Relief of Carbon Dioxide Narcosis by Simple Intermittent Positive Pressure Therapy

THEODORE H. NOEHREN, M.D., F.C.C.P.*

Buffalo, New York

Right heart failure has long been a difficult therapeutic problem. Even more of an enigma has been the small percentage of these cor pulmonale patients whose failure is complicated by the progressive accumulation of carbon dioxide in their system, with eventual narcosis of the central respiratory center.

Carbon dioxide narcosis has been the subject of progressively effective study and treatment since the basic pathologic physiology was defined by Scott in 1920.1 He demonstrated that in subjects of longstanding hypoxia, particularly due to pulmonary emphysema, the alveolar air and blood show progressive increases in carbon dioxide tension as a result of impaired ventilation. During this process the respiratory center gradually becomes adjusted to higher carbon dioxide levels, thereby losing its sensitivity of response to this principle stimulus to respiration. Other centers, the chemoreceptors of the aortic and carotid bodies, then must assume control of respiration with hypoxia as their only stimulus. The dangerously hypercapnic and acidotic patient depends upon these secondary centers to regulate his respiration.

The extreme cyanosis often suggests the urgent use of oxygen in these patients. Its administration in the hypercapnic, acidotic individual whose respiration is dependent upon hypoxia, results in relieving hypoxia but in doing so depresses respiration to an even more dangerous level. The patient may deteriorate into coma, delirium, mania or may even die. This contradictory response to oxygen therapy is known as the “oxygen paradox,” and is a cause of much difficulty in treating this condition. Various approaches have been taken to handle this paradox. Cohn, Carroll and Riley2 have detailed the uses of carbon-dioxide-oxygen mixtures, bronchodilators, progressively increasing concentrations of oxygen, carbonic anhydrase inhibitor “6063,” pneumoperitoneum, breathing exercises and the Drinker respirator all of which have been advocated.

The prime need of such patients is the elimination of carbon dioxide by hyperventilation to restore sensitivity to their respiratory center. Wilson3 has demonstrated the need for mechanical assistance in patients with severe emphysema since voluntary hyperventilation leads to only slight increase in minute volume. In 1950 Motley4 advocated the use of intermittent positive pressure for the treatment of pulmonary emphysema. Boutourline-Young and Whittenberger5 later reported success of hyperventilation by the use of the Drinker respirator. Lovejoy6 and his associates confirmed the effectiveness of mechanical ventilation by

*Assistant Professor of Medicine, University of Buffalo School of Medicine, and Department of Medicine, Buffalo General Hospital.
the Drinker respirator and Stone\textsuperscript{7} has added further successes to support this rationale of therapy.

The purpose of this report is to present a more convenient application of intermittent positive pressure therapy and its use with compressed air instead of oxygen in the relief of carbon dioxide intoxications.

\textit{Case Report}

J. M. (B. G. H. A-5401) a 57 year old Italian bellhop was admitted to the Buffalo General Hospital by Dr. Walter Zimdahl, May 28, 1954 with the history of (1) wheezing, productive cough, and intermittent dyspnea for seven years; (2) weakness and persistent shortness of breath for three months and (3) swelling of lower extremities of three weeks duration.

Seven years prior to admission he first suffered episodes of dyspnea associated with wheezing, lasting one to two hours. These were commonly provoked by exertion or upper respiratory tract infections that were not related to any specific insulting agent, although frequently associated with heavy smoking. Copious volumes of thick, white sputum accompanied these attacks. Raising this sputum considerably relieve his respiratory distress.

These attacks increased in frequency and severity until three years prior to admission. Since that time he had little relief. His dyspnea was aggravated by lying down and his ability to work was severely limited. One flight of stairs was his maximum exertional effort. His lips and nail beds became blue. Drowsiness developed into a severe handicap and he frequently fell momentarily asleep while conversing, even when standing.

Three weeks prior to admission, generalized swelling of his lower extremities and abdomen increased his incapacity. Palpitation was marked, particularly after a coughing spell.

Prior to this illness his general health had always been good. There is no history of previous cardiac or respiratory disease; no evidence of asthma. He has a history of urticarial reactions to ingestion of cherries, peaches and prunes. Rather profuse post-nasal and nasal discharge were attributed to sinusitis. He also complained of sharp chest pains during severe attacks of coughing.

