Physiologic Therapy in Diseases of the Respiratory System

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INTRODUCTION

In selecting the term "physiologic therapy" we had the aim of emphasizing forms of treatment that were outgrowths of studies on the pathologic physiology of respiratory illness. Its basic purpose may be defined as the attempt to correct deviations from the normal functioning of the lungs and bronchi and to eliminate, whenever possible, reversible pathology in these organs. Inhalation of oxygen is an early example of physiologic therapy, since it has long been recognized as a specific remedy for impaired lung function. When administered to normal subjects at moderately high altitude, damage to the respiratory, circulatory, and central nervous systems as the result of progressive anoxia is prevented. Clinical disorders of breathing have especially lent themselves to measures that improve the physiologic behavior of the lungs and bronchi. Anoxic dyspnea in clinical disease has often been successfully combated, as manifested by decrease in pulmonary ventilation, fall in pulse rate, and disappearance of cyanosis, by inhalation of oxygen-enriched atmospheres.

The therapeutic use of gases includes carbon dioxide, which has the physiologic objective of stimulating the breathing, especially in the respiratory depression of carbon monoxide poisoning and in the preventive or actual treatment of postoperative pulmonary atelectasis. Besides its employment for the treatment of hiccough, this gas is now rarely used as an aid in the management of clinical dyspnea. The

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1 This is the first of a series on this general subject.
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administration of 75 to 80 percent helium with 25 to 20 percent oxygen was advocated to decrease the physical effort of breathing in obstructive dyspnea, such as occurs in asthma and constrictive lesions of the larynx, trachea, and bronchi. In addition, this lighter than air mixture, as a consequence of its higher diffusion capacity, has been shown to penetrate alveoli that may be relatively impermeable to air or oxygen. Inhalation therapy also includes introduction into the lungs and bronchi of bronchodilator, bronchovasoconstrictor, and antibiotic aerosols. Nebulized epinephrine and neosynephrine have been used to increase the diameter of the respiratory passageway by the production of local bronchodilatation and bronchovasoconstriction. The sulphonamides, penicillin, and streptomycin are currently used as therapeutic aerosols in the treatment of bronchopulmonary and sinus infections.

Another form of physiologic therapy of respiratory disease involves the use of various types of pressure. Alternating pressure has long been used for resuscitation. In more recent years positive pressure has been shown to have significant physiologic advantages in the treatment of obstructive dyspnea and pulmonary edema and more recently in the anoxia of very high altitudes. Equalizing the pressure on both sides of the chest wall, in combination with alternating pressure, will be especially dealt with as a method that immobilizes the lungs of the living subject, providing a hitherto unachieved form of lung rest that has now been shown to be of value in the treatment of pulmonary tuberculosis. Finally, the use of negative pressure in the nasal accessory sinuses is illustrative of a method of local introduction of penicillin and other therapeutic aerosols.

I. Total Lung Rest in the Treatment of Pulmonary Tuberculosis

In 1926, Thunberg constructed the barospirator in which an alternating pressure of one-sixth of an atmosphere was produced twenty-five times a minute. A person inclosed in a chamber of this type appeared to obtain an adequate pulmonary ventilation. The device was used to maintain artificial respiration in patients with poliomyelitis in whom respiratory paralysis had taken place. When patients with pulmonary disease were studied by Barach, alternating pressure by itself resulted in a variable compression and expansion of the chest, depending on the degree of constriction of the passageway between the nose and the pulmonary alveoli. In patients with asthma and pulmonary emphysema the effect of alternating pressure was a marked

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increase and decrease in the volume of the chest. It was also observed that expansion of the chest took place during the negative phase of pressure, in the course of which the influence of the rarefaction of air was toward the elimination of air from the lungs. In other words, in cases with constriction in the bronchial passageway an inspiratory cycle was expanding the lungs at a time when an opposite influence was being exerted, i.e., withdrawing air from the lungs.

