The Lewis A. Conner Memorial Lecture
The Nature of Cardiac and of Pulmonary Dyspnea

By Dickinson W. Richards, Jr., M.D.

Dyspnea has many characteristics, differing from one clinical state to another. In pulmonary diseases the immediate cause is usually a disproportion between actual ventilation (breathing requirement) and breathing capacity. The hyperventilation of organic pulmonary disease is often mistakenly diagnosed as psychoneurosis. In early cardiac dyspnea, muscular fatigue associated with inadequate cardiac output may be a factor. True pulmonary congestion becomes important in more advanced left ventricular failure.

Dr. Lewis Atterbury Conner, for whom this lectureship is named, died on Dec. 4, 1950, at the age of 84. A man of outstanding achievement and broad interests, he was throughout his long life primarily a clinician and a teacher of medicine. He was a master in the art and science of physical diagnosis, and was among those who hold firm to the belief that new advances should support and add to our simpler forms of knowledge, rather than replace them; that in the analysis and treatment of disease, laboratory findings, whatever their nature, should be our servants and not our masters.

In dealing with clinical situations generally one can well argue for an approach that is and remains comprehensive and inclusive, not exclusive or partial. As Whitehead has so powerfully argued, the unit of reality is not a name, or a definition, or a formula, or even a theory. It is an event, a whole event, an experience. In clinical medicine the event is the patient.

Nowhere in medicine, perhaps, does the patient, whole and entire, so much need to be considered as in the field of respiration. Breathing is truly a strange phenomenon of life, caught midway between the conscious and the unconscious, and peculiarly sensitive to both. Dyspnea, the major symptom of disordered breathing, which is the subject of this lecture, deserves, therefore, at the very start of our discussion, some orientation as to its intrinsic nature, and we come, even upon the most casual examination, to a realization that this is actually very different from one clinical state to another.

There is, for example, the dyspnea of the athlete, the mountain climber, a powerful muscular effort that becomes a part of the exhilaration of utmost physical effort. Very different is the dyspnea of asthma, the hard gasping, the combination of panic and exhaustion that oppresses the man whose airways are closing down; or the even more agonizing slow suffocation of the man with a tracheal tumor. Still different is the dyspnea of the cardiac, breathlessness compounded with profound exhaustion, sometimes also with cardiac pain, anxiety, and fear. Thus, in addition to differences in dyspnea itself, there are not infrequently adjuvant bodily disturbances, such as muscular fatigue or pain, that are unconsciously included, both by patient and doctor, in the symptom. In my further discussion, I shall endeavor to keep before us an awareness of these important distinctions.

Physiologically, dyspnea is defined as breath-
ing associated with effort or distress, including here both subjective breathlessness and the objective evidences of labored breathing. As a simple description of the process, Courand and I\(^2\) suggested, a number of years ago, the statement that dyspnea occurs whenever the individual’s actual ventilation cannot easily be provided by his breathing capacity—a statement not greatly different from that by Means\(^3\) a decade earlier. This is obviously an oversimplification, but it applies well to several forms of dyspnea, especially those occurring in chronic pulmonary disease. It also brings forward three of the main features to be studied: breathing capacity, an anatomic and mechanical function; breathing effort, also a mechanical function; and ventilation or respiratory drive producing actual ventilation, largely a physicochemical or neurogenic function.

This simple statement of factors, or influences, producing dyspnea is set forth in the chart in figure 1, and this will form the plan of this presentation. Referring very briefly to such conditions as obstructed or retarded breathing. The simplest method of including the time factor is to have the subject’s maximum voluntary effort measured, as for example, by a tracing recorded on a moving drum to produce the familiar spirogram.\(^4\) The details of the spirogram, in quiet and maximum breathing, and in normal and abnormal subjects, are well known and do not require special review.

The maximum breathing capacity has in fact been used as an index of pulmonary function or of dyspnea, just as vital capacity formerly was; and simplified indices have been developed which give a measure of speed and volume of ventilation. The recent air velocity index of Gaensler\(^5\) is a modification of this, an extension of the earlier method of Gaubatz.\(^6\) This, however, leaves out of consideration the amount that the individual actually does ventilate under the given conditions of rest or stress, whether hyper- or hypoventilation. There have also been indices of actual ventilation only, with no regard for ventilatory capacity. Among the best known of these is the so-called ventilatory equivalent of Anthony\(^7\) and Knipping,\(^8\) the amount of ventilation needed per liter of oxygen consumption, a factor obviously increasing as hyperventilation increases.

We have found, however, as might be expected, that ventilatory sufficiency, or insufficiency or dyspnea, is better evaluated by considering both factors, breathing capacity and actual ventilation. We have therefore used the breathing reserve (Knipping\(^9\)), which is the maximum breathing capacity minus the actual ventilation, or the reserve of ventilation still available at any moment. This difference, expressed as a percentage of the maximum breathing capacity, was found by Courand and myself\(^10\) to define quite well the appearance of dyspnea, in various normal and abnormal subjects, when it reached a value below about 70 per cent or 65 per cent. Wright\(^11\) has a somewhat similar dyspnea index which is the actual ventilation divided by the maximum breathing capacity. These two are of course only approximate measures of the entire process. The factors of rate of breathing and effort of breathing in the dyspneic state are not included. I will refer to these later.