He was born in Buffalo, New York and has lived there all his life, residing in one of the industrial areas. He has worked as a bellhop for 18 years. There is no evidence of exposure to concentrations of specific dusts. There have been no operations or injuries.

The functional inquiry revealed the following positive information: lacrimation of the right eye, frequent “colds,” frequent epigastric distress with postprandial gaseous eructations. He smokes two packs of cigarettes and drinks three to four “shots” of liquor and several glasses of beer each day. His eating habits are irregular and he drinks up to 30 cups of coffee a day. His father and mother are alive and well at 88 and 78 years, respectively. Five brothers and two sisters are in good health. He has been married 38 years, has three sons and two daughters, all of whom are now in good health. There is no history of any familial disease except for recent pulmonary tuberculosis in one son.

On physical examination his temperature was 100.2\textsuperscript{\circ} F. (oral), pulse 120, respirations 26 and blood pressure 148 mm. Hg. systolic and 88 mm, Hg diastolic. He weighed 149 lbs. and was a well nourished, well nourished white man who was comfortable, cooperative, and well oriented, but quite drowsy. His mucous membranes were profoundly cyanotic and the general appearance was identified with the text book illustrations of a “black cardiac.” The other positive physical findings included complete edentia and marked distension of his neck veins. Expansion of the thoracic cage was bilaterally equal but limited and expiration was prolonged. There was flaring of his costal margins. The percussion note was hyperresonant throughout, somewhat obscuring the area of cardiac dullness. Expiratory wheezes were heard throughout both lung fields, particularly in the supine position. The heart was enlarged with the point of maximal impulse palpable in the sixth interspace at the midclavicular line. The rhythm was regular and sounds were distant. There was a split first mitral sound and a soft systolic murmur was audible at the apex. His abdomen was soft and pendulous with the liver palpable three fingers below the costal margin. No other organ or mass could be felt. The rectal examination was negative. There was marked pitting edema of both legs extending above the knees. Slight clubbing of the nails was present and the nail beds were deeply cyanotic. His neurologic reflexes were in order.

After admission he was confined to bed and treated with aminophyllin, digitalis, aerosol bronchodilators, diuretics, penicillin, chloramphenicol, and low salt diet. At-
tempts to improve his color with oxygen resulted in periods of irrationality and distress, and had to be discontinued. The admission chest roentgenogram was interpreted by Dr. Gordon Culver as follows: "The leaves of the diaphragm are depressed with multiple diaphragmatic impressions produced by emphysematous bullae at the bases. The vascular markings are increased at the hila, probably secondary to the emphysematous changes. The cardiac silhouette is increased in size; the transverse diameter of the chest is 30 cm., of the heart 15½ cm., suggesting cor pulmonale."

Admission laboratory data included blood glucose—163 mgm. per cent, blood urea nitrogen—18 mgm. per cent, serum sodium—138 mEq./L., bicarbonate—31.8 mEq./L., chlorides—51.0 mEq./L., and a leucocyte count of 18,000 with 30 bands, 51 filaments, one basophil, eight lymphocytes and 10 monocytes. The erythrocyte count was 5,900,000 with a hematocrit of 63 mm., hemoglobin of 16.2 gm., and sedimentation rate 2 mm./hour. The blood smear was interpreted as macrocytic. The electrocardiogram showed sinus rhythm of 112/min. The P-R interval measured 0.18, and the QRS complex was 0.06. There was right axis deviation with a tall RAVR. Right ventricular activity was preponderent as far as the V6 position. It was interpreted as compatible with the diagnosis of cor pulmonale.

Following a week of therapy for the cardiac status, his weight had been reduced to 136 pounds, a loss of 13 pounds with associated improvement in edema of his extremities but with essentially no change in general condition. Arterial gas analyses were determined at this point with the results as charted in Table I.

