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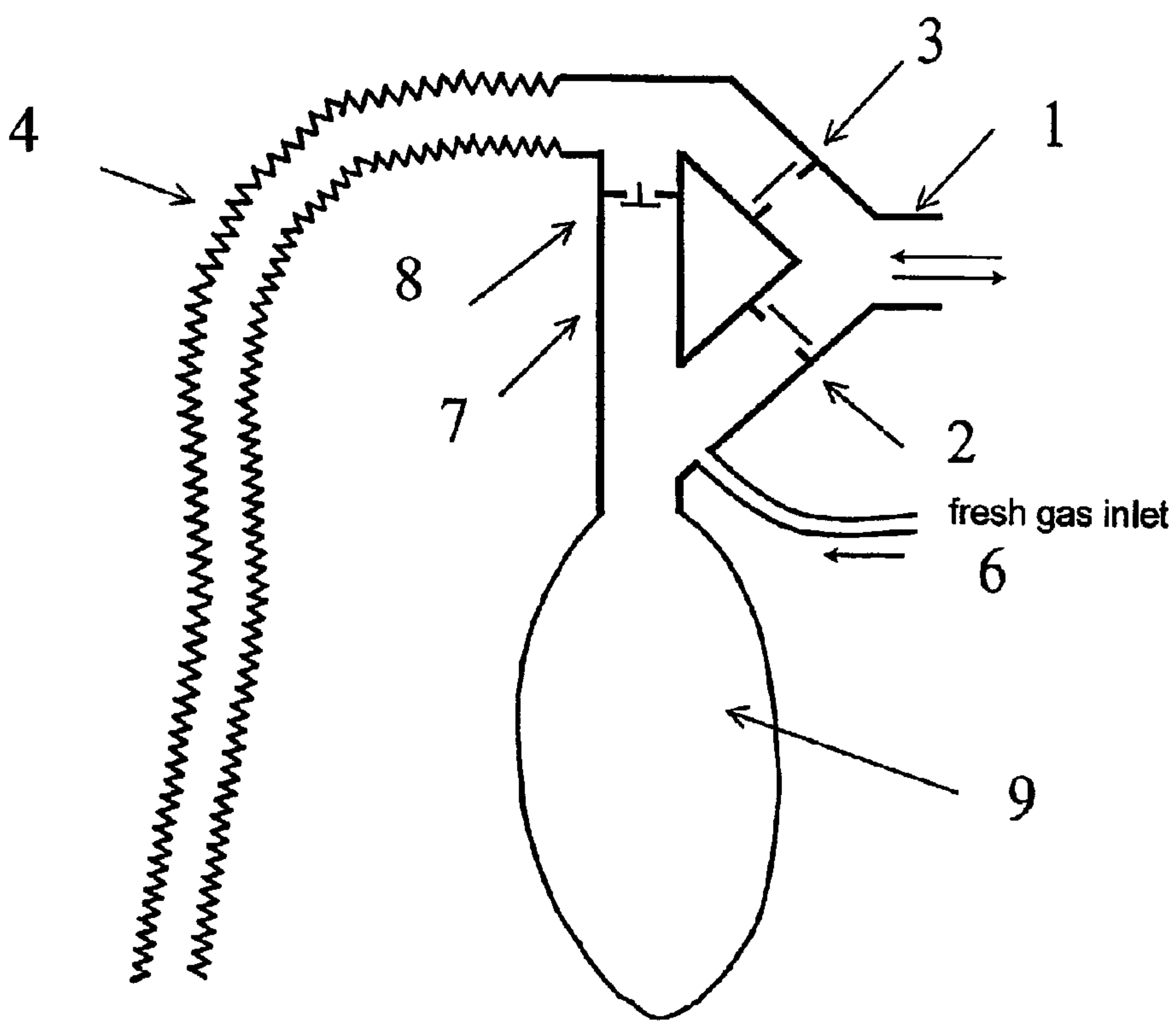
(54) Titre : CIRCUIT AMELIORE DE REINHALATION POUR ETABLIR ET STABILISER LA PCO_2 DE FIN D'EXPIRATION ET ARTERIELLE MALGRE DES VARIATIONS DE DEBIT-VOLUME

(54) Title: AN IMPROVED REBREATHING CIRCUIT TO SET AND STABALIZE END TIDAL AND ARTERIAL PCO_2 DESPITE VARYING LEVELS OF MINUTE VENTILATION



(57) Abrégé/Abstract:
A method of controlling PCO_2 in a patient at a predetermined desired level (s) comprising a breathing circuit which is capable of organizing exhaled gas so as to be preferentially inhaled during re-breathing when necessary by providing alveolar gas for re-breathing in preference to dead space gas.

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ABSTRACT

A method of controlling PCO_2 in a patient at a predetermined desired level (s) comprising a breathing circuit which is capable of organizing exhaled gas so as to be preferentially inhaled during re-breathing when necessary by providing alveolar gas for re-breathing in preference to dead space gas.