![Diagram](image-url)

**Fig. 1.**
The mechanical factors that may limit maximum breathing capacity are of course many: deformities of the chest cage, defects in the musculature involved in respiration, pleural thickening, hydrothorax, loss of pulmonary elasticity and expansibility through fibrosis or other intrinsic pulmonary disease, and other factors.

The many patients in this category can be illustrated by the first case, that of a woman of 40 with widespread fibrotic pulmonary tuberculosis, who had also had a partial left thoracoplasty. She became dyspneic on moderate exertion, the dyspnea subsiding promptly when she stopped and rested. Figure 2 shows a ventilatory tracing from each lung obtained by bronchopneumotachometry, and indicates a marked decrease in ventilatory capacity as well as oxygen consumption of the left lung. Table 1 gives her over-all respiratory function. As you will see, her difficulty is simply that of restricted breathing mechanics. Inelastic lungs have shrunk her vital capacity and reduced her maximum breathing capacity to one-half the estimated normal for an individual of her size and age. Her actual ventilation, in rest and exercise, and her blood aeration are practically within the limits of normal. She is dyspneic on exertion solely because of restricted ventilatory capacity.

This is probably the most benign form of dyspnea, at least in its moderate stages. With symptoms appearing only on considerable exertion, many are unaware of any limitation in their physical capacity. As Wright11 has shown, many individuals with uncomplicated second-stage silicosis are in this category, so long as the silicosis is not complicated by emphysema.

In the majority of the more serious forms of diffuse pulmonary disease with functional disability, however, there is usually disturbance also in the third of the major influences on respiratory activity as given in our initial diagram, namely, respiratory drive or stimulus.

As to actual pulmonary ventilation, hyper- or hypoventilation in clinical conditions, there have been many general statements, but not much careful analysis. Even some modern textbooks, for example, still give out the general dictum that patients in chronic cardiac failure typically hyperventilate while patients with chronic pulmonary failure do not. We have been gathering data in both groups over a number of years, and can say categorically that no statement could be further from the truth than that.

But in order to understand the cause and nature of a patient's actual ventilatory performance, one should know several things: (1) the efficiency or inefficiency of the alveolar air exchange; (2) the effectiveness of aeration of the blood; (3) the effectiveness of transport of these gases, these chemical stimuli, to the respiratory centers by the circulation; and (4)

TABLE 1.—Chronic Pulmonary Tuberculosis
(Patient A. S. Female, Age, 40 years)

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Normal Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital capacity, cc</td>
<td>1175</td>
<td>3480</td>
</tr>
<tr>
<td>Maximum breathing capacity, L./min.</td>
<td>52</td>
<td>97</td>
</tr>
<tr>
<td>Pulmonary ventilation, L./min./sq.m.B.S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td>After 1 minute exercise</td>
<td>13.1</td>
<td>11.9</td>
</tr>
<tr>
<td>Arterial oxygen saturation, percent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>94</td>
<td>96</td>
</tr>
<tr>
<td>After 1 minute exercise</td>
<td>91</td>
<td>96</td>
</tr>
</tbody>
</table>
how these influences, and others as well, combine to produce the final respiratory stimulus.  

1. The distribution of inhaled tidal air to perfused alveolar spaces may be somewhat unequal even in normal subjects, and is often markedly so in many forms of pulmonary disease. Some air spaces are greatly overventilated, others underventilated. There is ventilation of regions having no blood perfusion. In the terms of respiratory physiology, the ineffectual or dead space component of ventilation is usually increased in diffuse chronic pulmonary disease.  

Thus to provide for adequate respiratory gas exchange total ventilation must also increase. Here respiratory rate is often of prime importance, the patient with rapid shallow breathing ventilating chiefly his pulmonary airways, with little effective aeration of alveolar spaces.  

2. As distribution of inhaled air deteriorates further, alveolar air stagnates in some parts, where active blood perfusion continues, and aeration of the blood becomes inadequate here, even in the presence of total pulmonary hyperventilation. Arterial anoxia then ensues. With a thickened or edematous alveolo-capillary membrane, the tendency to anoxia is increased.  

The elimination of carbon dioxide by the lungs differs from that of oxygen in that with sufficient hyperventilation of perfused and well ventilated spaces, the stagnation in poorly ventilated spaces can often be compensated and blood carbon dioxide levels remain normal. When there is carbon dioxide retention in chronic pulmonary disease, this usually indicates an inadequate respiratory stimulus. I will return to this point later.  

3. If there is retarded blood flow, venous anoxia and hypercapnia are increased in the tissues, including the tissues of the respiratory centers, and this may increase the respiratory stimulus.  