Since the air that entered the lungs swiftly built up a pressure on the inner surface of the chest and on the upper surface of the diaphragm, a certain time interval was necessary to equalize the pressure on both sides of the chest wall. Furthermore, the resistance in the tracheobronchial tree was observed to consume about 5 cm. of water pressure. A suitable chamber was used in which the air pressure wave entered the head end of the chamber first and then passed through a movable partition surrounding the neck of the patient into the body end. In this chamber the patient was completely inclosed, the pressure wave arriving in the head compartment and then, momentarily delayed and slightly decreased in total pressure, arrived at the body compartment. Patients were able not only to reside comfortably in the chamber without chest movement, but also to hold their breath for indefinite periods of time. When, however, these patients were exposed to alternating pressure alone, the impulse to breathe recurred after variable periods.

The principle of the method depends on the physical law that the number of molecules of a gas in a container varies with the pressure to which the gas is exposed when the volume and temperature of the gas are constant. In quiet breathing a change in the pressure of the air in the lung of 2 or 3 mm. Hg is produced by the respiratory musculature during inspiration and the elastic recoil of the lung in expiration. This is sufficient to accomplish a tidal air of 500 cc. or about one-sixth of the volume of air present in the lungs at the end of an ordinary expiration. When the muscles of respiration are no longer active, the lungs may be thought of as gas containers with a constant volume. Increasing the pressure of such a container one-sixth of the barometric pressure would therefore result in the passage into the container of an additional one-sixth number of gas molecules. If the container originally held 3,000 cc. of air, the number of molecules in it after pressure was applied would be the number contained in 3,500 cc. of air at atmospheric pressure. It was thought that the diameter of the chest did not change appreciably since pressure would be applied almost simultaneously to the outer and inner walls of the thorax.
It seemed evident that the tracheobronchial tree interposed a resistance to the passage of air into the alveoli and thus to the inner surface of the chest wall. This resulted in a decrease of pulmonary pressure at the start of each positive cycle, as compared to the pressure exerted on the outer chest wall. The diameter of the chest was, therefore, diminished when the pressure in the chamber was increased. The opposite sequence of events took place during the phase of negative pressure. The degree of these alterations in chest volume presumably varied with the degree of bronchial resistance. During compression of the chest, however, air entered the lung, and during expansion of the chest air left the lung. There are certain differences in the physiologic state in the lung during the negative and positive cycle of pressure that have received theoretical consideration. The air that leaves the lung in the negative cycle has been warmed from 68° to 100° F. and has been saturated with water vapor, which lowers its density and increases its velocity at a constant pressure. The decreased gas density decreases the factor of bronchial constriction, as shown by studies in which helium was mixed with oxygen in the treatment of respiratory obstruction. On the other hand, warming the air increases its volume, which creates a situation of more air leaving the lungs in the negative cycle than enters it in the positive cycle, in terms of volume, which counteracts the decrease in its density.

It became evident that a delay in application of pressure to the chest wall was necessary to equalize the resistance of the tracheobronchial tree in normal subjects and especially in patients with pulmonary disease. This was first accomplished by the construction of a wooden box that inclosed the chest and body of the patient, the head protruding through a sponge rubber collar. A number of small holes in the middle of the box served as entrance and exit of the air to be applied to the chest wall and abdomen. A retarded delivery of air pressure to the outer chest wall could now be regulated by varying the diameter of the holes in the box. Thus, in each phase the application of pressure was delayed at the start of the cycle until nearly equal pressure had been built up within the lung. Furthermore, the duration of the equalizing pressure was limited to the earliest phase of the cycle, as shown by the leveling off of the water manometer. The extent of the differential pressure required to effect continuous arrest of lung movement was determined first by the subjective reaction of the patient. In most instances, a pressure of 6 cm. of water higher in the outer chamber than within the box was maintained during the positive cycle. During the negative cycle, the pressure within the box was 5 cm. of water lower than in the outer chamber. The smaller difference in
the negative phase may be accounted for by a greater movement inward of the walls of the box in the phase of compression.

Air enters the lung during the phase of positive pressure. The theoretical basis for this belief may now be inspected. Let us consider that the atmospheric pressure at the start of an experiment is 760 mm Hg. The pressure swing is plus and minus 55 mm Hg. At the height of the positive phase the pressure advances to 815 mm Hg, and decreases to 705 mm Hg in the negative phase. Without the equalizing chamber there is a difference in the pressure between the inner and outer walls of the chest, the degree varying with the extent of bronchial constriction. Thus, when the pressure in the positive phase is elevated to 815 mm Hg in the outer chamber and therefore on the chest wall, there is a delay in the development of a comparable pressure within the lung; the pressure early in the early phase being smaller.

