

[54] ALVEOLAR GAS TRAP AND METHOD OF USE

[75] Inventors: Donald F. Ryan, 530 N. Lalonde, Lombard, Ill. 60148; Allan N. Williams, Griffith, Ind.

[73] Assignee: said Ryan, by said Williams

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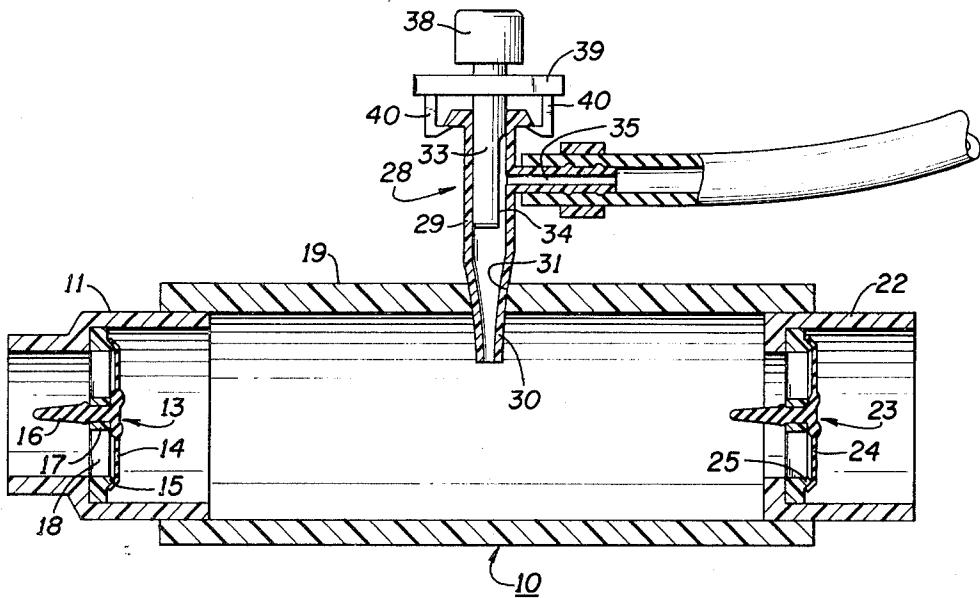
