The Effects of Pulmonary Infection on Cardiorespiratory Functions in Chronic Emphysema.*

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Investigations of cardiorespiratory functions in pulmonary diseases have in recent years contributed much to the understanding of the development of pulmonary heart disease. Harvey et al.1 in a recent publication have stressed the importance of anoxia in patients with chronic pulmonary emphysema as a cause for the deterioration of heart function. According to them, acute anoxia may precipitate the development of congestive heart failure and the relief of anoxia may bring about marked improvement in cardiac function. The main causes of acute anoxia may be bronchial obstruction and acute pulmonary infection.

Two cases of emphysema were recently observed in which the development of acute pulmonary infection and anoxia was associated with congestive heart failure. Recovery from the infection and anoxia was accompanied by regression of the signs of congestive heart failure. In one case, also, the interesting effects of treatment with adrenocorticotropic hormone on pulmonary functions in the different stages of pulmonary emphysema were recorded.

Methods

Pulmonary function tests: Lung volumes and maximum breathing capacity were measured by the spiographic technique.2 All the data were calculated to 37°C., saturated and prevailing barometric pressure. The predicted vital capacity and maximum breathing capacity were calculated by the formulas of Baldwin et al.3 Arterial blood gases were determined by the method of Van Slyke and Neill.4 Blood was obtained from the brachial artery using an indwelling Cournand-type needle. The blood was collected by the technique of Riley et al.5 using heparin to prevent clotting and a small globule of mercury in the syringe for proper mixing. Exercise tests on the Master two-step stairs were performed during three minutes.6 100 per cent oxygen breathing was maintained for three minutes. Venous pressure was measured by the direct Moritz and Tabor method. Circulation time was determined with decholin. ACTH was given by intravenous drip infusion of small doses.7, 8

Case 1: Z. M., a 45 year old male was admitted to the hospital on May 25th, 1952, for the fifth time. The chief complaints were fever, cough and shortness of breath. His past history revealed that for many years he had suffered from attacks of respiratory infections and bronchial asthma. A diagnosis of obstructive emphysema and spastic bronchitis had been made. On previous admissions the chief findings were cyanosis, wheezing and bronchial rales over both lung fields. The heart was not

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### TABLE I

#### ARTERIAL BLOOD

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<th>Date</th>
<th>CO₂ Content Before Exercise</th>
<th>CO₂ Content After Breathing</th>
<th>O₂ Content Before Exercise</th>
<th>O₂ Content After Breathing</th>
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<th>Maximum Brain Capacity</th>
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### TABLE II

#### ARTERIAL BLOOD

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enlarged, but the electrocardiogram showed signs of right ventricular strain. Circulation time and venous pressure were normal. The red blood cell count was 5,500,000. Three weeks before his present admission he noted fever which persisted until admission. During this period he suffered from severe cough, marked shortness of breath, severe headaches and pounding sensations in his head.

Physical examination disclosed a well nourished male, propped up in bed; temperature 38.8° C; pulse 120 per minute; blood pressure 120/70; respirations 28 per minute. He appeared acutely ill and was dyspneic at rest. There was marked cyanosis of the face, lips, ears and fingers. The neck veins were markedly congested. The area of cardiac dullness could not be exactly determined because of the marked emphysema. The heart sounds were normal; the second pulmonic sound was accentuated. The chest was barrel shaped with practically no expansion and the lung borders were lower than normal. The breath sounds were distant over both lungs with a prolonged expiratory phase. There were sibilant and sonorous ronchi. Over the lower half of the right lung field, coarse and medium crepitations were heard. The liver edge was three finger-breathths below the costal margin and tender. The spleen was two finger-breathths below the costal margin. The extremities were normal. There were “watchglass” nails.