![Diagram](image)

**Figure 1.** At the atmospheric pressure the size and shape of B are constant. However, during the positive phase the increased pressure reaches the outer surface of the chamber B first, because of the resistance of long entrance tube to B. This causes collapse of wall of B. During the negative phase the pressure is reduced on surface of B sooner than that within B, and we find expansion of container B. This corresponds to the usual alternating pressure chamber used in respiratory arrest in cases of bulbar poliomyelitis. B corresponds to the chest of a patient. The dots indicate concentration of air molecules.
in the lung. As a result, during simple alternating pressure there is a compression of the chest. At the same time, however, the increased pressure in the outer air forces air into the lung, since the pressure inside the lung is lower than in the outer atmosphere. Compression of the air as a result of increased pressure of itself causes an increased number of molecules of oxygen and nitrogen to enter the lung.

![Diagram](https://via.placeholder.com/150)

**Figure 2.** Same as figure 1 with the addition of a baffle-plate between entrance tube of B and its main compartment. With this in place there is a delay in arrival of positive pressure to outer wall of container B to the same degree as that resistance in tube entrance to compartment B. Thus, the positive pressure wave reaches inside and outside of container B at exactly the same time. This prevents contraction of container B. During negative phase air leaves both chambers with some speed and there is no expansion of container B. This is the principle that is in play in the equalizing alternating pressure chamber used to give complete lung rest in tuberculosis therapy.

When the shift to the negative phase takes place, there is a swift reduction of pressure to 705 mm. Hg in the outer atmosphere; a relatively higher pressure is now present in the lung, since there is a delay in the reduction of this pressure in the lung because of bronchial resistance. The air in the lung (under higher pressure) tends to move outward to a point of lower pressure. The decreasing pressure of the
atmosphere itself results in a passage of gas outward. Since the pressure applied to the chest wall is at first lower than that in the lung, the chest wall necessarily expands as air is leaving it. The situation is thus radically different from that present in ordinary breathing, when an increase in volume of the lung is associated with an entrance of air into the alveoli. These principles are illustrated in figures 1 and 2.

The equalizing chamber prevents the chest compression of the positive phase and, if the differential pressure is sufficiently advanced, may engineer an actual expansion of the chest, as may be seen in animal experiments. Inspection of patients with pulmonary tuberculosis who have suspended voluntary respiration in the equalizing chamber generally reveals no movements of the costal musculature. At times, minimal changes of the chest surface are seen. The abdomen may, if gas is present in the intestine, show a variable amount of compression in the phase of positive pressure and expansion in the phase of negative pressure. Motion pictures on five patients have confirmed these observations.

Figure 3. X-rays of ribs and diaphragm: A, Normal quiet respiration, two exposures. Note blurring of rib margins and diaphragm. B, Alternating pressure respiration; exposed at peak of the negative and the positive phase. Note the double margin of the diaphragm. C, Equalizing alternating pressure; exposure at the peak of negative and positive phase. Note the absence of diaphragmatic movement.

During fluoroscopy of the diaphragm in normal breathing, the diaphragmatic excursion was plainly visible. When equalizing alternating pressure was used, no diaphragmatic excursion was discernible (figure 3). It appeared likely that the movement of the abdomen was caused by alternate compression and expansion of gas within the abdomen and that pressure applied to the abdomen was counteracted by pressure on the upper surface of the diaphragm. Exposures taken on the same plate during the positive and negative
cycle in the presence of equalizing positive pressure revealed a clear-cut diaphragmatic line as well as a single shadow of the rib margins. Alternating pressure respiration conducted in an equalizing chamber may be accomplished without discernible movement of the chest or diaphragm. It may well be that minimal excursions of the lung are present, but they appear to be of such magnitude as not to be discerned by the methods of study mentioned above.