TITLE OF INVENTION

An improved rebreathing circuit to set and stabilize end tidal and arterial PCO_2 despite varying levels of minute ventilation

FIELD OF INVENTION

The purpose of this invention is to provide a simple breathing circuit that only fresh gas is breathed unless the minute ventilation exceeds the fresh gas flow and further if minute ventilation does exceed fresh gas flow then alveolar gas is rebreathed in preference to dead space gas. Loss of fresh gas from the circuit is prevented at all times

BACKGROUND OF THE INVENTION

Physiology

Venous blood returns to the heart from the muscles and organs depleted of oxygen (<u>O_2</u>) and full of carbon dioxide (<u>CO_2</u>). Blood from various parts of the body is mixed in the heart (<u>mixed venous blood</u>) and pumped to the lungs. In the lungs the blood vessels break up into a net of small vessels surrounding tiny lung sacs (<u>alveoli</u>). The net sum of vessels surrounding the alveoli provides a large surface area for the exchange of gases by diffusion along their concentration gradients. A concentration gradient exists between the partial pressure of CO_2 (PCO_2) in the mixed venous blood (<u>$PvCO_2$</u>) and the alveolar PCO_2. The CO_2 diffuses into the alveoli from the mixed venous blood from the beginning of inspiration until an equilibrium is reached between the $PvCO_2$ and the alveolar PCO_2 at some time during the breath. When the subject exhales, the first gas that is exhaled comes from the trachea and major bronchi which do not allow gas exchange and therefore will have a gas composition similar to the inhaled gas. The gas at the end of his exhalation is considered to have come from the alveoli and reflects the equilibrium CO_2 concentration between the capillaries and the alveoli; the PCO_2 in this gas is called end-tidal PCO_2 ($PETCO_2$).

When the blood passes the alveoli and is pumped by the heart to the arteries it is known as the arterial PCO_2 ($PaCO_2$). The arterial blood has a PCO_2 equal to the PCO_2 at equilibrium between the capillaries and alveoli. With each breath some CO_2 is eliminated from the lung and fresh air containing little or no CO_2 (CO_2 concentration is assumed to be O) is inhaled and dilutes the residual alveolar PCO_2, establishing a new gradient for CO_2 to diffuse out of the mixed venous blood into the alveoli. The rate of breathing, or ventilation (V), usually expressed in L/min, is exactly that required to eliminate the CO_2 brought to the lungs and maintain an equilibrium PCO_2 (and $PaCO_2$) of approximately 40 mmHg (in normal humans). When one produces more CO_2 (e.g. as a result of fever or exercise), more CO_2 is produced and carried to the lungs. One then has to breathe harder (hyperventilate) to wash out the extra CO_2 from the alveoli, and thus maintain the same equilibrium $PaCO_2$. But if the CO_2 production stays normal, and one hyperventilates, then the $PaCO_2$ falls. Conversely, if CO_2 production stays constant and ventilation falls, arterial PCO_2 rises.

It is important to note that not all V contributes to blowing off CO_2. Some V goes to the air passages (trachea and major bronchi) and alveoli with little blood perfusing them, and thus doesn't contribute to blowing off CO_2. This V is termed "dead space" ventilation and gas in the lung that has not participated in gas exchange with the blood is called "dead space" gas. That portion of V that goes to well perfused alveoli and participates in gas exchange is called the alveolar ventilation (VA) and exhaled gas that had participated in gas exchange in the alveoli is termed "alveolar gas".

Referring to the PCT Application No. WO98/41266 filed by Joe Fisher (WO98/41266), there is taught a method of accelerating the resuscitation of a patient having been anaesthetized by providing the patient with a source of fresh gas and a source of reserve gas. When the patient breathes at a rate less than or equal to the fresh gas flowing into the circuit, all of the inhaled gas is made up of fresh gas. When the patient's minute ventilation exceeds the fresh gas flow, the inhaled gas is made up of all of the fresh gas and the additional gas is provided by "reserve gas" consisting of a composition similar to the fresh gas plus CO_2 such that the concentration of CO_2 in the reserve gas of about 6% is such that its partial pressure is equal to the partial pressure of CO_2 in the mixed venous blood. At no time while using this method, will the patient re-breathe gas containing anaesthetic. In order to accelerate the resuscitation of the patient, a source of fresh gas is provided for normal levels of minute ventilation, typically 5L per minute and a supply of reserve gas is provided for levels of ventilation above 5L per minute wherein the source of reserve gas includes approximately 6% carbon dioxide having a PCO_2 level substantially equal to that of mixed venous blood. It has been found that this method and various circuits and processes for implementing the method are advantageous not only for resuscitating individuals from surgery, but also to deal with carbon monoxide poisoning or the like as taught in the application. By allowing increased ventilation yet maintaining the PCO_2 level substantially equal to that prior to the increased ventilation, it has been found that in utilizing the method, maximum benefits of gas elimination are achieved without changing the CO_2 levels in the patient. However, one limitation is that a source of reserve gas and its delivery apparatus must be supplied to pursue the method and that the reserve gas must be at about 6% CO_2 concentration substantially having a PCO_2 equal to that of mixed venous blood or about 46 mm Hg.

To simplify the circuit taught by Fisher (WO98/41266), the reserve gas can be replaced by previously exhaled gas. The gas at the end of exhalation has substantially equilibrated with mixed venous gas and thus has a PCO_2 substantially equal to it. However if rebreathed gas is used instead of separately constituted reserve gas to prevent the decrease in PCO_2 with increased ventilation, the anesthetic and CO will also be rebreathed and their elimination will not be enhanced. There are other applications for a circuit that maintains PCO_2 constant with increased ventilation which are not invalidated by using exhaled gas as the reserved gas which are listed hereinafter.