4. We have just remarked that with ineffectual alveolar ventilation, total ventilation “must be increased” to provide normal gas exchange. This teleologic statement, of course, explains nothing, and requires mechanistic support. How is such hyperventilation brought about? What are the active respiratory stimuli? This question brings us into the midst of a controversy that has been tossed about among physiologists for well over half a century. In his great book on Blood: A Study in General Physiology, published 24 years ago, L. J. Henderson concluded that there was not one respiratory stimulus, but many. This point of view has been taken up again recently by J. S. Gray, who has developed a number of quantitative relations, on the basis of published data. He demonstrates that low oxygen tension, or partial pressure, in the blood, high carbon dioxide tension, and increased blood acidity are all positive stimuli to the respiratory center. Depending upon the level of each in a given physiologic situation, these supplement or inhibit one another, and the net respiratory stimulus is the algebraic sum of all. Thus Gray finds that pure anoxia of marked degree is a powerful respiratory stimulus, but the usual hyperventilation in anoxia promptly lowers carbon dioxide partial pressure and raises pH and so the net effect is small. On the other hand, anoxia in the presence of normal or high carbon dioxide tension and low pH should cause, and does cause, very marked hyperventilation. Table 2, taken from Gray’s monograph, shows how these three stimuli may interact in various clinical conditions associated with hyperpnea. In muscular exercise, the three stimuli are inadequate to explain total ventilation, and Gray postulates a fourth, as yet not identified.  

Given a certain total respiratory stimulus, the actual manner in which ventilation is car-

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**Table 2.—Behavior of Arterial Chemical Agents in Various Types of Hyperventilation**

(from Gray, J. S. Pulmonary Ventilation)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Max. Vent. L/min.</th>
<th>Changes in Arterial</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anoxia</td>
<td>12</td>
<td>− − +</td>
<td></td>
</tr>
<tr>
<td>CO₂ Inhalation</td>
<td>70</td>
<td>+ + −</td>
<td></td>
</tr>
<tr>
<td>Metabolic Acidosis</td>
<td>35</td>
<td>+ − −</td>
<td></td>
</tr>
<tr>
<td>Moderate Exercise</td>
<td>50</td>
<td>± ± ±</td>
<td></td>
</tr>
<tr>
<td>Severe Exercise</td>
<td>120</td>
<td>± − −</td>
<td></td>
</tr>
</tbody>
</table>

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ried out—rapid and shallow, slow and deep, regular or irregular—is conditioned, as Hess, Fleisch, and others pointed out years ago, by the patient’s anatomic limitations and by countless proprioceptive and other reflexes streaming in from all parts of the breathing mechanism. All breathing is thus reflexly stimulated and conditioned, just as all breathing is also chemically stimulated.

Finally, over and above the chemical and reflex influences, the final ventilatory performance is influenced, more or less, by conscious or subconscious psychic influences.

![Fig. 3. Patient M. C. Advanced silicosis.](image)

One further point on methods of study. To measure dyspnea, except in advanced states, the individual has to be put under some sort of stress. One simple technic has been the breath-holding time; but variations in conscious effort from patient to patient render this unreliable. The most direct and generally satisfactory is an exercise test. A continued mild-to-moderate exertion, such as walking on a treadmill, which provides a physiologic steady state, over several minutes’ time, is best. As a simple index of pulmonary function, however, a single step test of brief duration is often adequate. In most of our clinical studies we have used a single step, 30 times in one minute, and measured ventilation at rest, during exercise, and for five minutes during recovery. This gives a fairly consistent increase in oxygen consumption, an index of the amount of additional work done, although the total “oxygen debt” may not be completely paid by the end of the five-minute recovery period.

The next clinical case will illustrate the manner in which, in the course of severe, progressing pulmonary fibrosis, a restricted ventilatory capacity, combined with a hyperactive respiratory center, greatly aggravates the patient’s clinical dyspnea. The patient was a man of 66 with advanced silicosis, complaining of severe dyspnea on mild exertion. Figure 3 shows the x-ray of his chest, and table 3 a summary of the findings on physiologic study. The patient has a moderately reduced vital capacity and maximum breathing capacity, but a striking thing also is his marked hyperventilation, both at rest and in the mild standard exercise (30 steps in one minute), ventilation being almost twice that of a normal subject. His dyspnea is easily explained, since the reduced breathing capacity and high actual ventilation leave him with a much reduced breathing reserve.