Satisfactory exchange of blood gases was thus accomplished when dogs were kept for long periods in the double alternating pressure chamber, indicating adequate pulmonary ventilation. The lowering of the arterial carbon dioxide content suggested slight hyperventilation of the alveoli. It seems evident, therefore, that in the presence of experimental respiratory paralysis and circulatory insufficiency a more efficient ventilation of the lungs takes place in respect to exchange of blood gases when an equalizing chamber is employed than when alternating pressure is used alone. The effect on the eardrum of the oscillating pressure is similar to swift ascent to, and descent from, high altitudes. The drum changes its position slightly twenty-five times a minute in each direction. The sensation may be uncomfortable at first. In the early stages this sensation can be minimized by placing a sponge rubber covering over the ears. The majority of patients after the first day or two prefer to dispense with the sponge rubber covering and become oblivious to the sensation.

Barach has tested the pH, the CO₂, and the oxygen content of the arterial blood. These patients when taken out at four-hour intervals sometimes have a slightly reduced arterial CO₂ content with little change in pH. If the patient feels the pressure is a little less than he needs, he rings a bell and says, "I have to breathe now," and more pressure is then used. The patient can feel the need for as little as 1 or 2 mm. Hg equalizing pressure. Turning over his respiration to a machine introduces a special feeling of relaxation, so that these patients will lie for perhaps three hours, not only not moving their lungs, but also not even their hands. Arrest of lung movement creates certain discernible changes in the circulation, decreased blood pressure, decreased pulse rate, and elevation of the T wave. In patients with pulmonary tuberculosis in whom fibrosis and emphysema were present, immobilization of the lung could not be obtained, because the pressure wave could not be sufficiently delayed by the mechanism described above.

A transportable chamber (figures 4 and 5) has been made that can be moved into a room without difficulty. A headpiece has been added to the equalizing box, and a movable partition between the head and
body of the patient. Air is pumped into the head portion first and, through a by-pass, into the body part of the chamber. The differential pressure can be regulated by a gage in the circuit of the by-pass. The degree of pressure is shown by a mercury manometer, with connections in the head and chest compartments. A photoelectric cell is focused just above at the 55 mm. Hg mark with electrical connections to the compressor. If for any reason the pressure does not maintain itself at the desired level, the photoelectric cell is activated and the motor is turned off. A telephone in the chamber allows the patient to com-
municate with the attendant. Cooling is accomplished by brine or water circulating in pipes at the bottom of the chamber.

The procedure of immobilizing both lungs has been investigated in the past eleven years. Of twenty-one patients with advanced bilateral and moderately advanced pulmonary tuberculosis, clinical recovery took place in fifteen, slight to moderate temporary benefit in three, and no change in two. Follow-up observations extend between one and ten years. Of the twenty-one patients, sixteen were given a single course of three to five months for eight to eleven hours daily; three had two courses; and one had three courses. The first patient, who was in the group receiving a single course, was treated six hours a day for two months. A typical result of treatment is shown in figure 6.

That closure of tuberculous cavities is a specific result of the immobilization of both lungs has been demonstrated by x-ray evidence of cavity disappearance during treatment, its re-appearance on bed rest following termination of chamber therapy, and a repetition of closure of the same cavity by a subsequent course. This sequence of events has been observed in one patient who had two courses and another patient who had three courses of treatment. In a third patient collapse of the cavity took place in three months and re-expanded to its original size after two weeks of activity. Control of hospital food,
nursing, and medical care was afforded in two earlier investigations on the effect of continuous residence (1) in an oxygen room and (2) in a filtered air chamber, both at bed rest. Although some of these cases were quite similar to those in the present series, no comparable clearing of tuberculous infiltration, healing of cavities, or clinical recovery took place in either of the two previously reported therapeutic procedures.

**SUMMARY**

Total lung rest may now be provided to patients with pulmonary tuberculosis by means of the equalizing pressure chamber that provides for ventilation without lung movement. In fifteen of twenty-one patients with far advanced and moderately advanced pulmonary tuberculosis, clinical arrest of the disease occurred as a result of this method of treatment. Closure of cavities has been shown to be a specific result of total lung rest. The procedure is applicable to cases without pulmonary emphysema and pulmonary fibrosis of such an extent as to prevent equalizing pressures on each side of the chest wall. The new type of chamber makes it possible for the patient himself to enter and leave the chamber, as well as to turn on the alternating and differential pressures and at the same time adjust a thermostat which provides automatic regulation of temperature. The procedure has none of the complications of collapse therapy, and it would now appear to be indicated in many patients with this disease in preference to either pneumothorax or thoracoplasty.