Discussion of Prior Art Circuits Used for Rebreathing

Prior art circuits used to prevent decreases in PCO_2 resulting from increased ventilation, by means of rebreathing of previously exhaled gas are described according to the location of the fresh gas inlet, reservoir and pressure relief valve with respect to the patient. They have been classified by Mapleson and are described in Dorsch and Dorsch pg 168.

1. Maintenance of constant CO_2 with increased minute ventilation

Mapleson A

The circuit comprises a pressure relief valve nearest the patient, a tubular reservoir and fresh gas inlet distal to the patient. In this circuit, on expiration, dead space gas is retained in the circuit, and after the reservoir becomes full, alveolar gas is lost through the relief valve. Dead space gas is therefore preferentially rebreathed. Dead space gas has a PCO_2 much less than mixed venous PCO_2. This is less effective in maintaining PCO_2 than rebreathing alveolar gas, as occurs with the circuit of the present invention.

Mapleson B, C

The circuit includes a relief valve nearest the patient, and a reservoir with a fresh gas inlet at the near patient port. As with Mapleson A dead space gas is preferentially rebreathed when minute ventilation exceeds fresh gas flow. In addition, if minute ventilation is temporarily less than fresh gas flow, fresh gas is lost from the circuit due to the proximity of the fresh gas inlet to the relief valve. Under these conditions, when ventilation once again increases there is no compensation for transient decrease in ventilation as the loss of fresh gas will prevent a compensatory decrease in PCO_2.

With the present invention circuit, when minute ventilation is temporarily less than fresh gas flow, no fresh gas is lost from the circuit. Instead, the reservoir acts as a buffer, storing the extra fresh gas, and when ventilation increases once more, breathing the accumulated fresh gas allows PCO_2 to return to the previous level.

Mapleson D and E

Mapleson D consists of a circuit where fresh gas flow enters near the patient port, and gas exits from a pressure relief valve separated from the patient port by a length of reservoir tubing. Mapleson E is similar except it has no pressure relief valve allowing the gas to simply exit from an opening in the reservoir tubing. In both circuits, fresh gas is lost without being first breathed. The volume of gas lost without being breathed at a given fresh gas flow is dependent on the minute ventilation such that only at infinite ventilation is all the fresh gas used for alveolar ventilation. Thus the alveolar ventilation and the PCO_2 level are also dependent on the minute ventilation. Fresh gas is lost because during expiration, fresh gas mixes with expired gas and escapes with it from the exit port of the circuit. Furthermore, the amount of fresh gas lost is a function of expiratory time, and hence by changing the pattern of breathing, one can increase or decrease the proportion of fresh gas breathed. With our circuit, all of the fresh gas is breathed by the subject.

Circle anaesthetic circuit with CO_2 absorber removed

There are many different possible configurations of fresh gas inlet, relief valve, reservoir bag and CO_2 absorber (see Dorsch and Dorsch, pg.205-207). In all configurations, a mixture of expired gases enters the reservoir bag, and therefore rebreathed gas consists of combined dead space gas and alveolar gas. This is less efficient in maintaining PCO_2 constant than rebreathing alveolar gas preferentially as occurs with our circuit, especially at small increments of V above the fresh gas flow.

Circuit previously described by Fisher (WO98/41266)

Fisher (WO98/41266) has previously described a circuit that maintains PCO_2 independent of minute ventilation. Instead of making up the difference between fresh gas flow and minute ventilation with gas expired from a previous breath, Fisher (WO98/41266) requires an external source of CO_2. Our circuit exploits the same principle in maintaining PCO_2 constant however it uses the patient's own previously expired CO_2 instead of externally provided CO_2. Thus our circuit is much less expensive to operate, more compact and portable and thus would be more practical for applications where the maintenance of CO_2 is desired but the elimination of other gases such as anesthetics and carbon monoxide is not required.

2. Changes in CO_2 or other gas

For other applications such as a) maintaining a constant PCO_2 or instituting two or more levels of arterial PCO_2 during nuclear magnetic resonance imaging, b) raising PCO_2 i)during pregnancy to improve placental blood flow, ii) to prevent shivering, iii) to increase tissue perfusion, and iv) protect tissues from oxidative damage, prevention of rebreathing of exhaled gases is not necessary.

It would therefore be advantageous to reap the benefits of controlling the PCO_2 at a constant level and not having to incur the expense of supplying reserve gas. It has been determined that traumatized patients may be assisted in certain circumstances by maintaining the PCO_2 level substantially constant or increased. It is also been determined that various diagnostic procedures can be enhanced by pursuing the same. This hereto for was not contemplated in the prior art nor in the prior disclosure of Joseph Fisher (WO98/41266) discussed above.

It is therefore a primary objective of this invention to provide a simplified method of controlling PCO_2 at a predetermined desired level.

It is a further objective of this invention to provide a simplified method of changing the PCO_2 of a patient by changing the fresh gas flow in the circuit.

It is a further object of the invention to provide a circuit to affect the method that prevents loss of fresh gas and that ensures that a patient breathing at a rate greater than the fresh gas flow receives all the fresh gas independent of the rate and pattern of breathing.