But why should he hyperventilate? He has an increased pulmonary dead space—that is, he ventilates unperfused alveolar spaces—but

### Table 3.—Cardiopulmonary Function in Advanced Silicosis

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital capacity, cc.....</td>
<td>2210</td>
<td>3800</td>
</tr>
<tr>
<td>Maximum breathing capacity, L./min.</td>
<td>64</td>
<td>88</td>
</tr>
<tr>
<td>Ventilation, L./min./sq.m.B.S.....</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>5.1</td>
<td>3.9</td>
</tr>
<tr>
<td>1 minute exercise</td>
<td>23.0</td>
<td>11.2</td>
</tr>
<tr>
<td>1st minute recovery</td>
<td>22.0</td>
<td>14.5</td>
</tr>
<tr>
<td>Arterial oxygen saturation, percent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>95</td>
<td>96</td>
</tr>
<tr>
<td>Exercise</td>
<td>97</td>
<td>96</td>
</tr>
<tr>
<td>Arterial CO₂ tension, mm.Hg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>34</td>
<td>40</td>
</tr>
</tbody>
</table>
even so the ventilation of perfused alveolar spaces is such that he keeps his blood carbon dioxide level, his carbon dioxide tension, well below normal (34 mm. Hg compared with the normal 40 mm. Hg). Arterial oxygen saturation is normal, at rest and in exercise. There was no evidence of cardiac insufficiency here. Catheterization showed that cardiac output was normal; there was only a mild pulmonary arterial hypertension and no increase of systemic venous pressure.

Figure 4 shows the same phenomenon, a moderate hyperventilation compared with normal values in a group of 14 patients with uncomplicated pulmonary fibrosis, at rest, in exercise, and during five minutes’ recovery.

| Fig. 4. Pulmonary ventilation, at rest, exercise, and recovery, in 25 cases of pulmonary fibrosis (solid line) compared with normal subjects (dotted line). |

Is this hyperventilation functional, a sort of hysterical dyspnea? Such is always conceivable, but there is, by and large, nothing else to support such an explanation in this large group of chronic advanced cases of diffuse pulmonary fibrosis.

Is it reflex dyspnea? In the sense that the patient does overbreathe to the extent of keeping his blood carbon dioxide at an arterial tension of 34 mm. Hg, which is well below normal, one may well argue that the Hering-Breuer impulses or other reflex mechanism are exaggerated in this case. We do not have a complete and satisfactory explanation here, but there is some evidence to suggest that if we could add up correctly all the basic chemical stimuli, after the manner of Gray, we might come out with a sufficient chemical explanation. One fact of importance is that with lowered carbon dioxide tension, a respiratory center does become more sensitive. Another is that in this type of case, in spite of practically normal blood oxygen values and apparently normal circulatory performance, the administration of oxygen often definitely lowers pulmonary ventilation. This has been known for many years. It suggests that there may be here a significant anoxic respiratory stimulus, in spite of apparently normal arterial oxygen saturation.

But the question of the functional or psychic aspect of clinical dyspnea is a most important one, both in pulmonary and cardiac dyspnea, and frequently difficult of analysis. I am not speaking of the true respiratory neuroses; these are relatively simple, either the compulsion neurosis, the repeated sighing respirations, or the attacks of hysterical dyspnea in the typical anxiety state. The difficult problem is that of the patient with some pulmonary disease, and much dyspnea and hyperpnea.

An interesting group in this category is that studied during the war by Galdston, Luet-scher, and their collaborators following acute phosgene poisoning. These cases presented many interesting details; one of the striking features being the frequent persistence of the symptom of dyspnea long after the patient’s x-ray had completely cleared, physical examination was normal, and pulmonary function measurements had returned nearly to normal, also.

I shall present one of their cases briefly: a woman of 43 with a past history including considerable nervous and emotional instability. She suffered moderately severe exposure to phosgene, with development of pulmonary edema and acute respiratory insufficiency, requiring pressure-oxygen therapy and other measures for several days. X-ray and physical signs then improved steadily, but for several months thereafter, her nervous symptoms were aggravated, and she suffered from exertional dyspnea and, in addition, from independent
episodes of breathlessness coming on without apparent cause.

The measurements of her pulmonary function several months after the phosgene exposure, when x-ray and physical signs were normal, consisted of a normal vital capacity, maximum breathing capacity that was somewhat reduced, some hyperventilation at rest and on exertion. Arterial oxygen saturation was essentially normal. Thus with the mild degree of these deviations from normal, it would seem that the functional factor here was an important one. On the other hand, the pattern of respiration was not dissimilar from that of the cases of unquestioned pulmonary fibrosis just considered. Are we entirely sure that this patient may not have had mild recurrences of pulmonary edema, giving symptoms, but sub-clinical to x-ray and physical signs?

There is no doubt that anxiety may play a part in the dyspnea of these patients, and the more so the more they become pulmonary cripples; and this mental state needs study and care. On the other hand, we are seeing more and more of these patients whose physical disease has been either undetected or else disregarded, and who are considered to be mental cases only. Surely there is no more bitter punishment that a doctor can inflict upon a patient than a mistaken diagnosis of psychoneurosis. With no treatment, understanding or even sympathy for his underlying condition, he is often driven, by doctor, friends, and family alike, into activities which he cannot endure. Physically sick and exhausted, he can get no honest hearing, his perplexity deepens into depression, only to have himself further stigmatized as a hopeless neurotic. Our pulmonary clinics are increasingly populated by the victims of these blunderings of our psychosomatic enthusiasts.