Laboratory data—Urine analysis, normal; R.B.C. 6,810,000; hemoglobin, 17.5 g. per cent; hematocrit, 60; leucocytes, 18,100 with 60 per cent neutrophiles, 1 per cent eosinophiles, 1 per cent basophiles, 30 per cent lymphocytes and 8 per cent monocytes. Sedimentation rate was 3/5 Westergreen. Kahn serological test was negative. Blood urea, sugar and protein were normal. A sputum culture revealed N. catarrhals and staphylococcus citreus.

X-ray film of the chest on admission showed diffuse cloudiness in the lower part of the right lung, increased markings of the hila and a small amount of fluid in the right costophrenic sulcus. The electrocardiogram showed sinus tachycardia, P pulmonale and signs of right ventricular hypertrophy. Circulation time was 15 sec.; antecubital venous pressure 22.5 cm. H₂O.

The presumptive diagnosis was bronchopneumonia, emphysema and spastic bronchitis.

Treatment with penicillin, 600,000 units daily, was instituted and oxygen was administered intermittently. On the third day after admission phlebotomy of 350 cc. was performed. On the same day the temperature dropped to normal and his condition started to improve. On June 1st, six days after admission, the venous pressure was 11 cm. H₂O and the liver edge was now palpable one finger-breathths below the costal margin. On June 5th, the x-ray showed clear lung fields. The clinical improvement continued, and on June 15th the venous pressure was 6.5 cm. H₂O. He had lost 3 kg. in weight and was discharged in a markedly improved condition.

**Pulmonary Function Tests**

The results are summarized in Table I. The ventilatory function tests performed seven months before his present admission showed a marked reduction in vital capacity and maximum breathing capacity which were 25 and 17 per cent respectively of the predicted normal values. At the time of his present admission vital capacity and maximum breathing capacity had decreased further to 21 and 13 per cent respectively of the predicted normal values. The expiratory slope of the spirogram was markedly prolonged (Fig. 1). The oxygen saturation of the arterial blood was 55.2 per cent and the CO₂ content was 61.32 Vol. per cent. Four days later, after the temperature dropped to normal, the oxygen saturation rose to 69.7 per cent and the CO₂ content was 66.67 Vol. per cent. After breathing 100 per cent oxygen, the saturation rose to 90 per cent. Two weeks after his admission the oxygen saturation was 85.2 per cent and the CO₂ content had dropped to 57.7 Vol. per cent. After exercise the oxygen saturation rose to 86.2 per cent. Marked improvement in ventilatory function was manifested by the increase of vital capacity and maximum breathing capacity, which were now 33 and 19 per cent respectively of the predicted normal values. The expiratory slope of the spirogram was still very pro-
longed (Fig. 1). At a control examination five months later, nearly the same values were obtained. The oxygen saturation was now 86.5 per cent and rose to 99 per cent after oxygen breathing.

Effects of ACTH Treatment

Treatment with adrenocorticotropic hormone during his previous admission half a year ago, caused marked improvement in the ventilatory function tests. The vital capacity and maximum breathing capacity increased by 9 and 5 per cent respectively of the predicted normal values (Table I). The same treatment during his present admission, after recovery from congestive heart failure, caused a decrease in the vital capacity from 33 to 26 per cent and in the maximum breathing capacity from 19 to 15 per cent. The oxygen saturation decreased from 85.2 to 83 per cent and after exercise it dropped further to 80 per cent.

Comment

This patient was known to have suffered for years from chronic bronchitis and obstructive emphysema. Signs of myocardial decompensation had not been seen previously. During his present admission, a diagnosis was made of pneumonia accompanied by an exacerbation of chronic bronchitis. The acute infection caused a marked deterioration of pulmonary function, manifested by reduction of ventilatory function tests, carbon dioxide retention and anoxia. The chief cause of the anoxia was apparently pneumonia associated with a large area of unventilated but well perfused lung parenchyma. This probably caused an admixture of unoxygenated venous blood from the pulmonary artery with blood from well ventilated alveoli, a situation analogous to a veno-arterial shunt, as seen in congenital heart disease. The fact that breathing of 100 per cent oxygen increased the oxygen saturation only to 90 per cent speaks in favor of this assumption and makes it improbable that the arterial oxygen unsaturation was due only to faulty distribution or diffusion. It should

![Figure 1](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21258/)
be pointed out that five months later the oxygen saturation after 100 per cent oxygen breathing rose to 99 per cent.