It is a further object of this invention to provide a breathing circuit that prevents re-breathing unless the minute ventilation exceeds the fresh gas flow.

It is yet a further object of the invention to provide a circuit where alveolar gas is re-breathed in preference to dead space gas.

It is a further object of this invention to provide an improved breathing circuit to be used to assist patients who have been traumatized or run the risk of being traumatized, or alternatively to enhance the results of diagnostic procedures, or the benefits of medical procedures.

It is a further object of the invention to provide methods of treatment using the said circuit and the use of the said circuit to assist patients who have been traumatized or run the risk of being traumatized or alternatively to enhance the results of diagnostic procedures, or the benefits of medical procedures.

Further and other objects of the invention will become apparent to those skilled in the art when considering the following summary of the invention and the more detailed description of the preferred embodiments illustrated therein.

SUMMARY OF THE INVENTION

According to a primary aspect of the invention there is provided a method of controlling PCO_2 in a patient at a predetermined desired level (s) comprising a breathing circuit which is capable of organizing exhaled gas so as to be preferentially inhaled during re-breathing when necessary by providing alveolar gas for re-breathing in preference to dead space gas. The preferred circuit in effecting the above-mentioned method includes a breathing port for inhaling and exhaling gas, a bifurcated conduit adjacent said port, preferably being substantially Y-shaped, and including a first and second conduit branch, said first conduit branch including a fresh gas inlet, preferably oxygen, and a check valve disposed proximate the port, said check valve allowing the passage of inhaled fresh gas to the port but closing during exhalation, said second conduit including a check valve which allows passage of exhaled gas through said check valve but the prevents flow back to the breathing port once the gas passes through the check valve, said first conduit branch having located proximate the terminus thereof, a fresh gas reservoir of predetermined size and preferably a flexible bag, said second conduit branch having located proximate the terminus thereof, an exhaled gas reservoir, preferably being a rigid tube having an open end and being preferably approximately 3L in capacity, said terminus of said first and second conduit branches having extending there between an interconnecting conduit and having a check valve located therein, wherein when minute ventilation for the patient is equal to the fresh gas flow, for example 5 litres/minute, fresh gas enters the breathing port from the first conduit branch at a predetermined rate and preferably 5L per minute and is exhaled through the second conduit branch at a rate of preferably 5L per minute, wherein the exhaled gas travels down the exhaled gas reservoir which preferentially provides that dead space gas be disposed nearest the open end of the reservoir and that alveolar gas would be located proximate the end of the reservoir nearest the terminus of the second conduit branch, wherein when it is desirable for the minute ventilation to exceed the fresh gas flow, for example 5L per minute, the patient will inhale expired gas retained in the expired gas reservoir which will pass through the check valve in the interconnecting conduit at a rate making up the shortfall of the fresh gas flow of for example 5L per minute, wherein the shortfall differential is made up of rebreathed gas of which alveolar gas is preferentially rebreathed, thereby preventing a change in the PCO_2 level of alveolar gas despite the increased minute ventilation.

When setting the fresh gas flow to maintain a desired PCO_2 it is important that the fresh gas reservoir be allowed to first be depleted of gas until it just empties at the end of the inhalation cycle. In this way once it is desired to increase the minute ventilation, a slight negative pressure will exist in the interconnecting conduit during inhalation, opening its check valve and allow further breathing gas beyond the normal level of ventilation to be supplied by previously exhaled gas.

There are many uses for this particular circuit which will be described hereinafter. There may be situations which exist when treating a patient wherein it is desirable to prevent hypocapnia in the patient. For example, in the case of a pregnant woman having great anxiety due to the pain during delivery, it is desirable not to have her hyperventilate so as to contract the blood vessels in the placenta causing potential insufficient blood flow to the baby. By using the above-mentioned circuit during labour, this can be avoided. It also may be advantageous to induce hypercapnea during diagnostic procedures to enhance the diagnostic procedure or alternatively when a patient undergoes treatment as in treatment with ionizing radiation, to increase the sensitivity of tissue to the treatment. This for example would occur during radiation treatment for cancerous cells.

According to yet another aspect of the invention, there is provided a method of enhancing the results of a diagnostic procedure or medical treatment comprising the steps of:

providing a circuit which is capable of organizing exhaled gas so as to provide to the patient preferential rebreathing of alveolar gas in preference to dead space gas,(for example the circuit described above)

when the patient is ventilating at a rate greater than the fresh gas flow, and when inducing hypercapnea is desired, by decreasing the fresh gas flow and passively provide a corresponding increase in rebreathed gas so as to prevent the PCO_2 level of arterial blood from dropping despite increases in minute ventilation,

continuing inducing hypercapnia until such time as the diagnostic or medical procedure is completed,

wherein the results of said diagnostic or medical procedure are enhanced by carrying out the method in relation to the results of the procedure had the method not been carried out. Examples of such procedures would be MRI or radiation treatments or the like.