At all events, it would seem wise in cases like this not to brand the patient too freely as psychoneurotic; or at least to judge the special manifestations of neurosis on their own merits only; but in cases where there is or has been respiratory disease or injury, to treat the hyperventilation syndrome as primarily a response to organic disease.

A few comments now on dyspnea in the group of chronic pulmonary diseases known as diffusion insufficiencies. By diffusion insufficiency, I mean that group of diseases, to which Hamman and Rich first called attention in this country, including beryllium granulomatosis, Boeck's sarcoid, scleroderma of the lung and other conditions in which the important pathologic lesion is the creation by the disease process of an alveolar-capillary block causing impaired diffusion of oxygen into the pulmonary blood. The symptoms are marked dyspnea, hyperpnea and tachycardia, cyanosis after exercise, cough, often febrile episodes, clubbing of fingers and toes. Hyperventilation is so marked

![Graph](image-url)  
**Fig. 5.** Pulmonary ventilation in 25 cases of diffusion insufficiency (alveolar-capillary block), compared with normal subjects.

in these cases that they too have not infrequently been diagnosed as psychoneurosis.

Physiologically, these cases are characterized by a symmetric reduction in lung volumes due to their diffuse fibrosis, a remarkable maintenance of maximum breathing capacity, arterial oxygen saturation little reduced at rest but markedly decreased in exercise, carbon dioxide levels somewhat low in milder cases but essentially normal in the more advanced.

The extent of their hyperventilation is shown in figure 5, and this sufficiently explains the urgent and continuous dyspnea which is the dominant symptom of this disease. On the Gray hypothesis, with a normal or nearly normal carbon dioxide pressure and an unimpeded anoxic stimulus, the chemical basis for hyperp-
nea is perhaps adequate but there may well be other factors. There is, for example, the question whether there may not be a cardio-circulatory element as well, a retarded circulation increasing the stimulus in the respiratory center. We have measured cardiac output in some of these cases and it appears to be adequate both in rest and in exercise, except late in the disease. A further evidence of the significance of anoxia in diffusion insufficiency is the striking relief which is obtained, with sharp reduction in ventilation, through adequate oxygen therapy.

I have given but little attention thus far to the second of the categories of ventilatory me-

Table 4.—Forms of Pulmonary Dysfunction Causing
Dyspnea in Chronic Obstructive Emphysema

<table>
<thead>
<tr>
<th>I. Factors Decreasing Breathing Capacity, and Increasing Ventilatory Effort</th>
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<tbody>
<tr>
<td>Narrowing of Air Passages</td>
</tr>
<tr>
<td>Inelasticity of Pulmonary Tissue</td>
</tr>
<tr>
<td>Hyperinflation of Lungs and Chest</td>
</tr>
<tr>
<td>Spasm and Asynergy of Respiratory Muscles</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>II. Factors Increasing Respiratory Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enlarged Intrapulmonary Volume, and Poor Distribution of Inhaled Air</td>
</tr>
<tr>
<td>Impaired Alveolar-Capillary Diffusion</td>
</tr>
<tr>
<td>Anoxia</td>
</tr>
<tr>
<td>Hypereapnia</td>
</tr>
<tr>
<td>Decreased Arterial pH</td>
</tr>
</tbody>
</table>

chanics concerned in dyspnea, namely, the effort or work involved in the breathing process. Is the effort per breath increased in these cases of diffuse pulmonary fibrosis? We have no good information on this point. We do know that the air passages are not obstructed, but it may well be that the loss of elasticity in pulmonary tissues provides an added burden to respiratory effort. However this may be, this factor becomes a very potent contributing cause of dyspnea in the next and final group of pulmonary diseases to be considered, namely, pulmonary emphysema.

It would be difficult to construct, scarcely even to imagine, a type of disease in which there occurred simultaneously more different kinds of pulmonary dysfunction than are found in advanced pulmonary emphysema. Correspondingly, a great deal has been learned about pulmonary and cardiopulmonary function through continued studies, in a number of clinics in this country and abroad, on this disease or group of diseases.

Table 4 summarizes the more important of these dysfunctions. The basic change morphologically is usually a combination of obstruction of air passages, loss of intrinsic elasticity, and trophic change in pulmonary tissue. These lead early to the assumption of the chronically maintained state of hyperinflation of the chest, since thus air passages are wider, and intrapleural pressure can again be negative or neutral. But hyperinflation with elevated anterior chest and lowered diaphragm is most unfavorable for ventilatory activity. The whole muscular framework in emphysema becomes spastic and asynergic. All these factors increase greatly the actual work or effort per breath. This was well demonstrated by Christie some years ago in his measurements of intrapleural pressure, in relation to breathing, in normal and emphysemous subjects, in which he showed that inspiration and expiration in emphysema were associated with wide swings of pleural pressure above and below zero level, indicating an inelastic lung and greatly increased effort in providing its ventilation.