### Table I

<table>
<thead>
<tr>
<th>Re Cardiac Regime Throughout</th>
<th>Control</th>
<th>IPPB/I with Comp. Air at 29 cm./H₂O</th>
<th>Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>1-7</td>
<td>8-9</td>
<td>10-11</td>
</tr>
<tr>
<td>Weight lbs.</td>
<td>149</td>
<td>136</td>
<td>138</td>
</tr>
<tr>
<td>Temperature</td>
<td>100⁰</td>
<td>99⁰</td>
<td>99⁰</td>
</tr>
<tr>
<td>pCO₂ mm. Hg.</td>
<td>63</td>
<td>49</td>
<td>42</td>
</tr>
<tr>
<td>(Normal 40)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂ Per Cent Sat.</td>
<td>63</td>
<td>94</td>
<td>86</td>
</tr>
<tr>
<td>(Normal 90 &lt;)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH (Normal 7.4)</td>
<td>7.36</td>
<td>7.38</td>
<td>7.43</td>
</tr>
<tr>
<td>Hgb (Normal 14.6)</td>
<td>15.5</td>
<td>15.7</td>
<td>17.5</td>
</tr>
<tr>
<td>Vital Capacity Predicted:</td>
<td>3400 cc.</td>
<td>1680</td>
<td>1957</td>
</tr>
<tr>
<td>Maximum Breathing Capacity</td>
<td>93 L/m.</td>
<td>15.7</td>
<td>30.9</td>
</tr>
</tbody>
</table>

A summary of the clinical and laboratory findings before, during, and following intermittent positive pressure (IPPB/I) therapy. The arterial blood O₂ and CO₂ content were analyzed immediately according to the method of Van Slyke and Neill. The pCO₂ was determined from the nomogram of Singer and Hastings and pulmonary function studies determined by a Collins spirometer as originally described by Baldwin, Courand, and Richards. The pH was determined by glass electrode. (Technical assistance by Mr. Daniel Brittain and Mrs. Leida Ajango).

Throughout the remainder of his course there was no change in medication or treatment with the exception of mechanical hyperventilation by intermittent positive pressure (IPPB/I) on the Pulmonary Ventilator.* (The pressure curve for this machine is illustrated on Figure 1).

For three days he was maintained almost constantly on intermittent positive pressure using compressed air as the motivating power. It was noted during the first 24 hours that he developed periods of apnea lasting 20 to 30 seconds which necessitated constant nursing attention to keep them breathing voluntarily. He was allowed brief periods to rest, eat, go to the bathroom, and have an occasional cigarette. He did

not complain of discomfort at any time during the treatment. Results of this procedure on his blood gases can be seen in Table I. It will be noted that hyperventilation decreased the pCO₂ from 63 to 49 mm. Hg. and increased oxygen saturation from 63 per cent to 94 per cent. Pulmonary ventilation was also increased though this may be more a measure of improved ability to perform the test rather than actual organic change. Improvement was maintained spontaneously thereafter.

Clinically, dramatic improvement emerged. He was more alert, breathing increased in depth, frequency and ease of respiration. His color improved. He was more awake during the day, and was able to sleep at night which he had not previously been able to do. He slept while on the intermittent positive pressure machine. On the fourth day, the intermittent positive pressure was decreased to several 10 minute periods each day accompanied by aerosol bronchodilators.

His clinical condition continued to improve to a nearly normal state. His liver was now palpable only one finger below the costal margin and his peripheral edema was no longer evident. He spontaneously volunteered that he had not felt so well for many months. His exercise tolerance progressively increased to the time of discharge on the 19th hospital day. A venasection of 500 cc. of blood, prior to discharge, altered neither his clinical condition nor the blood chemistries significantly.

Following discharge he returned to work where he was able to perform duties as a bellhop without significant discomfort. He stated that although previously unable to carry an ordinary suitcase from the front door to the desk, he was now able to carry a small trunk up one flight of stairs. This improvement has been maintained for over seven months without further pressure therapy but with continuation of his cardiac regime.