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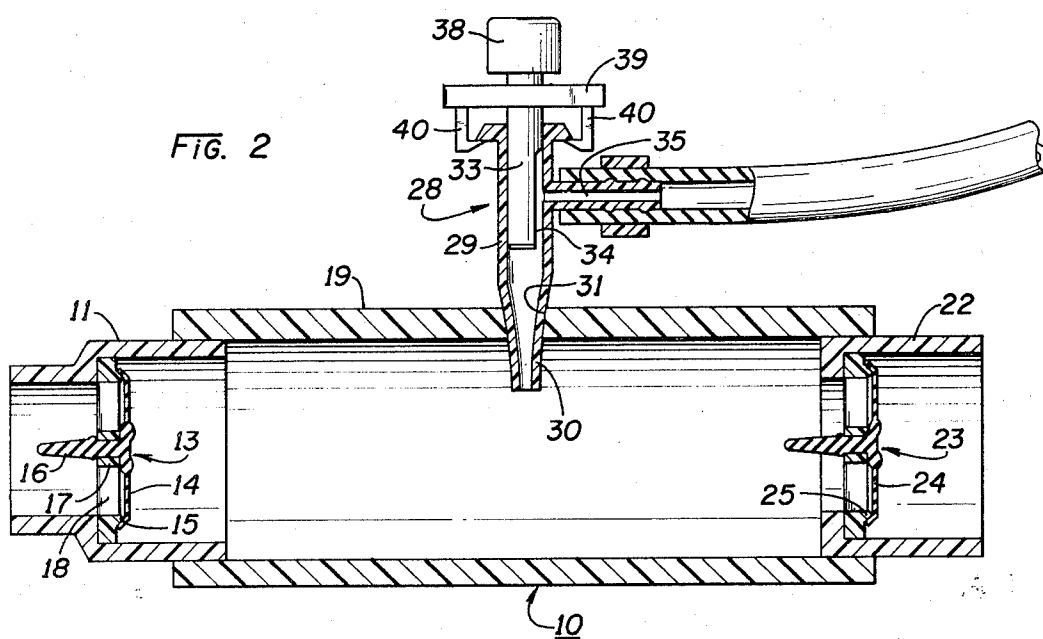
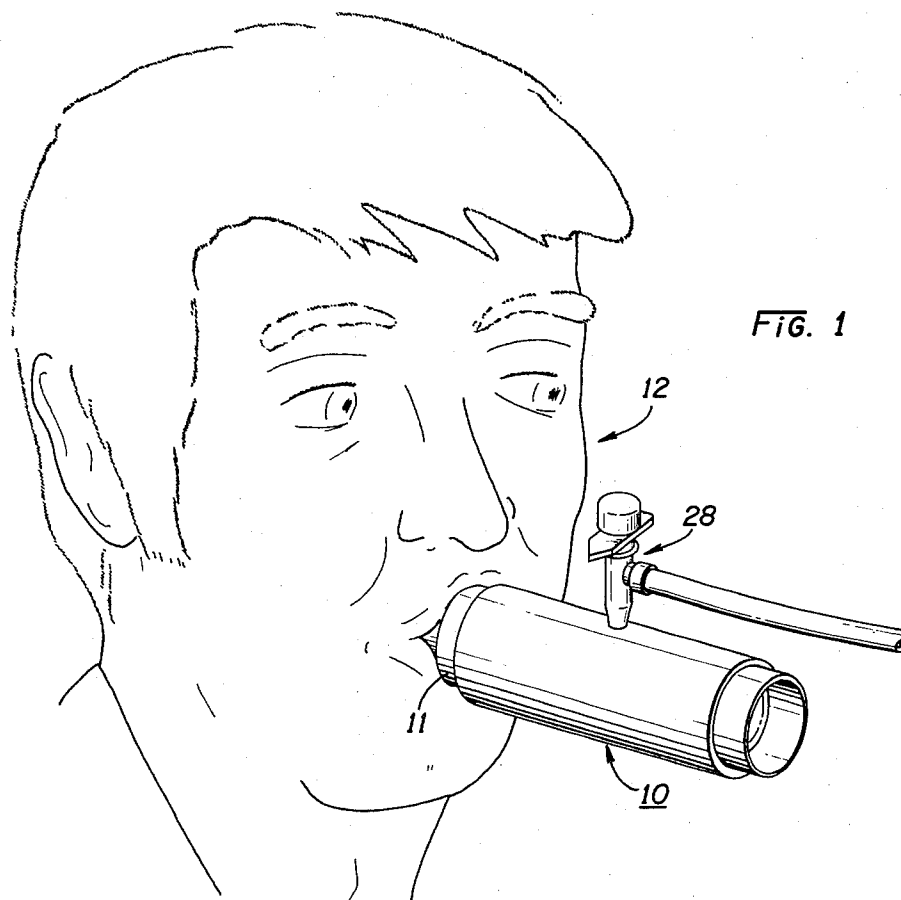
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Primary Examiner—Richard A. Gaudet
Assistant Examiner—Lee S. Cohen
Attorney, Agent, or Firm—Edmond T. Patnaude

