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(54) METHOD AND SYSTEM FOR THE DELIVERY OF CARBON DIOXIDE TO A PATIENT

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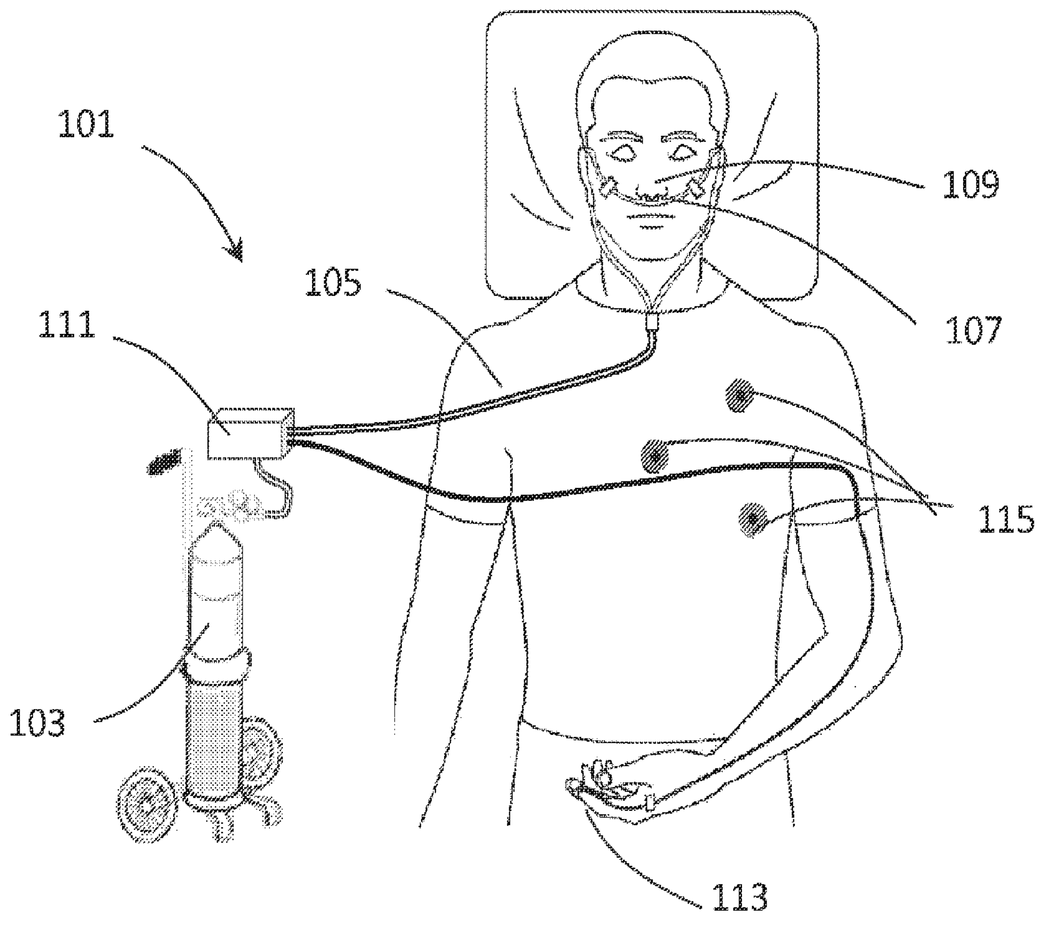
(57) **ABSTRACT**

A method and system for delivering a gas containing carbon dioxide to a patient are described. The method comprises measuring a physiological parameter of breathing stability in the patient; determining an optimal gas delivery parameter based on the physiological parameter of breathing stability; and delivering the gas to the patient in accordance with the optimal gas delivery parameter.