Intrapulmonary air exchange in emphysema is greatly compromised. Maximum breathing capacity is reduced, due chiefly to expiratory retardation. Hyperinflation, with increased residual air, means relative ineffectiveness of tidal air aerating the lung spaces, but much more important is the uneven distribution of mixing within the lung itself, some parts being hyperventilated, others greatly hypoventilated. The former leads to hyperpnea, the latter to anoxia and eventually to carbon dioxide retention. Finally, the attenuated pulmonary capillaries and often a progressively developing pulmonary arteriosclerosis lead to pulmonary arterial hypertension and eventually right heart failure.

Clinically, the progress of emphysema can be considered as falling into four classes. At first there is decreased maximum breathing capacity, some hyperpnea, with therefore exertional dyspnea as a major symptom, but normal aeration of the blood. When pulmonary
ventilation deteriorates further, there is inadequate oxygenation of arterial blood, especially in exercise. Still further insufficiency brings inadequate carbon dioxide elimination by the lungs, and carbon dioxide levels in blood and tissues rise, along with more advanced anoxia. With the rising anoxia and carbon dioxide levels, and falling blood pH, one would expect that the final stage would be associated with excessive hyperventilation and dyspnea, but at this point another change has occurred. The chronic hypercapnia, the increased carbon dioxide, actually deadens the respiratory center, and its insensitivity results in a failure of ventilatory volume even to reach normal values. This is shown in figure 6, where the ventilation in rest and exercise of the four stages of emphysema are charted. Anoxia is of course now further increased, and the vicious cycle becomes in fact complete.

Thus in the most advanced emphysema, usually the cases with cor pulmonale in failure, the patients, while dyspneic, are sometimes not urgently so, in spite of profound anoxia. It is in this state that the use of morphine is especially hazardous, and oxygen therapy, by removing the anoxic stimulus to respiration, induces ventilatory stagnation, with excessive carbon dioxide retention and carbon dioxide narcosis.

With the above principles in mind, it is not surprising that the present-day treatment of
emphysema has shifted from the mere administration of cough mixtures, sedation and oxygen, to a vigorous effort to open the air passages, and ventilate the lungs by mechanical aids, corrective exercises, and artificial respirators.

To those of you primarily interested in heart disease, this excursion into pulmonary physiology has been a long introduction. But I believe that the nature of cardiac dyspnea can be clarified by comparison with these simpler pulmonary forms.

While the principles explaining the causes of dyspnea in heart failure have not changed greatly since, let us say, the publication of Harrison's *Failure of the Circulation* in 1935, much has been added in the way of evidence: by cardiac catheterization, by new methods of pulmonary study, and quite recently by some of the physiologic results of mitral valve surgery.

Obviously the basic defect in heart failure as compared with pulmonary failure, is inadequate performance of heart and circulation, rather than inadequate performance of the lungs. Ever since it was known that the cardiac patient could not increase his oxygen consumption, his oxygen intake, in exercise as much as a normal subject, it was assumed that this was because cardiac output failed to increase adequately, oxygen thus could not be conveyed to tissues, and carbon dioxide from tissues, in sufficient quantity. Relatively retarded blood flow, increasing anoxia and acidity in the respiratory center would induce hyperpnea; and the prolongation of the hyperpneic state during the recovery period, so characteristic a feature of cardiac dyspnea, was explained by the slow restoration of tissues to their metabolic resting state.

A more specific pulmonary component of congestive heart failure was postulated some 60 years ago by von Basch—the stiffening of the lungs that would be expected to occur with pulmonary vascular congestion— and this received much emphasis when Peabody demonstrated the decrease in vital capacity and ventilatory capacity with advanced congestive failure.

Cardiac catheterization studies have now amply confirmed both hypotheses: the failure of normal increase in cardiac output in exercise, and the early abnormal rise in pulmonary arterial pressures in exercising cardiac subjects.

There has recently arisen also something of a controversy on the nature of cardiac failure, whether the failure of cardiac output is all-important, or whether the congestive state as such, "pressure failure," so to speak, may itself play a dominant part in the symptomatology.

Some evidence which I shall now present suggests that there may be differences in rela-

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**FIG. 7.** Pulmonary ventilation in 17 cases of ambulatory rheumatic heart disease, with limited cardiac reserve.

**FIG. 8.** Maximum breathing capacity and mean pulmonary arterial pressures at rest in 15 rheumatic cardiac patients (dots) and two patients with emphysema (triangles).
tive importance of these factors as one moves from the milder degrees of heart failure to the more severe. Specifically, the effects of retarded blood flow appear to be dominant early in failure, the evidences of pulmonary congestion becoming more important when failure is advanced.

Let us take first the ambulatory cardiac patient. West, Bliss, and Wood have recently studied cardiopulmonary function in a group of subjects with rheumatic valvular disease, by measurements at rest and in steady exercise during cardiac catheterization.