[57] **ABSTRACT**
An alveolar gas trap includes a small tubular reservoir having check valves at opposite ends and a mouthpiece so that when a person exhales through the mouthpiece, the exhalation gasses pass through the reservoir to the ambient with the last or alveolar gas being collected in the reservoir.

5 Claims, 2 Drawing Figures





ALVEOLAR GAS TRAP AND METHOD OF USE

The present invention relates in general to an apparatus and method of collecting alveolar gas samples from human beings and to the normal use of such samples for making cardiopulmonary analyses.

Prior to the present invention, it had been both difficult and costly to collect a sample of alveolar air, and the samples actually collected did not result in accurate measurements. One such attempt to obtain an alveolar air sample employed a Douglas bag in which the expired gas over a number of breaths was collected. However, anatomical variances between individuals make it impossible to determine the actual alveolar gas concentration from the mean expired sample so collected. Another method which has been used in the prior art employs a servo-electric valve which operates on a fixed time basis to select the alveolar gas from the total expired gas in a single breath. Not only is such equipment costly, but since any change in the ratio of inspiratory to expiratory time changes the sample, the sample is easily taken at the wrong point in the breathing cycle with resulting erroneous readings.

We have recognized, however, that if a true alveolar air sample could be derived from the gas exhaled by the patient, cardiopulmonary analyses could be greatly expedited with minimum body invasion, and could provide accurate cardiopulmonary measurements not heretofore obtained except over long periods of time with substantial patient duress. At the present time, such measurements, as for example, cardiac output, oxygen consumption, carbon dioxide production and respiratory quotient can only be determined with the use of expensive, complicated and sophisticated equipment.

OBJECTS OF THE INVENTION

Therefore, a principal object of the present invention is to provide a new and improved method and means for obtaining an alveolar gas sample from respiratory gasses.

Another object of this invention is to provide a new and improved method of making cardiopulmonary measurements using alveolar gas samples.

A further object of this invention is to provide a new and improved method for determining the overall efficiency of a patient's cardiopulmonary system.

SUMMARY OF THE INVENTION

Briefly, there is provided in accordance with one aspect of the present invention, a device through which a patient exhales and which automatically separates and traps a sample of the alveolar gas from the total respiratory gasses. The device incorporates a relatively small gas reservoir on opposite sides of which low pressure, positive sealing check valves are located. As the patient exhales through the device, the respiratory gasses pass directly through the device to the ambient, with the final small amount of the expired gas being trapped in the reservoir compartment. Since the alveolar air is the last to leave the lungs during normal exhalation, the gas which is trapped in the reservoir is an accurate sample of alveolar air from which the oxygen and carbon dioxide pressures can be readily determined in a conventional blood-gas analyzer. As is explained in greater detail hereinafter, these partial pressures in combination with samples of arterial and ve-

nous blood taken substantially simultaneously with the alveolar gas sample permit the rapid calculation in a normal manner of oxygen consumption and carbon dioxide production as well as what we term the "Index number of cardiopulmonary disability." In addition, calculations of shunt ratio, cardiac output, physiological dead space, respiratory quotient, ventilation perfusion ratio, mitral valve flow, alveolar ventilation and total blood volume can be readily performed using the alveolar air sample. Using the method and apparatus of the present invention, all of these measurements can be completed within about fifteen minutes, as compared to the previous minimum of about two to three days if the physiological condition of the patient would actually permit it.

Further objects and advantages and a better understanding of the invention may be had from the following detailed description taken in connection with the accompanying drawings, wherein:

FIG. 1 is an elevational view of the alveolar gas trap of the invention in use; and

FIG. 2 is a longitudinal section of the alveolar gas trap shown in FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawing, and particularly to FIG. 1 thereof, an alveolar gas trap 10 is there shown with the mouthpiece portion 11 in the mouth of a patient 12. The trap is both small in size and light in weight so as not to be uncomfortable to the patient who simply breathes in the normal manner, inhaling through the nostrils and exhaling through the mouth and thus through the alveolar gas trap 10.

As best shown in FIG. 2, the gas trap 10 includes the tubular mouthpiece 11 in which a check valve 13 is mounted. The valve 13 is a light, flexible disc 14, suitably formed of rubber and overlying an annular valve seat 15 mounted to the mouthpiece tube 11. The disc 14 has a centrally disposed post 16 which is secured in a mounting ring 17 connected to the main body of the seat member 15 by a spider made up of a plurality of spaced apart radial arms 18.

The mouthpiece tube 11 sealably extends into one end of a transparent plastic tube 19 and an exhaust tube 22 sealably extends into the other end of the tube 19. A check valve 23 is mounted in the tube 22 and is identical in construction to the inlet check valve 13 and includes a flexible valve disc 24 overlying an annular valve seat 25. The valves 13 and 23 should operate at low pressure differentials of less than one centimeter of water pressure and must provide a good hermetic seal at a substantial zero pressure differential. We have found that a light silicone spray applied to the valving surfaces of the rubber discs 14 and 24 provides satisfactory results.

The space within the tube 19 between the valves 13 and 23 thus constitutes a reservoir in which the alveolar gas is trapped. While the size of the reservoir is not critical, it must have a substantially smaller volume than that of a normal exhalation tidal volume. In a normal adult person, there is between 100 and 200 cc of alveolar air in the lungs upon inhalation. We have successfully used a reservoir size of thirty-one cubic centimeters. Since the normal tidal volume for an adult is in the range of about 400 cc to 800 cc, the gas trapped in the reservoir is less than the last ten percent of the expired gas, and less than one-third of the alveolar air. Since

the gas passing through the tube 19 makes a substantially clean sweep, there is only a negligible amount of turbulence and mixing of the earlier expired gas from the anatomical dead spaces with the alveolar gas.