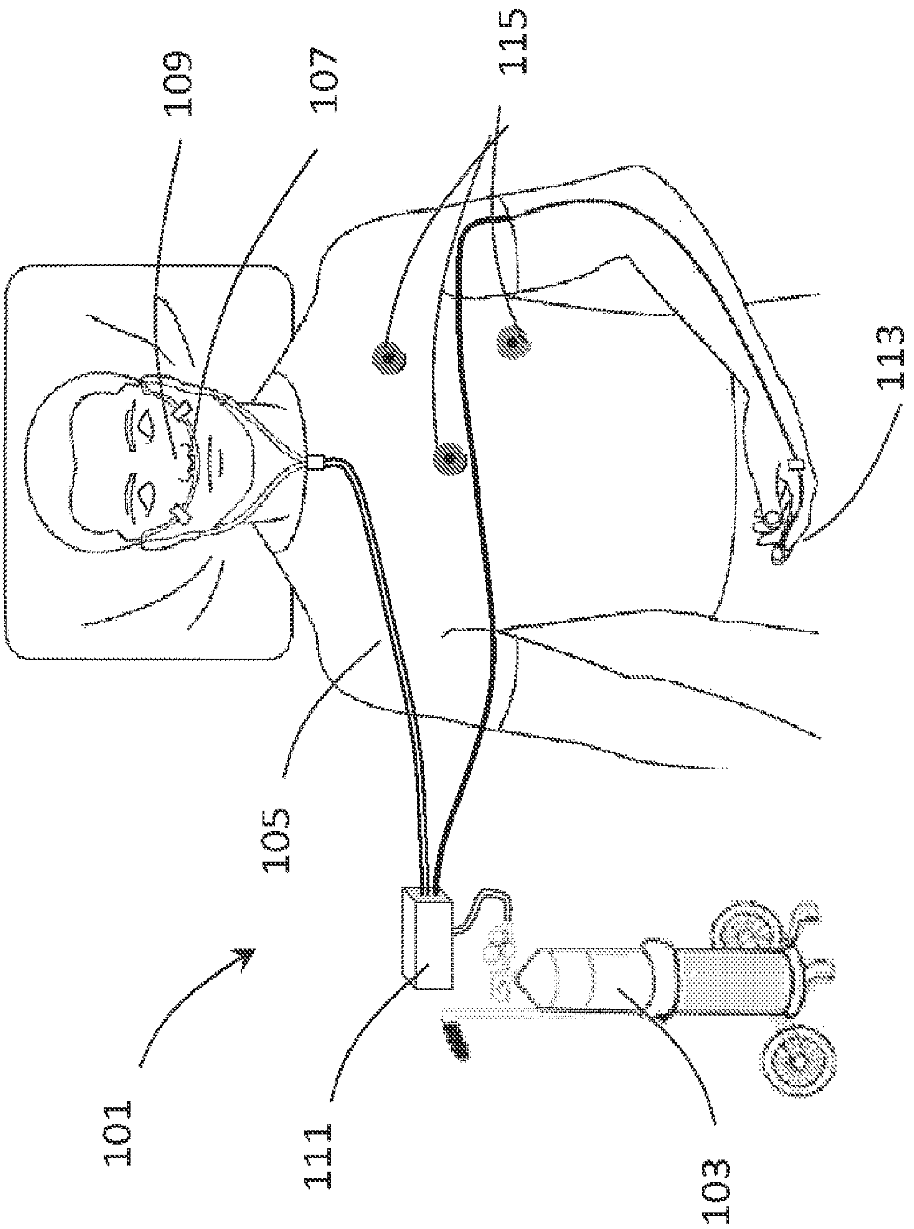


FIG. 1

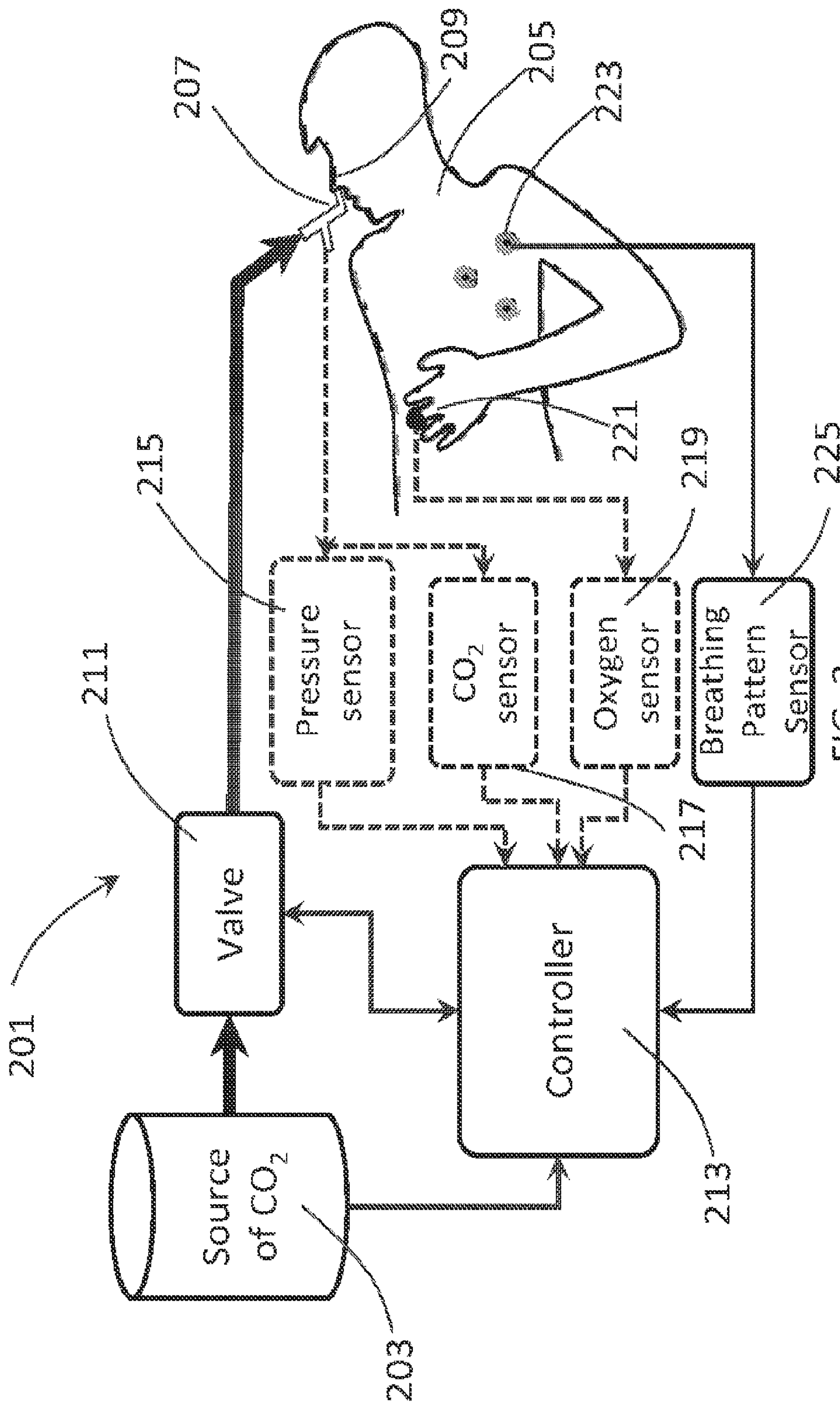

201
203
Source of CO_2
Valve
211
Controller
213
Pressure sensor
215
CO_2 sensor
217
Oxygen sensor
219
Breathing Pattern Sensor
225
207
209
205
223
221