At the time of the pulmonary infection signs of congestive heart failure appeared for the first time. With the recovery from the pulmonary infection, the anoxia gradually diminished and the oxygen saturation rose to the same level as at his control examination and the ventilatory function tests improved markedly. The presence of some oxygen unsaturation even after clinical recovery from the pulmonary infection might be explained by the continuation of pulmonary consolidations and spastic bronchitis. Pulmonary infiltrations have been frequently observed by x-ray studies and confirmed by pathological examinations even after the temperature has dropped to normal, because of the slow resorption of the alveolar exudates.13 The above observations suggested that in this case pneumonia with an accompanying veno-arterial shunt was the main cause of the pulmonary dysfunction and anoxia.

The different responses to treatment with adrenocorticotropic hormone in two different stages of the disease was well demonstrated in the lung function tests. On his previous admission, when the presenting disease was bronchial asthma without signs of heart failure, treatment with ACTH caused marked improvement. At his present hospitalization, when the patient was recovering from a bout of congestive heart failure, the same treatment led to a reduction of the ventilatory function tests and an impairment of the respiratory function tests. The cause for this deterioration might be sought in the increased tendency for salt and water retention during this particular phase of the disease, which probably resulted in interstitial edema and pulmonary insufficiency. This notion conforms with the observations of Lucas and Galdston et al., who also found a deterioration of pulmonary function after treatment with ACTH in cases with pulmonary heart disease.14, 15

Case 2: M.K., a 65 year old male Jew, was admitted on December 12th 1952, because of shortness of breath and cough. It was not possible to get a detailed history from him or his relatives. He was living in poor economical conditions and had suffered coughing attacks for years.

At the time of admission his temperature was 36.9° C.; pulse 104; blood pressure 125/85; respiratory rate 44; weight 70.6 kg. He was dyspneic and orthopneic. There was marked cyanosis of the face, lips, fingers and toes. The fingernails had a "watch-glass" appearance. The neck veins were markedly distended. The chest was barrel shaped and extended poorly bilaterally. The breath sounds were vesicular with prolonged expiration and there were diffuse bronchitic rales. Over the right lung base there was an area of dullness of three fingers breadth with bronchial breath sounds and crepitations. The heart was enlarged in all directions; there were no murmurs; the second pulmonary sound was accentuated. The liver edge was five finger-breadths below the right costal margin and tender. There were ascites and three plus pretibial edema.

An x-ray film of the chest (Fig. 2A) showed dilatation of the right and left heart with straightening of the left border and prominence of the right lower border; increased pulmonary hilar markings; especially on the right side; a density in the right lung base and fluid in the right costophrenic sulcus. The electrocardiogram showed P pulmonale and right ventricular hypertrophy.