Their performance was as follows: a moderate continued hyperventilation, a relatively poor increase in cardiac output in exercise, with a rise in pulmonary arterial pressure. Since there was some decrease in arterial carbon dioxide tension, a washing out of carbon dioxide by the hyperpnea, one could argue that some of the hyperventilation was on a “reflex” basis. So far as dyspnea is concerned, however, the actual increase in ventilation was slight, much less than in our pulmonary cases previously described. This is shown in figure 7. Furthermore, maximum breathing capacity was relatively well maintained, even with considerable increase in pulmonary arterial pressure. This is shown in figure 8. Thus breathing reserve was not greatly diminished.

Do we have then an adequate cause for the significant exertional symptoms that some of these patients complain of? It may be that there is increased effort per breath and that dyspnea may be aggravated by this. It seems probable, however, that there may be at least one other factor also.

A patient studied some years ago by Dr. Baldwin and myself may give a clue here. This was a man of 49 with longstanding cardiac hypertrophy and dilatation on a hypertensive basis. He had had one episode of congestive failure. At the time of study he was compensated at rest but his exercise tolerance was much reduced.

In our study he endeavored to carry out a mild 30-step exercise test, but could not finish, stopping after 16 steps only. Examination of his pulmonary function showed that his vital and maximum breathing capacities were perfectly normal both before and after the test; there was no abnormality either in arterial oxygen saturation or in carbon dioxide. His pulmonary ventilation during the slight exertion was but little increased, actually significantly less than a normal subject with the 1-minute step test, as shown in figure 9. Closer inquiry revealed that he really was not stopped because of dyspnea but because of fatigue or exhaustion. It was not cardiac pain; as a matter of fact, when the patient finally died two or three years later, he did not have significant coronary narrowing.
What was the cause of this muscular exhaustion? We have found it, as have others, to be a prominent symptom in some of our cases of advanced mitral disease admitted for surgery, and here it seems to be associated with very low and fixed cardiac output. These patients notice it more acutely if they suddenly become free of the symptom after successful commissurotomy. May it not be, therefore, that inadequate blood flow manifests itself by this symp-

ptom of fatigue, which has been mixed with, and yet is really separate from, the symptom of dyspnea itself? Perhaps by a more exact and careful clinical history, clinicians will be able to identify this fatigue or exhaustion factor, as well as by complex laboratory tests.

As the state of left ventricular failure advances, we find corresponding changes both in pulmonary and in cardiac measurements. Figure 10 from West, Bliss, and Wood shows how the oxygen concentration in expired air, which is essentially the reciprocal of pulmonary ventilation, decreases with rising pulmonary congestive hypertension. Expired air oxygen concentration is used in these spot charts, in preference to actual volumes of pulmonary ventilation, since it indicates the degree of ventilation or hyperventilation per unit of oxygen absorbed, and therefore permits comparison of values in individual subjects with different oxygen intakes.

The relation with cardiac output in exercise is even more striking: there appears to be only a moderate increase in ventilation (decreased oxygen per cent) until cardiac output has dropped to a really low value, below which the degree of hyperpnea is markedly aggravated, presumably associated with hypoxia of brain and tissues. This is due in large part to retarded blood flow, though we are finding a fair number of cases in which the acute pulmonary congestion of exercise is associated with some arterial anoxia, with therefore a further anoxic respiratory stimulus. One wonders whether an abrupt shift of this kind, in pressure or output, or both, may not be the trigger that sets off an attack of paroxysmal dyspnea or cardiac asthma, this in turn induced by some small
change in vascular fluid balance, vasomotor state, or intercurrent infection, a small pulmonary embolus or other disturbance.

Effort of breathing is increased in pulmonary congestion. This was well shown in the original studies of Christie and Meakins.\textsuperscript{28} By continuous intrapleural pressure recording, they showed markedly increased pressure swings between inspiration and expiration, during congestive failure, decreasing toward normal after recompensation.

As for the important question whether the pulmonary congestive state as such without alteration in cardiac output can be chiefly responsible for the disabling symptoms of advanced left heart failure, we believe that we have a definitive answer from some of our studies of mitral disease before and after commissurotomy. The following case is taken from a recent report\textsuperscript{29}:

The patient, an electrician of 38, had had increasing exertional dyspnea, with attacks of paroxysmal dyspnea, for two years, and at the time of admission had been totally disabled for six months, was orthopneic, dyspneic on talking or the least exertion in the hospital. He had auricular fibrillation and mitral stenosis. Figure 11 shows his cardiodynamics pre- and postoperatively. You will see preoperatively a low cardiac output, which failed to increase on exercise, and a marked pulmonary hypertension, which rose further during and for a time following the exercise test.