FIG. 2

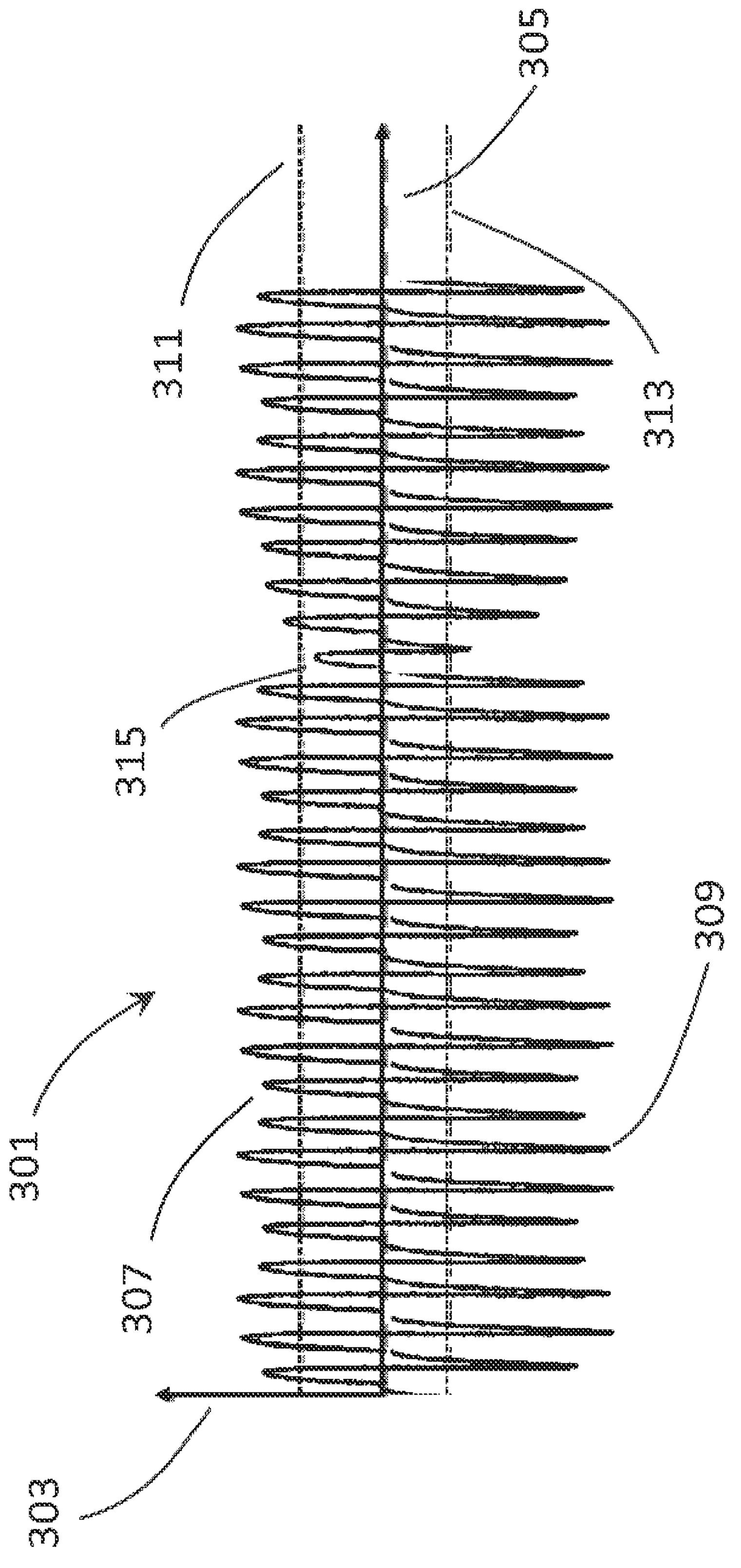


FIG. 3

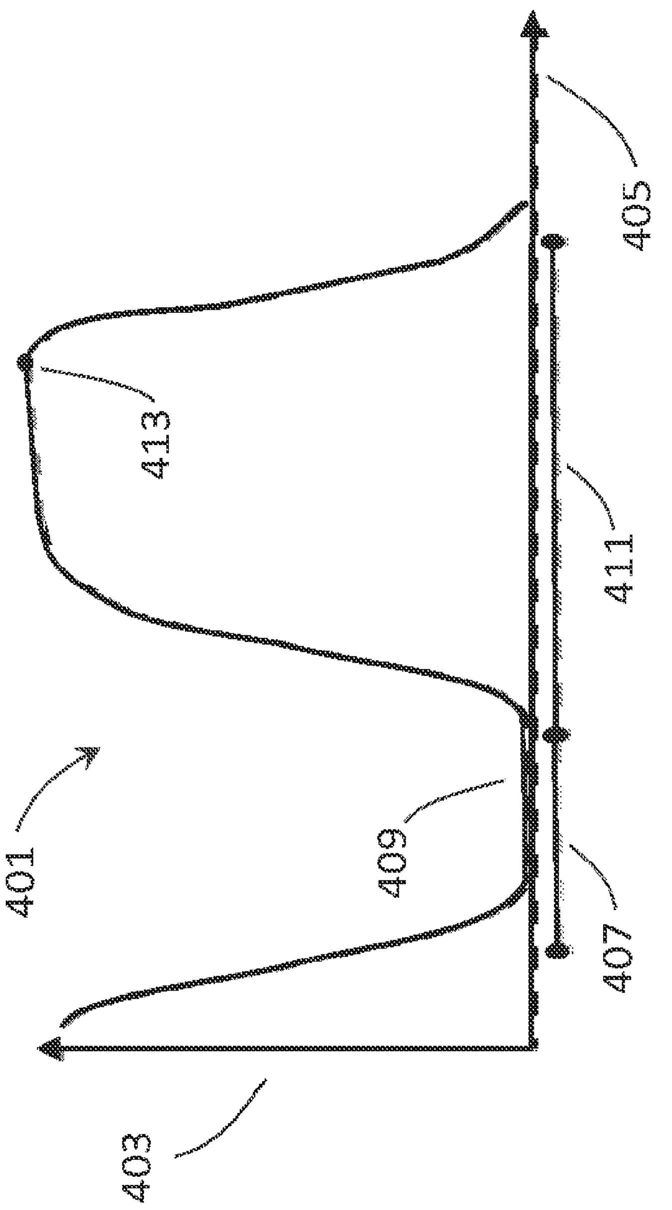


FIG. 4

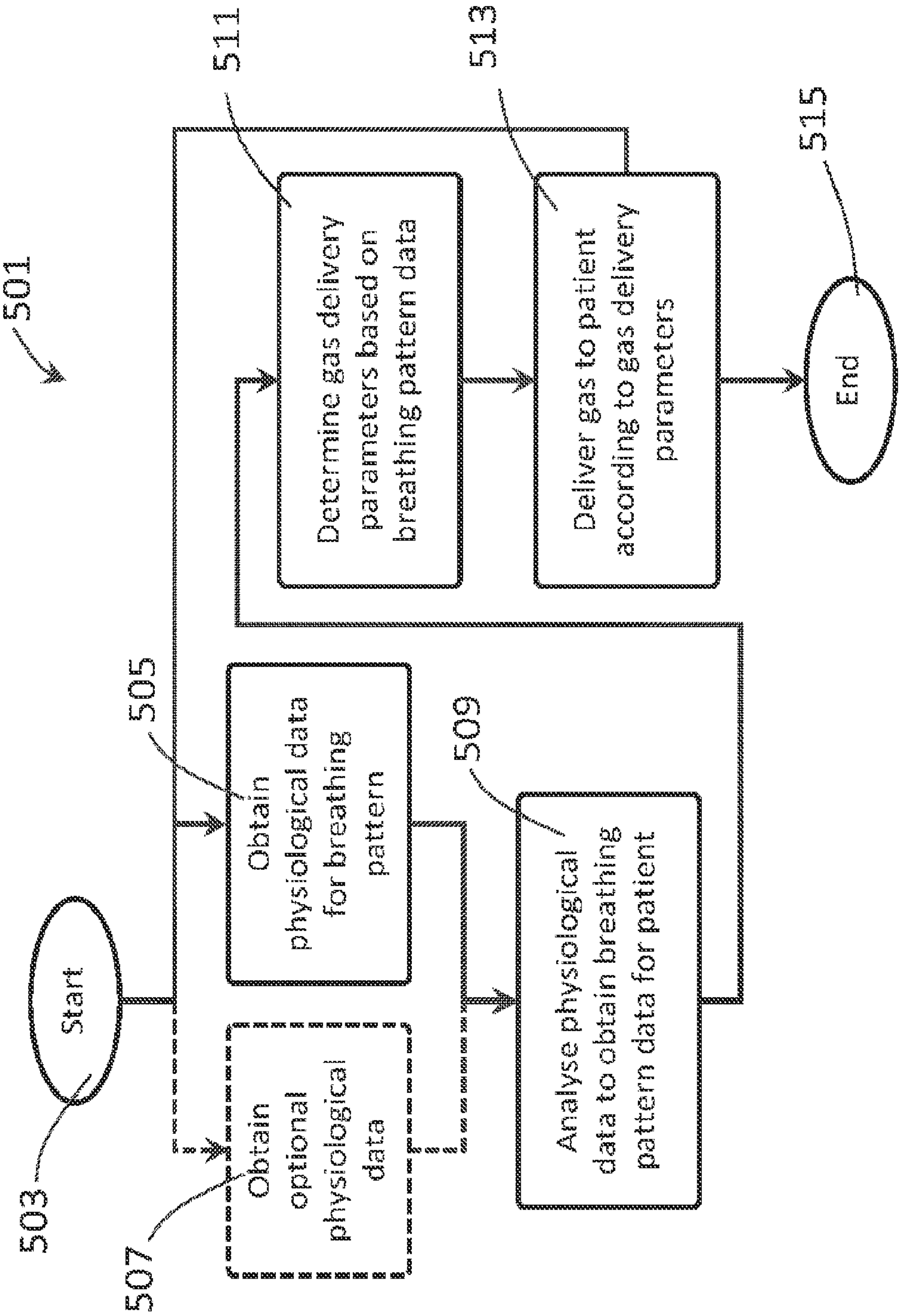

501
503
Start
505
Obtain physiological data for breathing pattern
507
Obtain optional physiological data
509
Analyse physiological data to obtain breathing pattern data for patient
511
Determine gas delivery parameters based on breathing pattern data
513
Deliver gas to patient according to gas delivery parameters
515
End