On admission the red cell count was 4,900,000; hemoglobin 14.0 g. per cent; hematocrit, 52; leucocytes, 24,400 with 59 per cent neutrophiles, 2 per cent bandforms, 4 per cent eosinophiles, 34 per cent lymphocytes and 1 per cent monocytes. The urine showed 2+ positive albumin, some leucocytes and erythrocytes. The sedimentation rate was ½ Westergreen. The Kahn serological test was negative. The blood urea was 52 mg. per cent; blood sugar 87 mg. per cent; NaCl, 525 mg. per cent; protein, 5.85 g. per cent; albumin, 3.2 g. per cent and globulin, 2.65 g. per cent. Circulation
time was 22 sec.; venous pressure on admission was 22 cm. H.O. Three days after admission his temperature rose to 39° C. and after three days dropped to normal. The presumptive diagnosis was bronchopneumonia, emphysema and spastic bronchitis. On the first day after admission, because of his serious condition, the patient was given 2 cc. of a mercurial diuretic and a phlebotomy of 400 cc. was performed. He was placed on a low salt diet, was given 0.9 g. aminophyllin daily, oxygen was administered intermittently and penicillin treatment was instituted. On the sixth hospital day digitalization was begun. He received 18 cc. digilanide during a period of three days and thereafter 0.1 mg. digitoxin daily orally. Eight days after admission his condition started to improve, the cyanosis decreased, urine output increased and the edema began to regress. On December 23rd, the venous pressure was 16 cm. H.O and the circulation time was 14 sec. During the following two weeks his weight dropped from 67.0 kg. to 53.0 kg. All the signs of congestive heart failure disappeared and there was no visible cyanosis. The venous pressure dropped to 5 cm. H.O. The physical signs over the lungs became normal. A control x-ray film on January 2nd, 1953 (Fig. 2B) showed a normal size and configuration of the heart with clear lung fields, increased hilar markings and evidence of emphysema. The electrocardiogram revealed again right ventricular hypertrophy.

Pulmonary Function Tests

The results are summarized in Table II. The first examination was performed four days after his admission. The ventilatory functions tests showed marked reduction. The maximum breathing capacity was 16 per cent and the vital capacity 30 per cent of the predicted normal values. The spirogram exhibited a marked prolongation of the expiratory slope (Fig. 3). The oxygen saturation of the arterial blood was 71 per cent at rest and dropped to 63 per cent after exercise. After breathing 100 per cent oxygen the saturation rose to 98 per cent. The carbon dioxide in the blood was 66.3 Vol. per cent, indicating marked retention. Five days later the arterial oxygen saturation rose to 82.5 per cent and exercise caused a drop to 70 per cent. Eleven days after the first examination the vital capacity rose to 45 per cent of the predicted value. The oxygen saturation was now 83 per cent and exercise caused a drop to 80 per cent. On January 7 the ventilatory tests showed further improvement. The vital capacity was now 50 per cent and the maximum breathing capacity 30 per cent of the predicted normal

FIGURE 2A  FIGURE 2B

Figure 2A, Case 2: X-ray film of the chest on admission. See text. Figure 2B, Case 2: X-ray film after recovery. See text.
values. The spiographic tracing showed a normal expiratory slope (Fig. 3). The arterial oxygen saturation was now 90 per cent, rising after exercise to 90.5 per cent and the carbon dioxide content was normal.

Comment

This patient was admitted to the hospital in a state of severe cardiac failure and dilatation of the heart. On the basis of clinical and x-ray findings, a diagnosis of spastic bronchitis and pneumonia was established. There was marked reduction of the ventilatory function tests, oxygen unsaturation and carbon dioxide retention. The spirogram showed a marked prolongation of the expiratory slope indicating bronchial obstruction. The oxygen unsaturation was corrected by the administration of 100 per cent oxygen, which justified the assumption that the main cause for the anoxia was faulty distribution or diffusion of air. With the subsidence of the pulmonary infection there was a gradual improvement in the ventilatory function tests and also the expiratory slope became normal, indicating relief from the ventilatory obstruction. The arterial oxygen saturation gradually returned to normal values and the carbon dioxide retention decreased. Accompanying the improvement of the pulmonary functions, the signs of congestive heart failure disappeared, the venous pressure and the circulation time became normal, the urine output increased and there was a marked loss in weight. The x-ray films revealed now a normal configuration of the heart. Table III illustrates the correlation between some pulmonary tests, circulatory measurements and the body weight. The lack of polycythemia in this case might be explained by the poor nutritional state, indicated also by the low blood protein levels. It might be assumed that the chief cause of the acute deterioration in the pulmonary functions in this case was bronchial obstruction, since the anoxia was completely corrected by oxygen breathing and the expiratory slope became normal after recovery from the acute infection.