Discussion

The use of the Drinker respirator by Boutourline-Young, Whittenberger and Lovejoy demonstrated the usefulness of intermittent positive pressure in the treatment of carbon dioxide narcosis. Segal has used the demand valve for short term effects. The use of a demand valve-type respirator has been a considerable improvement over the Drinker respirator for the treatment of this condition. Difficulties in accommodating patients of this type to the Drinker respirator were noted by the original workers. Our patient was relatively comfortable throughout the use of IPPB/I

![PULMONARY VENTILATOR](attachment:1955.png)

**FIGURE 1**: The pressure pattern recorded at the mouthpiece of the Pulmonary Ventilator during pressure breathing with this apparatus by a normal individual.
and was essentially self-sufficient. He was able to interrupt his own treatment at will temporarily for eating, talking, bathroom procedures and short periods of rest. Members of his family provided constant nursing attention required to prevent prolonged apnea and to keep him from inadvertently removing the mouthpiece during sleep. His only discomfort was mild irritation of the rubber mouthpiece on edentulous gums. Toward the end of treatment he accommodated completely enough to allow long periods of sleep while on the Ventilator.

The use of compressed air for activation of the IPPB/I avoided the difficulties frequently encountered with oxygen in this type patient. The "oxygen paradox" was not a concern though he went through short periods of apnea during the hyperventilation process. While this was not a serious concern to this patient, in other cases in which this method has been used the degree of apnea has been greater. Manual operation of the demand valve nicely accommodates for that situation and maintains respiration in spite of loss of inherent stimulus to respiration on the part of the patient. This, however, necessitates constant attendance to the patient during the early days of hyperventilation. An air piston actuator is being developed to make this process automatic when the patient becomes apneic.

It is to be emphasized that the ultimate effect of this treatment is entirely dependent upon the underlying cardio-pulmonary pathology. In the case presented, the cardio-pulmonary status was adequate to provide good function once the respiratory center was sufficiently refreshed to allow spontaneous hyperventilation by the patient. In another similar case the rejuvenation of the respiratory center was accomplished quite successfully, so much so, that overexertion following convalescence produced irreversible cardiac decompensation and death. In another case where the arterial carbon dioxide level was equally high but without actual narcosis, hyperventilation effected no reduction of the hypercapnia though anoxia was temporarily relieved. There was no permanent clinical improvement. It would seem, therefore, that the determining factor is not the level of carbon dioxide or oxygen but rather the efficacy of the cardio-pulmonary system to maintain that level within physiologic ranges. This can be improved by maintenance medications.

The most stimulating aspect of this case has been a consideration of possible explanations of the rather dramatic and prolonged success of hyperventilation. The relative influence of the mechanical ventilator, infection, spontaneous hyperventilation and the relationship of carbon dioxide blood tension to pulmonary artery pressure are all worthy of attention.

Prior to IPPB/I therapy this man was incapacitated in spite of adequate cardiac treatment. Following therapy his capacity for activity is markedly increased and maintained on essentially the same cardiac regime. It is difficult to believe that the pressure per se has accomplished this. Ventilation studies on a group of emphysema patients in our own laboratory before and after IPPB/I alone have demonstrated no such dramatic effects.
The relationship of infection to this whole problem is difficult to assay. Some individuals would choose to believe that clearing of the infectious process which, after all, was the final decompensating factor, is the mechanism of his improvement. While this undoubtedly influenced his progress, it is difficult to accept that successful therapy of inflammation of such proportion that it is almost non-existent roentgenologically, could determine the profound alteration in his cardio-pulmonary physiology.

Increased hyperventilation as a result of the reactivated respiratory center undoubtedly affects improvement. However, Wilson et al., have shown that emphysematous patients, in contrast to other anoxic states, are unable to effectively alter their work capacity by voluntary hyperventilation. On this basis, one can not ascribe this improvement entirely to hyperventilation. Another possible explanation is that some alteration is accomplished in the cardiac compensation by correction of the hypercapnic state. A lead in this direction is suggested by the studies of Cade and Miller that IPPB/I alone is of no benefit in chronic pulmonary disease except in cor pulmonale. A singular effect was noted in this group suggesting that there is some influence on the cardiac status.

Experimental studies of Whitaker suggest a possible contributing factor to this singular effect. He studied the pulmonary artery blood pressure by cardiac catheterization in patients with chronic pulmonary disease with, recovering from, and without congestive failure. Simultaneous observations were made on the pulmonary artery pressure, the blood oxygen and carbon dioxide content, the hematocrit value, and oxygen consumption. Patients without heart failure had pulmonary artery mean blood pressures which ranged from normal to twice normal, while those with heart failure had pressures consistently higher than this. Recovery from heart failure was accompanied by a fall of pulmonary artery blood pressure to the same range recorded in patients without failure. This observation suggested that heart failure was not caused by irreversible pulmonary hypertension, as has been frequently postulated in heart failure associated with chronic pulmonary disease.