FIG. 5

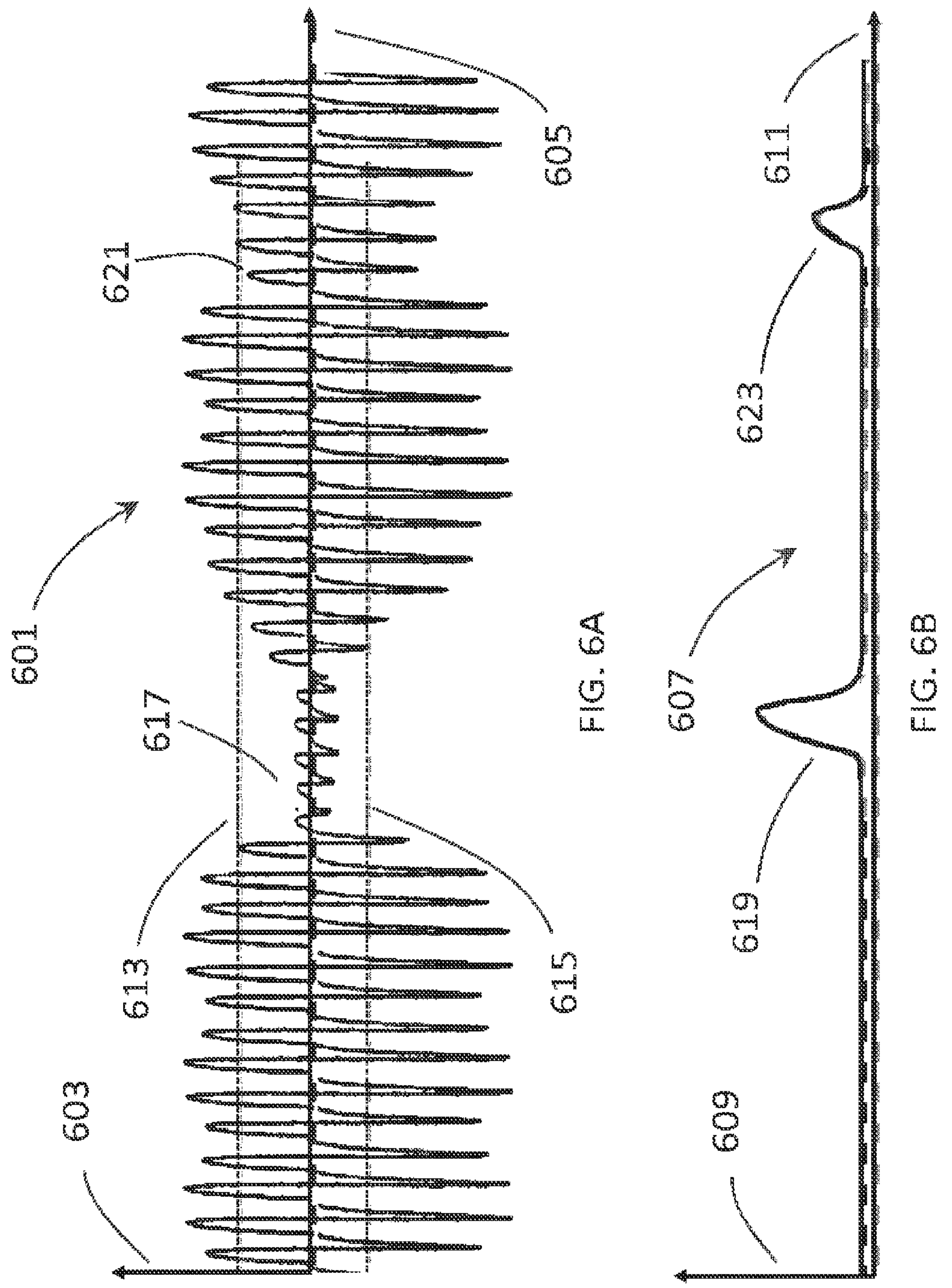


FIG. 6A

FIG. 6B

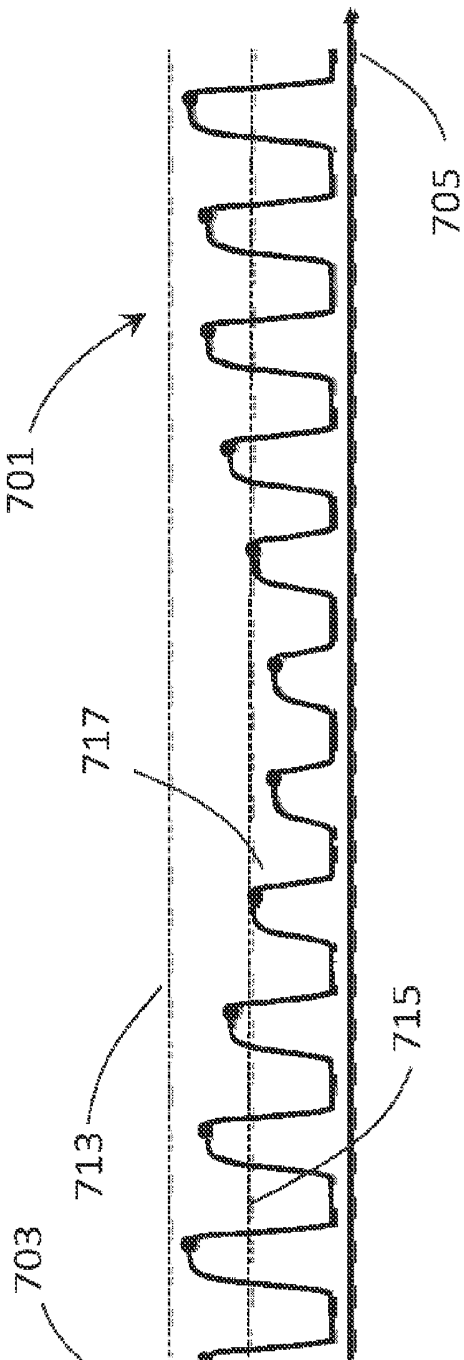


FIG. 7A

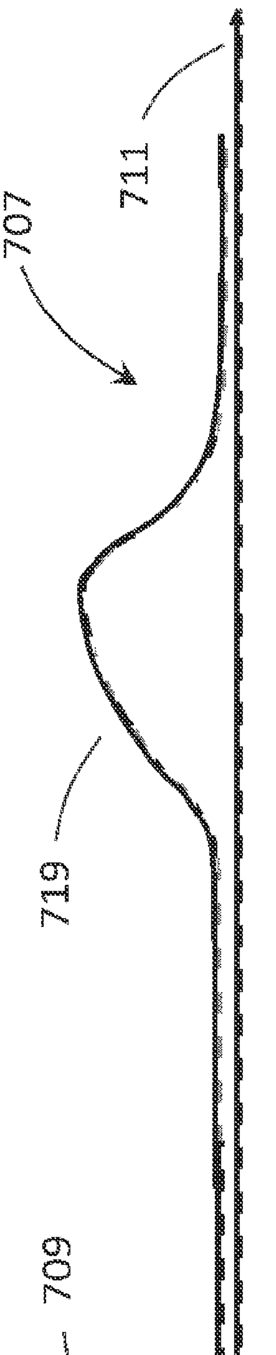


FIG. 7B

METHOD AND SYSTEM FOR THE DELIVERY OF CARBON DIOXIDE TO A PATIENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35USC§119 (e) of U.S. provisional patent application 61/432,371 filed Jan. 13, 2011 and is related to U.S. patent application Ser. No. 12/837,259 filed on Jul. 15, 2010 and published on Mar. 24, 2011 as US 2011/0067697, the specifications of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The invention relates to a device and method for the delivery of gas containing carbon dioxide (CO_2) to a patient and more particularly to a controlled delivery based on the detection of a breathing disorder.

BACKGROUND OF THE ART

[0003] Sleep disordered breathing (SDB) is characterized by irregular breathing both in rate and depth (amplitude). SDB can include periodic hypopnea (overly shallow breathing or an abnormally low respiratory rate) and periodic apnea (no breathing). It is established that SDB has two main causes: 1) obstructive abnormalities, which are associated with an obstruction of the pharyngeal airway and 2) central sleep disorders, which stem from a failure of the sleeping brain to generate regular rhythmic neural signals needed by the respiratory muscles.

[0004] Obstructive abnormalities can usually be treated using positive airway pressure (PAP) therapy, where a breathing gas is introduced in the airways of the patient at a pressure slightly higher than the atmospheric pressure. However, central sleep disorders are not treated effectively with PAP, even with the administration of oxygen-enriched breathing gases (oxygen therapy).