FIGURE 3. Case 2: Spirograms in the course of the disease showing an increase in the vital capacity and a normalization of the expiratory slope.
Discussion

Two patients are presented with signs and symptoms of severe cor pulmonale. In both of them chronic bronchitis and emphysema were present before the appearance of the current disease. Acute pulmonary infection, in one case predominantly pneumonia, in the other predominantly severe obstructive bronchitis, precipitated the appearance of severe congestive heart failure. In these two patients the preexisting chronic lung disease

TABLE III
Correlation between circulatory measurements, some pulmonary function tests and body weight.
had probably caused a reduction of the pulmonary vascular tree, long before the appearance of heart failure. This reduction resulted in an increased load on the right ventricle and induced right ventricular hypertrophy which was demonstrated in the electrocardiograms taken before and after the present acute illness.

Three factors were probably responsible for the development of acute congestive heart failure in these cases who suffered from chronic emphysema:

I. The decrease of the functional pulmonary parenchyma as a result of pneumonia and bronchial obstruction caused further diminution of the already reduced pulmonary vascular tree and thus a greater resistance in the pulmonary circuit. These factors were well demonstrated by the marked reduction of the pulmonary function tests, manifested by the low vital capacity and maximum breathing capacity.

II. The fever, induced by the pulmonary infection, caused a rise in the oxygen consumption as a result of increased metabolic requirements. This rise in oxygen consumption is generally accompanied by increased cardiac output, which in turn may lead to an increased pulmonary blood flow and embarrassment of the pulmonary circulation.

III. The third factor and probably the most important one was the anoxia. It has been shown that anoxia, apparently by direct action on the pulmonary vessels, augments their vasomotor tone and thereby increases the pulmonary artery pressure. This effect should be more marked in patients in whom there is already a reduction of the pulmonary vascular bed. Other sequelae of anoxia include hypervolemia, increased cardiac output and polycythemia. The first two of these latter increase the volume of blood in the pulmonary circulation and limit further the

FIGURE 4: Interrelation between the various factors causing heart failure in chronic pulmonary disease complicated by pulmonary infection.
capacity of the pulmonary vascular bed. Polycythemia,\textsuperscript{18, 19} with increased blood viscosity, augments the resistance to flow and raises the pulmonary artery pressure. These various mechanisms combine to produce pulmonary hypertension. Right ventricular dilatation and cardiac failure result when the hypertrophied right ventricle, whose function is impaired by the direct action of the anoxia on the myocardium, is no longer capable of coping with the overload of the increased pulmonary resistance and the demand for increased cardiac output.\textsuperscript{20, 21}

The interplay of these various mechanisms in the genesis of heart failure is illustrated in Fig. 4. Since there is no intrinsic disease of the heart muscle, as in rheumatic and arteriosclerotic heart disease, the cardiac failure is reversible following the removal of the cause of the acute pulmonary insufficiency. These two patients offered an exceptional opportunity to illustrate the parallelism between the severity of pulmonary insufficiency and the degree of congestive heart failure.

SUMMARY

Two cases of chronic emphysema in which pulmonary infection resulted in acute congestive heart failure have been presented. The predominant lesion in one case was pneumonia, and in the second obstructive bronchitis. The sequence of events resulting in heart failure are discussed.

The technical assistance of Mrs. K. Galewski and Miss L. Beck is acknowledged with gratitude.

RESUMEN

Se presentan dos casos de enfisema crónico en los que la infección pulmonar trajo como consecuencia una insuficiencia congestiva aguda del corazón. La lesión predominante fue en un caso, neumonía, y en el otro, bronquitis obstructiva. Se discuten series de eventos que condujeron a la insuficiencia cardíaca.

RESUME

Les auteurs rapportent deux cas d'emphysème chronique dans lesquels l'infection pulmonaire eut pour résultat une insuffisance cardiaco congestive aigüe. La lesion prédominante était dans un cas une pneumonie, et dans le second une bronchite obstructive. Les auteurs étudient la succession des circonstances qui entrainent une insuffisance cardiaque.

REFERENCES

EFFECTS OF PULMONARY INFECTION