Arterial and mixed venous anoxia was present in all patients with congestive failure in Whitaker's series, and recovery from failure was accompanied by increase of blood oxygen saturation. However, oxygen breathing in patients with congestive heart failure did not reduce the pulmonary artery blood pressure to recovery levels even though higher degrees of oxygen-saturation were achieved. Hence, Whitaker concluded pulmonary hypertension of congestive heart failure does not appear to be due solely to a pulmonary vasoconstriction produced directly by anoxia.

Carbon dioxide retention appears to be significantly related to the pulmonary hypertension of right heart failure, since it occurred in patients with heart failure and, since experimental work in animals has shown that such retention causes pulmonary hypertension. In 21 observations Whitaker found that the correlation coefficient between elevated pulmonary artery mean blood pressure and the increased carbon dioxide content of the mixed venous blood was 0.94. In cases of chronic pulmonary heart
disease which have been notoriously refractory to oxygen therapy, it is possible that a pulmonary vasoconstrictor effect due to the retention of carbon dioxide has been equal or greater than any dilator effect from the relief of anoxia.

Lovejoy has suggested this and has demonstrated it clinically in at least one patient. Hemodynamic studies prior to mechanical hyperventilation in a patient with carbon dioxide narcosis, revealed a mean pulmonary artery pressure of 60 mm. of mercury. Two and one-half months following clinical relief of carbon dioxide narcosis, the mean pulmonary artery pressure had fallen to 29 mm. of mercury with a decline in the partial pressure of the arterial carbon dioxide from 77 to 48 mm. of mercury, and an associated rise in oxygen saturation from 50.5 to 86.7 per cent.

In the cases such as reported by Lovejoy and in this paper, where the response to hyperventilation of carbon dioxide has been greater than anticipated, it is possible the correction of hypercapnia has lowered the pulmonary artery pressure sufficiently to allow compensation of the failing right ventricle. The combined effect of restoration of sensitivity to the respiratory center, plus this added compensation of the circulatory system may account for much of the continued improvement in our patient. In addition, recurrence of the hypercapnia is prevented by the sensitive respiratory center, which, in turn, avoids the pulmonary hypertension which previously induced cardiac failure. A balance then in both the respiratory and circulatory systems will allow a greater work tolerance. Hyperventilation in patients with carbon dioxide narcosis could conceivably produce both of these effects and afford considerable increase in activity to the patient, as was demonstrated in our case. Further catheterization studies similar to those of Whitaker and Lovejoy will be necessary in patients of this type to substantiate these concepts.

SUMMARY

The history of a patient is presented in which severe carbon dioxide narcosis and right heart failure resulted from long standing pulmonary emphysema. The usual cardiac regime was ineffective and relief was obtained by the use of simple intermittent positive pressure therapy on compressed air. It is suggested that pulmonary hypertension from the hypercapnia may be the controlling factor in patients of this type.

RESUMEN

Se presenta la historia de un enfermo en el que ocurrió narcosis severa causada por el dióxido de carbono e insuficiencia cardíaca derecha como resultado de enfisema pulmonar de larga duración.

El régimen cardíaco habitual fue ineficaz y el alivio se obtuvo por el uso simple de presión positiva intermitente con aire comprimido. Se sugiere que la hipertensión pulmonar por hipercapnia puede ser el factor dominante en enfermos de este tipo.

RESUME

L'auteur rapporte un cas dans lequel une sévère perte de connaissance, avec insuffisance du coeur droit due à l'acide carbonique provenait d'un
emphysème pulmonaire déjà ancien. La thérapeutique cardiaque habituelle fut inefficace et le soulagement ne fut obtenu que par respiration d'air comprimé sous pression positive intermittente.

L'auteur émet l'hypothèse que l'hypertension pulmonaire due à l'hypercapnie pourrait être le facteur décisif chez les malades de ce type.

REFERENCES