In the next column of this figure are the measurements one month after a successful commissurotomy. The patient at this time was clinically well, with no dyspnea, no orthopnea, able to climb two flights of stairs, though his exercise tolerance was still significantly reduced. From the measurements you will see that while there was a slight increase in resting cardiac output, this did not increase further in exercise. The major change was the considerable drop in pulmonary vascular hypertension. The point here, therefore, is that pulmonary congestion would appear to be the chief and key disability in some at least of these cases of rheumatic heart disease in failure, and that its relief restores the patient to clinical compensation on limited activity.

The last column in figure 11 shows how 11 months later, this patient had made definite further improvement with even lower pulmonary vascular pressures and a better cardiac output. Now the patient had returned to normal activity in practically all respects.

The forms of dyspnea in far advanced congestive failure need not detain us long. Orthopnea, one of the standbys in differentiating cardiac from pulmonary dyspnea, seems at least partly explained since we know that the supine position brings more blood to the heart and lungs, adds to an already excessive cardiac filling, increases pulmonary congestion, decreases vital capacity and breathing capacity.

The increased tachypnea and hyperpnea in advanced heart failure raises again the question of reflex factors in lungs, great vessels or elsewhere, but again the marked and consistent relief obtained by oxygen therapy brings us back to a basic chemical control.

Cardiac asthma, sometimes truly asthmatic in form, is still basically an acute pulmonary congestion. While it may respond to bronchodilators, its relief more often depends upon the use of oxygen, frequently with positive pressure, upon digitalization, sedation, and diuretics.

Cheyne-Stokes respiration in heart failure has not been sufficiently explained. We know that it occurs clinically in advanced failure with retarded circulation, more in arteriolesclerotic or cardiorenal forms than in rheumatic, that it never occurs in the dyspnea of chronic pulmonary disease. We can measure the anoxia and hypercapnia in the apneic phase and the hypocapnia in the hyperpneic; we can stop it by breathing carbon dioxide, occasionally by breathing oxygen. The exact chemical and dynamic circumstances that determine its onset, however, or the true relation between this and experimental periodic breathing of central nervous, or anoxic, or hypocapneic origin, are not known.

My last case and final point in this presentation concerns the patient bedeviled all his life by a cardiac murmur. It brings us back again to our starting point, the importance of considering the whole patient in the analysis of his clinical state. There is nothing new about
this. Dr. Conner's fine paper 20 years ago on the psychic factors in cardiac disorders pointed the way. Various recent writers have referred to "iatrogenic" heart disease, an excellent term. We have encountered some flagrant examples, as others doubtless have also, in examining cases referred for cardiac surgery. They are individuals with a story of severe exertional dyspnea who have been found to have entirely normal cardiac and pulmonary function, both at rest and on the standard exercise test. Going back to the patient again, we have found that having had a cardiac murmur all his life, the patient has not been allowed exertion to the point of even normal breathlessness. He has suffered not from dyspnea, but the fear of dyspnea. Figure 12 shows the measurements on one such patient in rest and exercise. Perhaps as great satisfaction as we have had in our physiologic studies has been the demonstration to these patients that they need no severe restriction, but can lead essentially normal lives.

It may seem inconsistent that I am arguing for more emphasis on the psychogenic factor in cardiac dyspnea, and less in pulmonary dyspnea. My impression may be mistaken, but it has been, in fact, that the diagnosis of neurosis is made rather too often in chronic pulmonary disease and perhaps not often enough in rheumatic heart disease with a valvular murmur but no failure.

In summary, I should like to stress the following:

1. Dyspnea, or distressed breathing, is a very different entity from one disease to another, and its special qualities in each deserve both physiologic and clinical analysis.
2. In general, it can be thought of as a balance between breathing capacity and breathing effort, on the one hand, and on the other, the actual ventilation produced by the existing respiratory stimulus.
3. The multiple or summation theory of respiratory stimulus has made a significant contribution to our understanding of dyspnea.
4. Hyperventilation is common both to pulmonary and to cardiac dyspnea, often more pronounced in the former.
5. One should be cautious in explaining dyspnea on a functional or neurotic basis when organic pulmonary disease is present.
6. In cardiac dyspnea, the factor of muscular exhaustion, due to reduced blood flow, may be significant.
7. Pulmonary hypertension and congestion may be the chief element producing symptoms in advanced left-sided congestive failure.
8. In general, the dyspnea of mild cardiac failure appears to be due chiefly to inadequate cardiac output; that of advanced congestive failure to pulmonary congestion.
9. "Iatrogenic" heart disease still occurs; that is, the patient with a cardiac murmur whose physical activity is needlessly restricted.

**SUMARIO ESPAÑOL**

Disnea tiene muchas características que diferencen de un estado clínico a otro. En enfermedades pulmonares la causa inmediata es usualmente una desproporción entre la ventilación actual y la capacidad respiratoria. La hiperventilación de enfermedad pulmonar orgánica es frecuentemente confundida con psiconeurosis. En disnea cardíaca temprana, cansancio muscular con una producción total cardíaca insuficiente puede que sea un factor. Conges-
tión pulmonar es un factor importante en casos mas avanzados de decompensación del ventrículo izquierdo.

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