A sampling valve assembly 28 is mounted to the tube 19 and is used for extracting a gas sample from the reservoir in the tube 19. The assembly 28 includes a tubular body 29 having a necked down end portion 30 which extends a short distance into the tube 19 through a hole 31 in the wall thereof. The end portion 30 is suitably sealed to the tube 19 to prevent escape or contamination of the gas trapped in the reservoir. A valve member 33 is rotatably mounted in the body 29 and has a flat 34 provided on one side for opening an outlet port 35 in the side of the body 29. A flexible tube is connected to the outlet port 35 for coupling it to a bloodgas analyzer. A knob 38 is provided at the distal end of the valve member 33 for rotating it between the open position shown in FIG. 2 wherein the flat 34 is opposite the port 35 and a closed position wherein the member 33 sealably engages the wall portion of the body 29 surrounding the port 35 to close it. The position of the valve member 33 is indicated by an elongated, pointed flange 39 which is aligned with the flat 34. A pair of spring fingers 40 depend from the flange and fit under an annular flange at the top of the body 29 to hold the valve member in place therein.

OPERATION OF GAS TRAP

In use, the patient is asked to breath normally by inhaling through the nose and exhaling through the mouth. With the valve 28 closed, the mouthpiece 11 of the trap is then placed in the patient's mouth as shown in FIG. 1 and breathing continued with the patient's lips sealingly engaging the mouthpiece so that the entire respiratory breath passes into the trap. The exhaust gas pressure is sufficient to open both the inlet and exhaust check valves until exhalation ceases, at which time both valves close to trap the last or alveolar portion of the exhaust gasses from the lungs. Because of the construction of the trap 10, there is little turbulence in the reservoir which could cause mixing of the alveolar gas and the previously exhaled gasses from the anatomical dead space and other areas of the lungs. Moreover, since the capacity of the reservoir is but a small fraction of the tidal volume, i.e. quantity of gas exhaled in each breath, the gas thus trapped in the reservoir is, for all practical purposes, only alveolar gas.

A small portion of say one-half a cubic centimeter of the trapped sample is pumped from the reservoir through the valve 28 at a pressure less than the biasing forces on the inlet and outlet valves and is supplied to any suitable device, such for example, as a blood gas analyzer to measure the partial pressures of the oxygen and carbon dioxide in the alveolar gas sample.

Since, in order to maintain a steady state within the respiratory system, oxygen consumption must be equal to oxygen uptake and carbon dioxide production must be equal to carbon dioxide release, these values may be calculated by taking arterial and venous blood samples substantially simultaneously with the taking of the alveolar gas sample. We have determined that the blood samples should be taken at as nearly the same time as the alveolar gas sample is obtained, but at least within one minute thereafter. Ordinarily, there is substantial pain associated with the taking of the arterial blood sample, and since a person's reaction to pain affects the

alveolar gas, it is important that the gas sample not be taken after the arterial blood sample is taken, or the data will be erroneous. Other well-known and easily measured factors, such as tidal volume, respiratory rate, approximate anatomical dead space and barometric pressure are also used in these calculations. The various cardiopulmonary measurements or indices, referred to above may be readily calculated from the equations given below wherein the following well-known terms are used:

Q_t = cardiac output (ml/min)

Q_s = pulmonary physiological shunt (ml/min)

P_{eO_2} = expired alveolar oxygen tension (mm Hg)

P_{eCO_2} = expired alveolar carbon dioxide tension (mm Hg)

P_{aO_2} = arterial blood oxygen tension (mm Hg)

P_{aCO_2} = arterial blood carbon dioxide tension (mm Hg)

P_{vO_2} = mixed venous blood oxygen tension (mm Hg)

P_{vCO_2} = mixed venous blood carbon dioxide tension (mm Hg)

P_iO_2 = inspired air oxygen tension (mm Hg)

P_iCO_2 = inspired air carbon dioxide tension (mm Hg)

C'_cO_2 = alveolar oxygen content per 100 ml

C_vO_2 = mixed venous oxygen content per 100 ml

C_aO_2 = arterial oxygen content per 100 ml

S_cO_2 = alveolar oxygen saturation

S_aO_2 = arterial oxygen saturation

S_vO_2 = mixed venous oxygen saturation

VO_2 = oxygen consumption (ml/min)

ADS = anatomical dead space

TV = average tidal volume

F = respiratory rate

P_b = barometric pressure

V_{CO_2} = CO_2 production

R = respiratory quotient

V_a = alveolar ventilation (l/min)

F_aCO_2 = concentration of CO_2 in alveolar gas

Q_c = blood flow through pulmonary capillaries

C_vCO_2 = CO_2 concentration in venous blood

C_cCO_2 = CO_2 concentration in alveolar air

C_aO_2 = O_2 concentration in arterial blood

MVF = mitral valve flow

The following equations are used to calculate the various measurements or indices used in making a cardiopulmonary diagnosis.