[0005] Disturbed sleep usually results in chronic fatigue, and impairs the patient's daytime cognitive functions and quality of life. SDB is frequently observed in patients with heart failure. For these patients, central sleep apnea is a serious condition that is believed to aggravate cardiac arrhythmia and to increase the occurrence of strokes and myocardial infarctions. Unfortunately, there exist no approved methods for the treatment of central sleep apnea.

[0006] The most well-known central sleep disorder is the Cheyne-Stokes respiration (CSR) where a patient experiences a succession of hyper- and hypoventilation periods. This type of disorder is mainly experienced late at night, during nights where obstructive apnea/hypopnea episodes were observed in the early hours of sleep. CSR can also be observed at any time of the night and even during wake time in advanced forms of heart failure. The prevalence of CSR in the population with congestive heart failure is estimated at between 15 and 35%.

[0007] The central respiratory function is a complex system that comprises multiple feedback mechanisms based on chemical receptors sensing carbon dioxide (CO_2), oxygen (O_2) and blood acidity (pH). When the feedback signals are not sufficiently intense, the central rhythmic neural signals to the respiratory muscles are perturbed or can stop completely. Hyperventilation associated with unstable breathing also contributes to lower the blood concentration of CO_2.

[0008] It has been shown that increasing the concentration of CO_2 in the breathing air has a stabilizing effect on patients with CSR, because of the increased CO_2 feedback signal. However, no practical methods for administering CO_2 to a patient are commercially available.

[0009] A prior art method of administering CO_2 relies on the accepted PAP technique. PAP requires leak-proof masks that are uncomfortable because they need to be secured tightly over the patient's face. PAP gases with low humidity content also contribute to the drying of the respiratory passageways and the patient's discomfort. One should note that the administration of a continuous flow of CO_2, such as is proposed in this prior art method, is a significant medical expense due to the large quantities of gas used.

[0010] An alternate prior art method utilizes a dead space in an external breathing apparatus as a simple way to increase the fractional concentration of inspired CO_2 (FICO2). This method has the disadvantages of requiring a leak-proof mask and demanding an increased respiratory effort to move the gases in the external breathing circuit.

SUMMARY

[0011] According to one broad aspect of the present invention, there is provided a method for delivering a gas containing carbon dioxide to a patient. The method comprises measuring a physiological parameter of breathing stability in the patient; determining an optimal gas delivery parameter based on the physiological parameter of breathing stability; and delivering the gas to the patient in accordance with the optimal gas delivery parameter.

[0012] In one embodiment, the gas containing carbon dioxide is a mixture of gases including carbon dioxide.

[0013] In one embodiment, the method further comprises repeating the step of measuring the physiological parameter of breathing stability in the patient, after the delivering the gas, to determine an effect of the delivering on the physiological parameter.

[0014] In one embodiment, the method further comprises repeating the steps of determining the optimal gas delivery parameter and delivering the gas to adjust the delivering consequently to the effect.

[0015] In one embodiment, the optimal gas delivery parameter is selected from the group consisting of a fraction of carbon dioxide in the gas and a flow rate of the gas during the delivering.

[0016] In one embodiment, the method further comprises issuing an alarm if the physiological parameter is measured to be outside of a predetermined threshold.

[0017] In one embodiment, the physiological parameter is the breathing pattern for the patient, the breathing pattern including at least the respiratory amplitude.

[0018] In one embodiment, the physiological parameter is analyzed to obtain a breathing pattern index for the patient and the determining the gas delivery parameter is carried out using the breathing pattern index.

[0019] In one embodiment, the physiological parameter further includes at least one parameter selected from the group consisting of arterial hemoglobin oxygen saturation, respiratory rate, respiratory amplitude, chest movement pattern, end tidal CO_2 ($ETCO_2$) level, Rapid Eye Movement (REM) pattern, rate of apnea, rate of hypopnea, rate of desaturation, respiratory rate variability, heart rate variability, heart rate synchrony and snoring noise level.

[0020] According to another broad aspect of the present invention, there is provided a system for delivering a gas containing carbon dioxide to a patient. The system comprises a physiological sensor for measuring a physiological parameter of breathing stability in the patient; a controller receiving the physiological parameter from the physiological sensor for determining an optimal gas delivery parameter based on the physiological parameter of breathing stability; and a gas delivery sub-system having a gas source and a gas delivery controller for delivering the gas to the patient in accordance with the optimal gas delivery parameter received from the controller.

[0021] In one embodiment, the gas containing carbon dioxide is a mixture of gases including carbon dioxide.

[0022] In one embodiment, the optimal gas delivery parameter is selected from the group consisting of a fraction of carbon dioxide in the gas and a flow rate of the gas during the delivering and wherein the gas delivery controller uses the gas delivery parameter to deliver the gas from the source.

[0023] In one embodiment, the system further comprises an alarm sub-system including an alarm emitter and an alarm controller, the alarm controller having a predetermined threshold, the alarm controller receiving the physiological parameter from the controller and controlling the alarm emitter to issue an alarm if the physiological parameter is measured to be outside of the predetermined threshold.

[0024] In one embodiment, the physiological parameter is the breathing pattern for the patient, the breathing pattern including at least the respiratory amplitude.

[0025] In one embodiment, the system further comprises a breathing pattern index calculator for analyzing the physiological parameter to obtain a breathing pattern index for the patient and wherein the controller uses the breathing pattern index to determine the gas delivery parameter.

[0026] In one embodiment, the physiological parameter further includes at least one parameter selected from the group consisting of arterial hemoglobin oxygen saturation, respiratory rate, respiratory amplitude, chest movement pattern, end tidal CO_2 ($ETCO_2$) level, Rapid Eye Movement (REM) pattern, rate of apnea, rate of hypopnea, rate of desaturation, respiratory rate variability, heart rate variability, heart rate synchrony and snoring noise level.

[0027] In one embodiment, the system further comprises an analysis module for analyzing the measured physiological parameter and determined gas delivery parameter to detect a trend for the patient.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] Having thus generally described the nature of the invention, reference will now be made to the accompanying drawings, showing by way of illustration a example embodiment thereof and in which

[0029] FIG. **1** is a schematic illustration of an example embodiment;

[0030] FIG. **2** is a functional block diagram of the main components of an example embodiment;

[0031] FIG. **3** is a graph of an example breathing pattern plotted against the time;

[0032] FIG. **4** is a graph of an example expired CO_2 concentration plotted against the time;

[0033] FIG. **5** is a flowchart illustrating the main steps of an example method for delivering the CO_2 to a patient with the example system shown in FIG. **1**;

[0034] FIG. **6** includes FIG. **6**A and FIG. **6**B, wherein FIG. **6**A is a graph of an example breathing pattern with some low amplitude respirations plotted against the time and FIG. **6**B is a graph of an example delivery of CO_2 in response to the breathing pattern shown in FIG. **6**A; and

[0035] FIG. **7** includes FIG. **7**A and FIG. **7**B, wherein FIG. **7**A is a graph of an example expired CO_2 concentration with some low end tidal CO_2 ($ETCO_2$) values plotted against the time and FIG. **7**B is a graph of an example delivery of CO_2 in response to the respiratory pressure shown in FIG. **7**A.

[0036] It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

DETAILED DESCRIPTION

[0037] The present invention proposes an adaptive system and method where CO_2 is delivered based on the patient physiological data with the aim to stabilize, or at least improve, the breathing pattern. The physiological parameter detected is therefore indicative, in some respect, of breathing stability.

[0038] A closed control loop is used to deliver CO_2 intermittently in response to respiratory abnormalities or patterns, thereby helping to reduce central apnea and hypopnea. The quantity of CO_2 used in the proposed method and system is reduced with respect to existing systems which deliver CO_2 since the CO_2 is administered according to delivery parameters (flow rate, time and duration) determined using measured physiological data. In most cases the administration of CO_2 will be intermittent, thus greatly reducing the amount of delivered CO_2 compared with a continuous delivery.