A method of treating or assisting a patient, preferably human, during a traumatic event characterized by hyperventilation comprising the steps of:

providing a circuit which alveolar ventilation is equal to the fresh gas flow and increases in alveolar ventilation with increases in minute ventilation is prevented by a circuit (for example the preferred circuit described above) which is capable of organizing exhaled gas so as to provide to the patient preferential rebreathing alveolar gas in preference to dead space gas

following ventilating the patient at a rate of normal minute ventilation, preferably approximately 5L per minute, and when desired inducing hypercapnea so as to increase arterial PCO_2 and prevent the PCO_2 level of arterial blood from subsequently dropping below that achieved as a result of decreasing the fresh gas flow,

continuing maintaining normocapnia despite the ventilation at an increased rate until such time as the traumatic event and concomitant hyperventilation is completed,

wherein the effects of hyperventilation experienced during the traumatic event are minimized for example the mother during labour becoming light headed or the baby during the delivery also being effected with the oxygen delivery to its brain being decreased as a result of contraction of the blood vessels in the placenta and fetal brain.

A list of circumstances in which the method enhancing the diagnostic procedure results or the experience of the traumatic event are listed below.

Applications of this method and circuit

1) Maintenance of constant PCO_2 and inducing changes in PCO_2 during MRI

2) Inducing and/or maintaining increased PCO_2

a) to prevent or treat shivering and tremors during labor, post-anesthesia, hypothermia, and certain other pathological states

b) to treat fetal distress due to asphyxia

c) to induce cerebral vasodilatation, prevent cerebral vasospasm, and provide cerebral protection following subarachnoid hemorage cerebral trauma and other pathological states

d) to increase tissue perfusion in tissues containing cancerous cells to increase their sensitivity to ionizing radiation and delivery of chemotherapeutic agents

e) to aid in radiodiagnostic procedures by providing contrast between tissues with normal and abnormal vascular response

f) protection of various organs such as the lung, kidney and brain during states of multi-organ failure

3) Prevention of hypocapnia with O_2 therapy, especially in pregnant patients

4) Other applications where O_2 therapy is desired and it is important to prevent the accompanying drop in PCO_2

It has been found in carrying out the above-mentioned method and preferably with the preferred circuit described that by maintaining a constant PCO_2 level and inducing changes in PCO_2 during a diagnostic procedure such as a MRI better quality pictures can be obtained. It is therefore according to another aspect of the invention provided that an improved method of creating MRI images is disclosed by following the above-mentioned method and particularly comprising the steps of maintaining a constant PCO_2 and inducing changes in that PCO_2 level during the MRI procedure in order to facilitate improvement in the quality of the pictures being taken. The method for inducing the changes in the PCO_2 include preferably using the above-mentioned circuit or any circuit known in the prior art and described in the background of the invention which might provide a substantial part or most of the benefits described herein. For example the Mapleson D and E circuits predictably may work as might a standard circle circuit with the carbon dioxide filter bypassed or removed; however fresh gas will be wasted and the efficiency would be reduced.

When minute ventilation is greater than or equal to fresh gas flow, the above-mentioned preferred circuit prevents loss of fresh gas and ensures that the patient receives all the fresh gas independent of the pattern of breathing since fresh gas alone enters the fresh gas reservoir, and exhaled gas enters its own separate reservoir. The fresh gas reservoir bag is large enough to store fresh gas for 5-10 seconds or more of reduced ventilation or total apnea, ensuring that even under these circumstances fresh gas will not be lost. The preferred circuit prevents rebreathing at a minute ventilation equal to the fresh gas flow because the check valve in the interconnecting conduit does not open to allow rebreathing of previously exhaled gas unless a negative pressure exists on the inspiratory side of the conduit of the circuit. Also, when minute ventilation exceeds the fresh gas flow, a negative pressure occurs in the inspiratory conduit, opening the conduit's check valve. The circuit provides that after the check valve opens, alveolar gas is rebreathed in preference to dead space gas because the interconnecting conduit is located such that exhaled alveolar gas will be closest to it and dead space gas will be furthest from it. The exhaled gas reservoir is preferably sized at 3L which is well in excess of the volume of an individual's breath, therefore it is unlikely that the patient shall be able to breathe any room air entering via the opening at the end of the exhaled gas reservoir.

The basic approach of preventing a decrease in PCO_2 with increased ventilation is similar as that taught by Fisher (WO98/41266). In brief, only breathing the fresh gas contributes to alveolar ventilation (VA) which establishes the gradient for CO_2 elimination. All gas breathed in excess of the fresh gas entering the circuit, or the fresh gas flow, is rebreathed gas. Fisher (WO98/41266) has in his prior application taught that the closer the partial pressure of CO_2 in the inhaled gas to that of mixed venous blood ($PvCO_2$), the less the effect on CO_2 elimination. Fisher (WO98/41266) expressed the relationship of alveolar ventilation, minute ventilation (V) and PCO_2 of rebreathed gas as follows:

$VA = FGF + (V - FGF) (PvCO_2 - PCO_2 \text{ of exhaled gas})/PvCO_2$
(Where FGF stands for the fresh gas flow, and other terms as described previously)

It is clear from this equation that as the PCO_2 of the exhaled gas approaches that of the mixed venous blood, the alveolar ventilation is determined only by the fresh gas flow and not the minute ventilation .