SHUNT EQUATION

$$Q_s/Q_t = C'_cO_2 - C_aO_2/C'_cO_2 - C_vO_2$$

O_2 CONSUMPTION

$$VO_2 = (P_iO_2 - PAO_2/P_b - 47) \times (TV - ADS) \times F$$

CARDIAC OUTPUT

$$Q_t = 100 VO_2/C_aO_2 - C_vO_2$$

PHYSIOLOGICAL DEADSPACE

$$V_d = V_t (P_aCO_2 - P_aCO_2/P_aCO_2)$$

CO_2 PRODUCTION

$$CO_2 = (P_aCO_2 - P_iCO_2/P_b - 47) (TV - ADS) (F)$$

RESPIRATORY QUOTIENT

$$R = VCO_2/VO_2$$

ALVEOLAR VENTILATION

$$V_A = VCO_2/FACO_2$$

APPROXIMATE EFFECTIVE BLOOD VOLUME

$$BV = VO_2 / (C_aO_2 - C_vO_2) \times 100$$

VENTILATION/PERFUSION RATIO

$$V_A/Q_c = R_x 0.863 (C_aO_2 - C_{vO_2}) / P_A CO_2$$

MITRAL VALVE FLOW

$$MVF = \text{cardiac output (cc)/Rate (Min)} \times \text{average duration of diastole (sec)}$$

In order to provide a repeatable measurement of the cardiopulmonary disability of a patient, we have found that the "Index Number of cardiopulmonary disability" is quickly and easily determined from the true alveolar gas sample. The following equation may be used to calculate this number:

$$I = C_a CO_2 - C' c CO_2$$

Extensive testing of patients having healthy and impaired cardiopulmonary systems indicated that an Index Number of about two or less indicates a normal cardiopulmonary function with the degree of impairment increasing in proportion to the value of the index number over two. For example, an index number of 13 or more shows extremely poor cardiopulmonary function with a consequent life expectancy of a few months or less.

While the present invention has been described in connection with a particular embodiment thereof, it will be understood that those skilled in the art may make many changes and modifications without departing from the true spirit and scope thereof. Accordingly, the appended claims are intended to cover all such changes and modifications as fall within the true spirit and scope of the present invention.

What is claimed is:

1. An alveolar gas trap for obtaining a sample of alveolar gas from a person, comprising means defining a gas reservoir having a volume equal to no greater than one hundred cubic centimeters, a mouthpiece for disposition in said person's mouth, a first one-way check valve mounted in proximity to

said mouthpiece and connected between said mouthpiece and said reservoir,

said means defining a gas reservoir being mounted directly to said mouthpiece with said check valve opening directly into said reservoir so that all of the gas passing through said check valve enters said reservoir,

a second one-way check valve connected between said reservoir and the ambient for passing gas from said reservoir to the ambient,

said valves being self biased into a closed position with a sufficiently low force so as to be opened by the normal exhalation pressure of said person,

a sampling port opening into said reservoir between said check valves, and

a valve connected to said port for controlling the removal of gas from said reservoir.

2. An alveolar gas trap, according to claim 1, wherein said means defining said reservoir comprises

a tube, and

said check valves are positioned at respectively opposite ends of said tube, whereby air flow is through said tube from one end to the other during exhalation.

3. An alveolar gas trap, according to claim 2, wherein said check valves open at a pressure differential of less than one centimeter of water.

4. An alveolar gas trap according to claim 1 wherein said reservoir has a volume no greater than about 50 cubic centimeters.

5. An alveolar gas trap according to claim 1, wherein said means defining said reservoir is a straight, transparent tube,

said mouthpiece is a tubular member aligned with said transparent tube and to which said transparent tube is mounted,

said check valves being positioned at opposite ends of said tube, and

said valve being mounted directly on said tube.

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