[0039] FIG. **1** is a schematic illustration of an example system **101** used to administer gaseous CO_2 from a CO_2 source **103** to a patient **105** by means of a nasal cannula **107** affixed to the patient's nose **109**. The quantity of CO_2 delivered to the patient **105** from the source **103** is controlled using the integrated system **111**.

[0040] Sensors are used to provide physiological signals that can be utilized by the integrated system **111** to change the amount of CO_2 administered to the patient **105**. At least one breathing pattern sensor **115**, for example an accelerometer, detects the breathing pattern (depth (amplitude) of breath, rate, presence or absence of breath, etc.) of the patient and sends its signal to the integrated system **111**. The breathing pattern could only detect amplitude of breath but typically detects both amplitude and rate. The integrated system **111** uses this physiological signal to adjust the delivery of CO_2.

[0041] The nasal cannula **107** can optionally include a pressure sensor and can also optionally include an end tidal CO_2 ($EtCO_2$) sensor as will be depicted in FIG. **2**. A blood oxygen sensor (oxymeter or SpO_2 sensor) **113** can also optionally be used with the system. The physiological signals acquired by the optional pressure sensor, $EtCO_2$ sensor and oxymeter can also be used by the integrated system **111** to adjust the delivery of CO_2.

[0042] FIG. **2** is a functional illustration of an example system **201** used to administer gaseous CO_2 from a source **203** to a patient **205** by means of a nasal cannula **207** affixed to the patient's nose **209**. The quantity of CO_2 delivered to the patient **205** from the source **203** is controlled using a motorized proportional valve **211** commanded by a controller **213**.

[0043] The motorized proportional valve **211** has an actuator (not shown) which allows a displaceable portion of the valve **211** to be moved between a closed position and an open position to allow the flow of CO_2 to be sent to the patient **205** from the source **203**. As will be readily understood, a partial opening is also possible to control the flow of CO_2. The valve **211** may or may not provide feedback information regarding its degree of opening to the controller, which may differ from the commanded value.

[0044] The controller **213** receives physiological signals from the patient and calculates the appropriate command for the valve **211**. In the example embodiment, the physiological signals can include the breathing pattern obtained from the breathing pattern sensor **225**, for example accelerometer **223**, the breathing amplitude and rate derived from pressure sensor **215**, the expired CO_2 concentration derived from CO_2 sensor **217**, as well as the arterial hemoglobin (blood) oxygen saturation measured by pulse oximetry (SpO_2) using O_2 sensor (oxymeter) **219** and the derived heart rate. In one example embodiment, only the expired CO_2 concentration derived from CO_2 sensor **217** is used by the controller **213** as a physiological signal. In another example embodiment, only the breathing pattern obtained from the breathing pattern sensor **225** is used by the controller **213** as a physiological signal.

[0045] Examples of physiological signals that can be tracked to evaluate the quality of sleep of the patient after delivery of CO_2 include the Rapid Eye Movement (REM) pattern, breathing pattern (respiratory flow, respiratory pressure, rate of apnea, rate of hypopnea, rate of desaturation, respiratory rate variability), heart rate variability, heart rate synchrony, movement of patient, electromyogram of muscles involved in breathing (for example from nasal muscles to intercostal muscles, diaphragm of sternocleido mastoids, etc.), detection of thoracic movements by plethysmography or other suitable method, the patient's temperature and the patient's snoring noise level. A quality of sleep parameter can be obtained using these physiological signals and can be used by the controller **213** to adjust the command for the valve **211**.

[0046] The CO_2 source **203** is usable for providing a gas including CO_2 to the patient **205**. In some embodiments of the invention, the gas source **203** is a CO_2 source providing a pre-determined concentration of CO_2 to the patient. This pre-determined concentration can be set to any useful concentration, for example a 100% concentration corresponds to pure CO_2. In these embodiments, the controller **213** is usable for controlling a gas flow rate of the gases source **203**. In other embodiments of the invention, the gases source **203** provides a mixture of air and CO_2. In these embodiments, the controller **213** is usable for adjusting a fraction of CO_2 in the gas and the gas flow rate of the gas source **203**. In some embodiments, the source of CO_2 could be the expired gas from the patient. In yet other embodiments of the invention, any other suitable gas source **203** is used. The mixture of gas delivered to the patient may or may not include oxygen.

[0047] As will be readily understood, any suitable gas delivery apparatus including a facial mask, a venturi mask and eyeglasses provided with gas delivery tubes can be used instead of the nasal cannula **207**.

[0048] The present invention provides an improved level of comfort for the patient. If the gas delivery apparatus is a mask, it does not have to be completely leak-proof. The comfort may be even further improved by having the patient wear a simple nasal cannula. Because the system has a retroaction via the physiological signals from sensors **215**, **217**, **219** and **225**, the system is able to compensate for small leaks.

[0049] In the example shown, the breathing pattern sensor **225** is used to monitor the respiratory cycles and determine phases of hypo- and hyperventilation and the respiratory amplitude. Accelerometer-based respiratory monitoring is based on the observation of small rotations at the chest wall due to breathing. MEMS accelerometers worn on the torso can measure inclination changes due to breathing, from which a respiratory amplitude and/or rate can be obtained. Tri-axial accelerometer data can track the axis of rotation and obtain angular rates of breathing motion. Other types of breathing pattern sensors can include an infra-red reflector monitored by a camera, a spirometer, a belt connected to a bellows or an inductive belt.

[0050] FIG. **3** is a graph **301** of the breathing pattern **303** obtained with the breathing pattern sensor **225**, plotted against the time **305**. A normal breathing pattern measured via the movements of the chest of the patient is composed of positive peaks **307** measured during inspiration when the chest stretches and negative peaks **309** measured during expiration when the chest deflates. As will be readily understood, a correlation of the measured chest displacements with the breath volumes of each patient will be necessary. The normal respiratory amplitudes during the expiratory and inspiratory phases vary according to the physical condition, level of physical effort and health condition of each person. It is possible to establish an acceptable inspiratory threshold **311** and expiratory threshold **313** for each person, for example by analyzing the breathing pattern during wake time. Using these respiratory thresholds, it is possible to classify normal or abnormal respiration. For example, the maximum value of the inspiration **315** did not reach inspiratory threshold **311**, so the inspiration **315** is considered abnormal. Hypo- and hyperventilation are defined by the occurrence of abnormal respiration for a certain number of respirations or a certain period of time. These thresholds are then optionally used by the controller **213** to adjust the delivery of CO_2.

[0051] FIG. **3** could also represent a graph of the respiratory pressure **303** obtained with the respiratory pressure sensor **215** and plotted against the time since both sensors will capture a volume reading. The inspiration as detected with the pressure sensor **215** will yield a negative peak and the expiration will yield a positive peak.

[0052] When the expired CO_2 concentration from the sensor **217** is used by the controller **213**, a potential issue arises depending on the location of the CO_2 sensor. The sensor could sample not only the expired gases, but also the inspired gases. The presence of CO_2 in the inspiratory phase may result in potential measurement errors of the expired CO_2 parameter by the CO_2 sensor **217**. FIG. **4** is a graph **401** of the CO_2 concentration **403** obtained with CO_2 sensor **217**, plotted against the time **405**. During the inspiratory phase **407**, the CO_2 concentration drops to the value of the inspired air **409**. During the expiratory phase **411**, the CO_2 concentration increases to approximately 5%. The maximum value **413** reached at the end of the expiratory phase **411**, is called the end tidal CO_2 ($ETCO_2$) concentration.