As one exhales, the first gas to exit the mouth comes from the trachea where little gas exchange has occurred. The PCO_2 of this gas is close to that of the inhaled gas and is termed 'dead space gas'. The last gas to exit the mouth has had the most time to equilibrate with mixed venous blood, has a PCO_2 closest to that of mixed venous blood and is termed 'alveolar gas'. Gas exhaled between these 2 periods has a PCO_2 intermediate between the two concentrations. The equation cited above explains why rebreathing alveolar gas would be the most effective in maintaining the PCO_2 at a constant level when minute ventilation increases.

Accordingly, in our circuit,

1. All of the fresh gas is inhaled by the subject when minute ventilation is equal to or exceeds fresh gas flow
1. The 'alveolar gas' is preferentially rebreathed when minute ventilation exceeds the fresh gas flow.

2. When minute ventilation is equal to or greater than fresh gas flow, all the fresh gas contributes to alveolar ventilation.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 illustrates schematically the nature of the simple breathing circuit and components enabling the PCO_2 to remain constant despite increase in minute ventilation.

DETAILED DESCRIPTION OF EMBODIMENTS

The patient breathes through one port of a Y-piece (1). The other 2 arms of the Y-piece contain 1-way valves. The inspiratory limb of the Y-piece contains a one-way valve, the inspiratory valve (2) which directs gas to flow towards the patient when the patient makes an inspiratory effort but during exhalation acts as a check valve preventing flow in the opposite direction. The other limb of the Y-piece, the expiratory limb, contains a one-way valve, the expiratory valve (3), positioned such that it allows gas to exit the Y-piece when the patient exhales but acts as a check valve preventing flow towards the patient when the patient inhales. Immediately distal to the expiratory limb of the Y-piece is attached large bore tubing (4), termed 'reservoir tube' that is open at its distal end (5). The reservoir tube is preferably greater than 22 mm in diameter, and its length is such that the total volume of the tubing is about or greater than 3L when it is being used for an average (70 Kg) adult. Larger volumes of reservoir tubing will be required for larger subjects and vice versa. The inspiratory port is connected to a source of fresh gas (6) i.e., gas not containing CO_2, flowing into the circuit at a fixed rate and a fresh gas reservoir bag (9) of about 3L in volume. A bypass conduit (7) connects the expiratory limb and the inspiratory limb. The opening of the conduit to the expiratory limb is preferably as close as possible to the expiratory one-way valve. This conduit contains a one-way valve (8) allowing flow from the expiratory to the inspiratory limb. The conduit's one-way valve requires an opening pressure differential across the valve slightly greater than that of the inspiratory valve. In this way, during inspiration, fresh gas, consisting of fresh gas flow and the contents of the fresh gas reservoir bag, is preferentially drawn from the inspiratory manifold.

Circuit function

When the subject's minute ventilation is equal to or less than the fresh gas flow (FGF), only fresh gas (FG) is breathed. During exhalation FG accumulates in the FG reservoir. During inhalation fresh gas flowing into the circuit and the contents of the fresh gas reservoir are inhaled. When minute ventilation exceeds FGF, on each breath, FG is breathed until the FG reservoir is emptied. Additional inspiratory efforts result in a decrease in gas pressure on the inspiratory side of the circuit. When this pressure differential across the bypass conduit's valve exceeds its opening pressure, the one-way valve opens and exhaled gas is drawn back from the expired gas reservoir into the inspiratory limb of the Y-piece and hence to the patient. The last gas to be exhaled during the previous breath, termed 'alveolar gas' is the first to be drawn back into the inspiratory limb and inhaled (rebreathed) by the subject.

While the foregoing provides a detailed description of a preferred embodiment of the invention, it is to be understood that this description is illustrative only of the principles of the invention and not limitative. Furthermore, as many changes can be made to the invention without departing from the scope of the invention, it is intended that all material contained herein be interpreted as illustrative of the invention and not in a limiting sense.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN ELUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE AS FOLLOWS:

1. A diagnostic method including an adjunct step of controlling partial pressure of carbon dioxide in a subject at a predetermined desired level(s), the method comprising:

arranging for a subject to breathe on a breathing circuit in which fresh gas is available at a controlled rate and gas exhaled by the subject is organized so that alveolar gas can be drawn back for rebreathing in preference to dead space gas, wherein fresh gas is provided first to the subject, and wherein alveolar gas is provided to the subject for the balance of a breath to the extent that the subject's inhalation of gas exceeds the provision of fresh gas.

2. The method of claim 1, comprising the steps of providing a controlled flow of fresh gas for the subject to breathe and arranging the alveolar gas to flow to the subject after the fresh gas is depleted in each inhalation cycle in which the minute ventilation of the subject exceeds the controlled flow of fresh gas.

3. The method of claim 1 or 2, wherein inspiratory gas is arranged to flow to the subject via an inspiratory limb of a breathing circuit and expiratory gas is arranged to flow away from the subject via an expiratory limb of the breathing circuit and wherein alveolar gas is prevented from flowing to the subject via the inspiratory limb when the minute ventilation is less than the fresh gas flow.

