1967), but recent studies (Yernault and Englert, 1974) seem to confirm the validity of the reference values which are used in the present work.

**TABLE III**

**MEASUREMENTS OF DIFFUSING PROPERTIES**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Transfer Factor (ml min⁻¹ mmHg⁻¹)</th>
<th>Krogh's Constant (min⁻¹ k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.3 (26.7)</td>
<td>19.9</td>
</tr>
<tr>
<td>2</td>
<td>10.7 (18.5)</td>
<td>11.5</td>
</tr>
<tr>
<td>3</td>
<td>10.2 (5.9)</td>
<td>10.5</td>
</tr>
<tr>
<td>4</td>
<td>12.1 (25.4)</td>
<td>13.6</td>
</tr>
<tr>
<td>5</td>
<td>12.1 (25.4)</td>
<td>13.7</td>
</tr>
<tr>
<td>6</td>
<td>12.1 (25.4)</td>
<td>13.7</td>
</tr>
<tr>
<td>7</td>
<td>7.1 (12.7)</td>
<td>18.4</td>
</tr>
</tbody>
</table>

Mean observed
SD        Mean predicted
SD

1To convert to SI units (mmol min⁻¹ kPa⁻¹) multiply by 0.335.

Predicted values are shown in parentheses. The mean value of the group studied is compared to the mean predicted value. The significance of the difference between the two groups is also reported.

**TABLE IV**

**MEASUREMENTS OF MECHANICAL LUNG PROPERTIES**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Airways Resistance (cmH2O 1⁻¹ sec⁻¹)</th>
<th>Inspiratory Quasi-static Compliance (l cmH2O⁻¹)</th>
<th>Expiratory Quasi-static Compliance (l cmH2O⁻¹)</th>
<th>Transpulmonary Pressure at Full Inspiration (cm H2O)</th>
<th>Coefficient of Retraction (cmH2O 1⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.4 (1.8)</td>
<td>0.158 (0.177)</td>
<td>0.160 (0.240)</td>
<td>27.1 (33.9)</td>
<td>4.8 (6.4)</td>
</tr>
<tr>
<td>2</td>
<td>1.5 (1.8)</td>
<td>0.133 (0.094)</td>
<td>0.174 (0.125)</td>
<td>18.5 (30.9)</td>
<td>4.5 (7.9)</td>
</tr>
<tr>
<td>3</td>
<td>2.1 (1.8)</td>
<td>0.153 (0.143)</td>
<td>0.200 (0.193)</td>
<td>27.8 (34.3)</td>
<td>5.3 (7.1)</td>
</tr>
<tr>
<td>4</td>
<td>1.8 (1.8)</td>
<td>0.136 (0.182)</td>
<td>0.141 (0.247)</td>
<td>24.5 (34.3)</td>
<td>5.1 (6.4)</td>
</tr>
<tr>
<td>5</td>
<td>1.4 (1.8)</td>
<td>0.181 (0.126)</td>
<td>0.190 (0.172)</td>
<td>21.7 (26.7)</td>
<td>4.4 (6.3)</td>
</tr>
<tr>
<td>6</td>
<td>2.5 (1.8)</td>
<td>0.148 (0.162)</td>
<td>0.181 (0.220)</td>
<td>35.2 (34.3)</td>
<td>5.9 (5.2)</td>
</tr>
<tr>
<td>7</td>
<td>—</td>
<td>—</td>
<td>0.215 (0.267)</td>
<td>30.1 (32.7)</td>
<td>6.0 (4.8)</td>
</tr>
</tbody>
</table>

Mean observed
SD        Mean predicted
SD

To convert to SI units:
1Multiply by 0.1 (kPa per cm H2O).
2Multiply by 0.1 (kPa per cm H2O).

Predicted values are shown in parentheses. The mean value of the group studied is compared to the mean predicted value. The significance of the difference between the two groups is also reported (NS = not significant).
These borderline abnormalities in FRC, RV, and RV/TLC could be related to the loss of lung recoil. It is not, however, of sufficient degree to suggest pulmonary emphysema, although in patients who died from 'solid lung', Wyatt (1973) described over-expansion of air ducts and air sacs in the unconsolidated areas. The most likely explanation seems a modification in lung surface properties: such modifications have indeed been induced experimentally by tracheal obstruction in dogs in vivo (Buhain, Brody, and Fisher, 1972) or by ventilation of excised dog lungs with an end expiratory pressure of 7 cmH₂O (Raimondi, Massarella, and Pride, 1971).

The important reduction of transfer factor of the lung is the most characteristic feature in all patients. Few studies have as yet been performed in this field. Interiano, Stuard, and Hyde (1972) showed a reduction of the diffusing capacity of the lung in one patient, studied after acute respiratory distress following acute pancreatitis. Downs and Olsen (1974) also reported a transient reduction of TF in one patient after adult respiratory distress syndrome. In the present series also the lowest values of TF are seen soon after the acute phase.

The reduction of diffusing capacity of the lung is probably related to disturbances at the capillary level. Extensive pulmonary arterial thrombosis can be excluded by the studies of the distribution of pulmonary perfusion performed in three cases, but diffuse thrombosis or destruction of the capillaries are known to occur during the acute phase of the disease (Hardaway et al., 1967; Daldorf et al., 1968; Martin, Soloway, and Simmons, 1968; Groves et al., 1972; Pariente et

**Figure** Representation of volume-pressure curves of the subjects studied. The thick line is the predicted curve, the thin line the measured one.
al., 1972). From the present results it appears that these disturbances are, at least partly, irreversible.

It should be emphasized that these disturbances of diffusing properties of the lung are present without any sign of pulmonary fibrosis, which is known to develop in fatal cases (Hardaway et al., 1967; Wilson et al., 1969; Bredenberg et al., 1969): pulmonary compliance and total lung capacity are indeed perfectly normal in all seven cases.

Although definite, the reported changes of lung function seem not to be of major clinical significance since Pao2 at rest was normal in each patient before discharge from hospital. The long-term evolution is, however, impossible to predict and needs further studies.

REFERENCES


Raimondi, A. C., Massarella, G. R., and Pride, N. B. (1971). The effects of ventilation on the elastic...


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