[0053] To reduce an impact of the potential issue of contamination of the expired CO_2 concentration measurement by inspired gases, the following algorithm can be used. Individual expiratory phases are identified and located in the CO_2 concentration versus time waveform by finding the places where the average over a typical expiratory period is maximized. Once the expiratory phases are located, the maxima of the measured values over each expiratory phase are extracted. These values correspond to the end tidal CO_2 concentrations and are free from inspired air contamination. These values are then optionally used by the controller **213** to adjust the delivery of CO_2

[0054] In another embodiment, the respiratory pressure sensor **215** can also be used in addition to the CO_2 concentration sensor **217** to determine or to improve the determination of when the inspiration and expiration phases begin and end, in order to reject data acquired during the inspiratory phase.

[0055] When the measurement of the blood oxygen saturation obtained using sensor **219** is used as a physiological signal, sensor **219** can take on different forms. In the example shown in FIG. **2**, the blood oxygen saturation is obtained via a finger probe **221**. In other embodiments, the blood oxygen saturation could be obtained via different means, such as using a toe probe or by placing an oximetry probe on another vascularized location on the body.

[0056] The controller **213** calculates the command to the proportional valve **211** as much as possible in real time in order to stabilize the condition of the patient shortly after a breathing anomaly or breathing pattern is detected by the controller based on the physiological data.

[0057] FIG. **5** is a flowchart illustrating an example method **501** for delivering the CO_2 to a patient **205**. FIG. **5** will be described herein in relation with the system described in FIG. **2**. After the system is powered up and initialized **503**, the controller **213** reads at steps **505** and **507**, the available physiological parameters, obtained with sensors **215**, **217**, **219** and **225**. Next the controller **213** analyses **509** the available physiological parameters and derives a breathing pattern index. A breathing pattern index of 100% indicates normal breathing while a breathing pattern index of 0% indicates a completely disrupted breathing pattern. The breathing pattern index is automatically determined by the controller **213** based on the variations of the detected signals compared to the thresholds. These thresholds may have been determined for example during wake time or derived from studies and then provided to the controller during a set-up procedure.

[0058] The controller **213** also calculates **511** the amount of CO_2 to administer to the patient based on the available physiological data and breathing pattern index. The valve **211** is commanded **513** to the appropriate level allowing the CO_2 to be administered to the patient **205** as long as the breathing pattern is considered to be disordered. The steps in the method **501** are iterated continuously, for example several times per minutes, until the system is turned off **515**, either by a trained person or by a system internal alarm.

[0059] The valve command is calculated using, for example, numerical servo computations based on the current values of the physiological signals as well as previous values measured in the preceding minutes. The function of the controller **213** can be implemented using a personal computer, but in the example embodiment, it is embedded in compact dedicated electronics composed of one or several micro-controllers, one or several digital signal processors (DSP), one or several field-programmable gate arrays (FPGA) or a combination of two or three of these types of electronic devices.

[0060] At step **511**, the gas delivery parameters can be obtained using a proportional-integral-differential (PID) controller. Gas delivery parameters are determined in order to maintain one or several of the measured physiological parameters within a predetermined interval or as close as possible to a target value. In an embodiment of the invention, the breathing amplitude is derived from the physiological data obtained. A target value of, for example, more than 95% of the expiration amplitudes are larger than the expiratory threshold is selected. This target value can be adjusted according to the patient **205** in accordance with conventional criteria.

[0061] FIG. **6**A is a graph **601** showing the breathing pattern **603** obtained with the breathing pattern sensor **225**, plotted against the time **605**. FIG. **6**B is a graph **607** showing the amount of CO_2 **609** delivered by the controller **213**, plotted against the time **611**. The time scales **605** and **611** are the same. The inspiratory threshold **613** and expiratory threshold **615** are predetermined for each person. When the respiratory amplitudes are measured **617** to be lower than the thresholds for a certain period of time, the controller **213** can command the valve **211** to release a certain amount of CO_2 **619**. When the respiratory amplitude returns to acceptable levels, the amount of CO_2 delivered can be nil. If a smaller deviation from the threshold is measured **621**, a smaller amount of CO_2 **623** can be administered by the system by controlling the valve **211**.

[0062] In another example embodiment of the invention, the measured physiological parameter is indicative of the expired CO_2 concentration in the patient and a target value of, for example, 40 mmHg is selected. This target value can be entered as a fixed parameter, adjusted according to the patient **205** in accordance with conventional criteria, including from data measured in a sleep evaluation laboratory or can be determined automatically by the controller **213** based on the acquired physiological data.

[0063] FIG. **7**A is a graph **701** showing the expired CO_2 concentration **703** obtained with the CO_2 sensor **217**, plotted against the time **705**. FIG. **7**B is a graph **707** showing the amount of CO_2 **709** administered by the controller **213**, plotted against the time **711**. The time scales **705** and **711** are the same. The expired CO_2 concentration is considered normal when it is lower than the upper limit **713** and higher than the lower limit **715**. These limits are determined in accordance with conventional criteria, including from data measured in a sleep evaluation laboratory, as fixed parameters or adjusted automatically by the controller **213** based on the acquired physiological data. When the expired CO_2 concentration is measured **717** to be lower than the lower limit for a certain period of time, the controller **213** can command the valve **211** to release a certain amount of CO_2 **719**. When the expired CO_2 concentration increases above the lower limit, the quantity of CO_2 delivered can be nil. When the expired CO_2 concentration is measured to be higher than the higher limit for a certain period of time, the controller **213** can trigger an alarm.

[0064] In yet another example embodiment of the invention, the measured physiological parameter is the respiratory rate of the patient and a target value of, for example, less than 30/min is selected. This target value can be adjusted according to the patient **205** in accordance with conventional criteria.

[0065] In yet another example embodiment of the invention, the breathing pattern index is derived from the physiological data obtained. A target value of, for example, 90% breathing pattern index is selected. This target value can be adjusted according to the patient **205** in accordance with conventional criteria.

[0066] At step **513**, the valve **211** is operated so that the gas is administered to the patient in accordance with the optimal gas delivery parameters determined at step **511**. This is typically performed by regulating the gas flow from source **203**

with valve **211**. Alternatively, a combination of proportional valves and on/off valves can be used to control the gas flow.

[0067] Safety mechanisms to limit the flow rate of administered CO_2 can be implemented. This can be done with a passive hardware flow limiter or with an active control approach using a flowmeter and a motorized limiter or safety valve.

[0068] The controller **213** determines the proper time of administration and amount of CO_2. For maximum efficiency, the administration of CO_2 would normally occur when the respiratory amplitude (quantity of air intake) is lower and would normally stop when it is returned to normal as illustrated in FIG. **6**A and FIG. **6**B. A dynamic and intermittent administration of CO_2 immediately proceeding and following hyperventilation is proposed.

[0069] In some embodiments of the invention, optional alarms can be issued if some of the physiological parameters are measured or calculated to be outside of predetermined intervals. Measured or calculated physiological parameters that may lead to the issuance of an alarm include, for example, respiratory amplitude and rate, expired CO_2 level, breathing pattern index, blood oxygen saturation, heart rate and temperature of the patient.

[0070] Examples of alarms that can be issued by an embodiment of the controller **213** are as follows: High End tidal CO_2 level (if this sensor is used), low SpO_2 level (if this sensor is used) or respiratory pressure (if this sensor is used) not available indicating that the nasal cannula is not in place should lead to an alarm.