4. A breathing circuit, comprising: a breathing port through which a subject inhales and exhales; a fresh gas reservoir; an exhaled gas reservoir; a first conduit branch fluidly connected to the breathing port and the inhalation reservoir and operatively associated with a fresh gas inlet and with a first check valve that allows fresh gas to pass through the first check valve to the patient and prevents exhaled gas from passing through the first check valve to the inhalation reservoir; a second conduit branch fluidly connected to the breathing port and the

exhalation reservoir and operatively associated with a second check valve that allows exhaled gas to pass through the second check valve to the exhalation reservoir and prevents flow back of exhaled gas to the breathing port; a third conduit branch connecting the first conduit branch and the second conduit branch at locations more remote from the breathing port than the first and second one-way check valves; and a third check valve disposed in the third conduit branch and operative to direct exhaled alveolar gas held closest to the third check valve into the first conduit when a pressure differential across the third check valve associated with depletion of the inhalation reservoir reaches a predetermined level.

5. The breathing circuit of claim 4, wherein the fresh gas inlet is connected to the first conduit branch between the third conduit branch and first check valve.

6. The breathing circuit of claim 4, wherein the exhalation reservoir defines an elongated flow path of predetermined volume for retaining a predetermined part of the exhalation gas proximal to the third check valve.

7. The breathing circuit of claim 6, wherein the exhalation reservoir is a tube connected at one end to the second conduit branch and open at the other end.

8. The breathing circuit of claim 7, wherein the exhalation reservoir is made of a rigid or a flexible tubing material.

9. The breathing circuit of claim 4, 6 or 7, wherein the exhalation reservoir includes a tube with a diameter larger than 22 mm.

10. The breathing circuit of claim 4, 6 or 7, wherein the exhalation reservoir has a total volume determined according to the weight of the subject.

11. The breathing circuit of claim 4, 6 or 7, wherein the exhalation reservoir has a total volume of about 3 L.

12. A method of enhancing the results of a diagnostic procedure performed for a subject comprising the steps of:

allowing a subject to breathe on a breathing circuit that is capable of providing fresh gas to a subject at a controlled rate and that organizes exhaled gas so as to provide for rebreathing an alveolar gas in preference to dead space gas;

providing fresh gas to the subject at a rate which is equal to or less than the patient's minute ventilation for the duration of the diagnostic procedure; and

wherein on each breath, fresh gas is provided first to the subject, and wherein alveolar gas is provided to the subject for the balance of that breath to the extent that the subject's inhalation exceeds the provision of fresh gas.

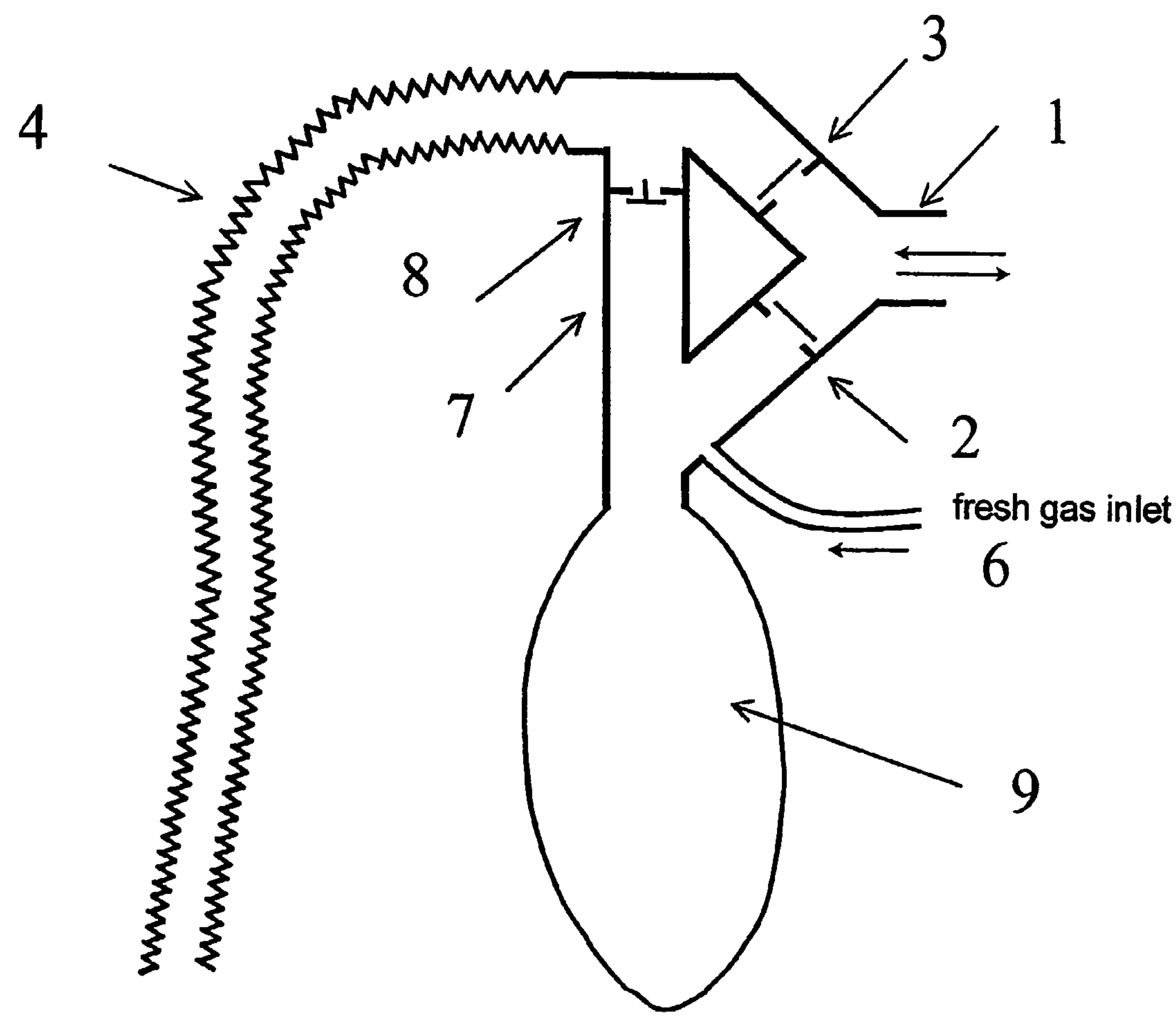
13. The method of claim 12, wherein the subject breathes on a circuit as defined in any one of claims 4 to 11 and wherein fresh gas is provided to the subject at a rate that is less than or equal to the patient's minute ventilation.