[0071] Other examples of alarms that can be issued by an embodiment of the controller **213** are provided in the following list:

[0072] If the blood oxygen saturation is less than or equal to 85% for more than 3 seconds, a message indicating that connections of the blood oxygen saturation sensor **221** should be checked is issued and the method **201** steps back to step **203**;

[0073] If the blood oxygen saturation is unmeasurable, a message indicating that connections of the blood oxygen saturation sensor **221** should be checked is issued and the desired CO_2 flow rate is set as a minimal safe flow rate, or as the last determined CO_2 flow rate;

[0074] If the expired CO_2 concentration is unmeasurable, a message indicating that connections of the CO_2 sensor **215** should be checked is issued;

[0075] If the expired CO_2 concentration is larger than or equal to 45 mmHg or has increased by more than 10 mmHg over the preceding hour, a message indicating the patient **205** should be closely monitored and that another CO_2 delivery technique may be preferable is issued;

[0076] If the expired CO_2 concentration is larger than or equal to 55 mmHg or has increased by more than 20 mmHg over the preceding hour, a message indicating that another CO_2 delivery technique may be preferable is issued.

[0077] The analysis of the data collected during periods where the CO_2 delivery system is used, for example during one night, can be performed automatically to provide a summary report of events after each operation period. It can include the amount of CO_2 delivered, a graph of the expired CO_2 concentration vs time, the number of apnea and hypopnea events, a graph of the respiratory amplitude and rate vs time, a graph of the breathing pattern index vs time, the number of desaturations (SpO_2<90%) and deep desaturations (SpO_2<80%), a graph of the blood oxygen saturation (SpO_2) level vs time, etc. Trends in the evolution of these parameters can also be made available for monitoring longitudinal changes in these patients.

[0078] The method allows monitoring by telemetry in the patients.

[0079] The proposed method and system can be used for the administration of CO_2 for a very wide range of clinical settings, in hospital setting for initial adaptations (sleep laboratory or respiratory ward) or at home from pre-hospital care to intra-hospital care (emergency department, intensive care units, respiratory/cardiology/internal medicine wards, rehabilitation units, post-anesthesia recovering rooms, for example). It can be used in portable settings, such as in ambulance vehicles, in camp sites during mountain climbing expeditions and the like. It can be used by patients at home for chronic respiratory and cardiac insufficiency and any cause resulting in breathing disorders. It can be used for adults or pediatric patients.

[0080] The proposed method **201** is typically performed without mechanically assisted ventilation of the patient **205**. However, in alternative embodiments of the invention, such mechanical ventilation is used. In case of breathing disorders in mechanically ventilated patients, this technique and algorithm may be used to stabilize or help improve the breathing pattern and the resulting sleep quality.

[0081] While illustrated in the block diagrams as groups of discrete components communicating with each other via distinct data signal connections, it will be understood by those skilled in the art that the illustrated embodiments may be provided by a combination of hardware and software components, with some components being implemented by a given function or operation of a hardware or software system, and many of the data paths illustrated being implemented by data communication within a computer application or operating system. The structure illustrated is thus provided for efficiency of teaching the described embodiment.

[0082] The embodiments described above are intended to be exemplary only. The scope of the invention is therefore intended to be limited solely by the appended claims.

1. A method for delivering a gas containing carbon dioxide to a patient, said method comprising:

measuring a physiological parameter of breathing stability in said patient;

determining an optimal gas delivery parameter based on said physiological parameter of breathing stability; and

delivering said gas to said patient in accordance with said optimal gas delivery parameter.

2. The method as claimed in claim **1**, wherein said gas containing carbon dioxide is a mixture of gases including carbon dioxide.

3. The method as claimed in claim **1**, further comprising repeating the step of measuring the physiological parameter of breathing stability in the patient, after said delivering said gas, to determine an effect of said delivering on said physiological parameter.

4. The method as claimed in claim **3**, further comprising repeating said steps of determining said optimal gas delivery parameter and delivering said gas to adjust said delivering consequently to said effect.

5. The method as claimed in claim **1**, wherein the optimal gas delivery parameter is selected from the group consisting of a fraction of carbon dioxide in the gas and a flow rate of the gas during said delivering.

6. The method as claimed in claim **1**, further comprising issuing an alarm if the physiological parameter is measured to be outside of a predetermined threshold.

7. The method as claimed in claim **1**, wherein the physiological parameter is the breathing pattern for the patient, the breathing pattern including at least the respiratory amplitude.

8. The method as claimed in claim **7**, wherein the physiological parameter is analyzed to obtain a breathing pattern index for the patient and the determining the gas delivery parameter is carried out using the breathing pattern index.

9. The method as claimed in claim **8**, wherein the physiological parameter further includes at least one parameter selected from the group consisting of arterial hemoglobin oxygen saturation, respiratory rate, respiratory amplitude, chest movement pattern, end tidal CO2 (ETCO2) level, Rapid Eye Movement (REM) pattern, rate of apnea, rate of hypopnea, rate of desaturation, respiratory rate variability, heart rate variability, heart rate synchrony and snoring noise level.

10. A system for delivering a gas containing carbon dioxide to a patient, said system comprising:

- a physiological sensor for measuring a physiological parameter of breathing stability in said patient;
- a controller receiving said physiological parameter from said physiological sensor for determining an optimal gas delivery parameter based on said physiological parameter of breathing stability; and
- a gas delivery sub-system having a gas source and a gas delivery controller for delivering said gas to said patient in accordance with said optimal gas delivery parameter received from said controller.

11. The system as claimed in claim **10**, wherein said gas containing carbon dioxide is a mixture of gases including carbon dioxide.

12. The system as claimed in claim **10**, wherein the optimal gas delivery parameter is selected from the group consisting of a fraction of carbon dioxide in the gas and a flow rate of the gas during said delivering and wherein said gas delivery controller uses said gas delivery parameter to deliver said gas from said source.

13. The system as claimed in claim **10**, further comprising an alarm sub-system including an alarm emitter and an alarm controller, the alarm controller having a predetermined threshold, the alarm controller receiving the physiological parameter from the controller and controlling the alarm emitter to issue an alarm if the physiological parameter is measured to be outside of the predetermined threshold.

14. The system as claimed in claim **10**, wherein the physiological parameter is the breathing pattern for the patient, the breathing pattern including at least the respiratory amplitude.

15. The system as claimed in claim **14**, further comprising a breathing pattern index calculator for analyzing the physiological parameter to obtain a breathing pattern index for the patient and wherein said controller uses the breathing pattern index to determine the gas delivery parameter.

16. The system as claimed in claim **15**, wherein the physiological parameter further includes at least one parameter selected from the group consisting of arterial hemoglobin oxygen saturation, respiratory rate, respiratory amplitude, chest movement pattern, end tidal CO2 (ETCO2) level, Rapid Eye Movement (REM) pattern, rate of apnea, rate of hypopnea, rate of desaturation, respiratory rate variability, heart rate variability, heart rate synchrony and snoring noise level.

17. The system as claimed in claim **10**, further comprising an analysis module for analyzing said measured physiological parameter and determined gas delivery parameter to detect a trend for said patient.

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专利名称(译)	用于向患者输送二氧化碳的方法和系统		
公开(公告)号	US20140158124A1	公开(公告)日	2014-06-12
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[标]申请(专利权)人(译)	lher Erwan LELLOUCHE FRANCOIS 系列FREDERIC		
申请(专利权)人(译)	L'她，二万 LELLOUCHE，FRANCOIS 系列，FREDERIC		
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[标]发明人	LHER ERWAN LELLOUCHE FRANCOIS SERIES FREDERIC		
发明人	L'HER, ERWAN LELLOUCHE, FRANCOIS SERIES, FREDERIC		
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摘要(译)

描述了一种用于将含有二氧化碳的气体输送到患者的方法和系统。该方法包括测量患者呼吸稳定性的生理参数;根据呼吸稳定性的生理参数确定最佳气体输送参数;并根据最佳气体输送参数将气体输送给患者。