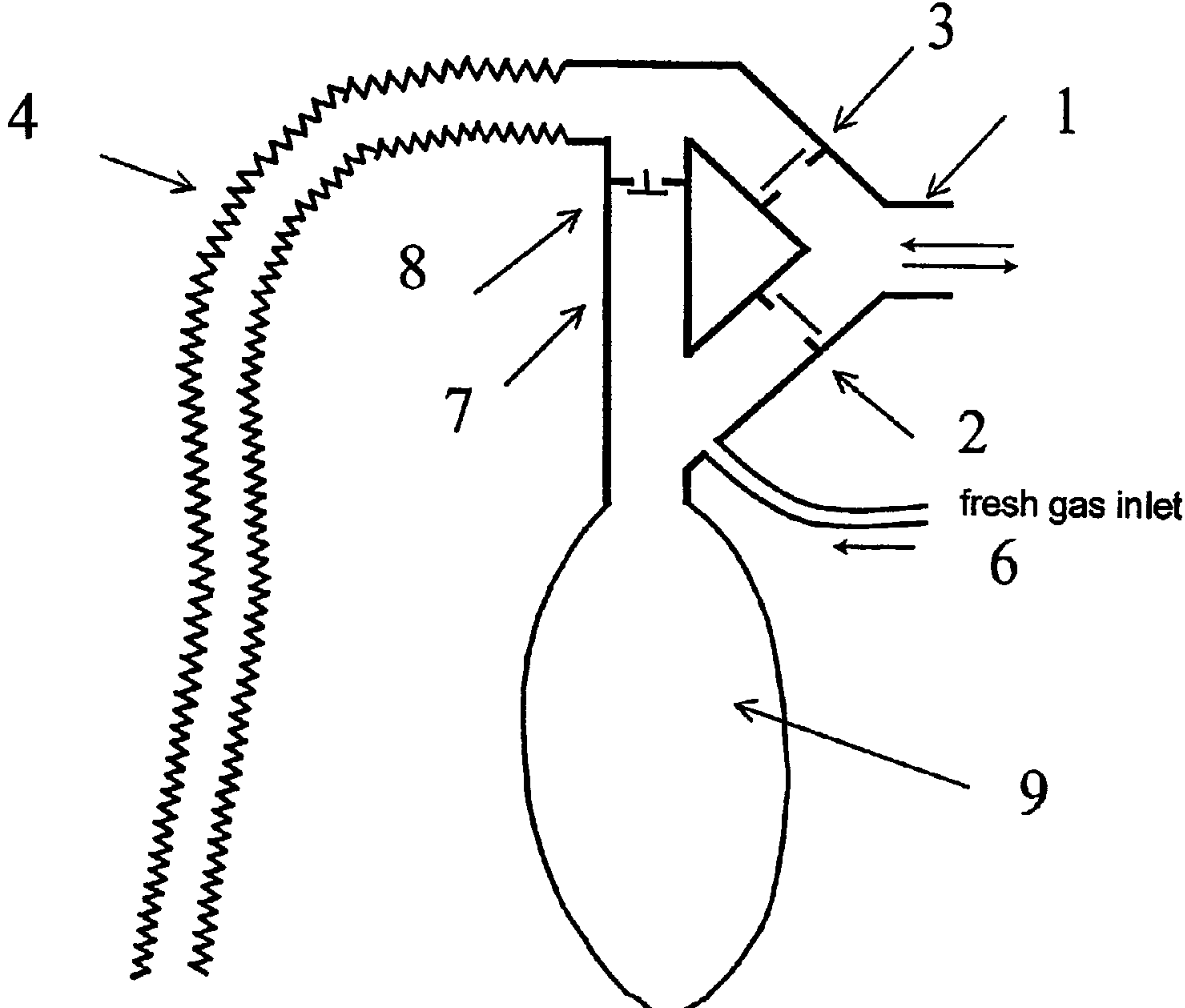
14. The method of claim 13, wherein the fresh gas flow is set so that the fresh gas reservoir just empties at the end of the inhalation cycle.

15. The method of claim 12, utilized for a MRI or radiation treatment procedure.

16. The method of claim 12, wherein the diagnostic procedure provides contrast between tissues with normal and abnormal vascular response.

Figure 1




4
3
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fresh gas inlet
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