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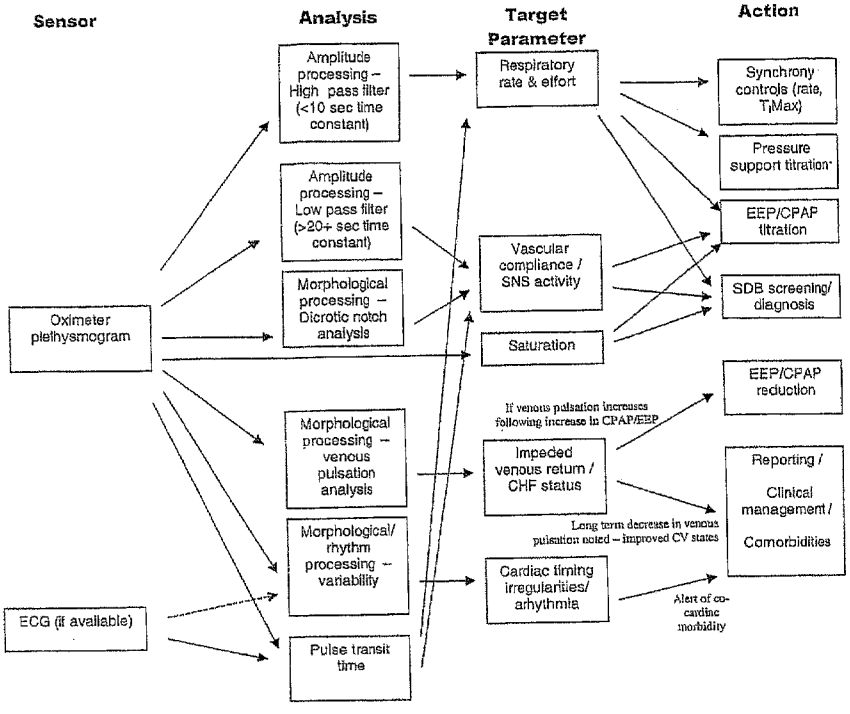
(54) **Title:** METHOD AND APPARATUS FOR NON-INVASIVE MONITORING OF RESPIRATORY PARAMETERS IN SLEEP DISORDERED BREATHING



(57) **Abstract:** An air delivery system includes a controllable flow generator operable to generate a supply of pressurized breathable gas to be provided to a patient for treatment and a pulse oximeter configured to determine a measure of patient effort during a treatment period and provide a patient effort signal for input to control operation of the flow generator.

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METHOD AND APPARATUS FOR NON-INVASIVE MONITORING OF RESPIRATORY PARAMETERS IN SLEEP DISORDERED BREATHING

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application Nos. 60/615,961, filed October 6, 2004, and 60/629,612, filed November 22, 2004, each incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The invention relates to monitoring of parameters relevant to Sleep Disordered Breathing (SDB).

BACKGROUND

[0003] Sleep Disordered Breathing (SDB) has been traditionally identified as being associated with Obstructive Sleep Apnea (OSA) and Cheyne-Stokes Respiration (CSR). Today there are a number of other conditions also recognised as being associated with SDB including, e.g., cardiovascular disease, stroke and diabetes, etc. Patients with these conditions and SDB may benefit from the treatment of their SDB with positive pressure ventilatory support by some form of mechanical ventilator.

[0004] While basic nasal Continuous Positive Airway Pressure (CPAP) ventilators may not monitor their patients, in general, the patients benefit from having a device which monitors the patients as part of some kind of control loop. In particular devices are known to monitor pressure, flow and patient effort.

[0005] An existing problem for known devices includes discriminating between obstructive sleep apnea (OSA) and central sleep apnea (CSA). OSA is indicative of upper airway collapse and can be used as an input to auto-titration algorithms for the CPAP pressure applied or the end-expiratory pressure (EEP) used in a bi-level device. CSA can be indicative of over-ventilation and can therefore be used as an input to algorithms that auto-titrate the

ventilation of the patient. Clearly, miscategorising an apnea as either closed or open results in these titration algorithms prescribing sub-optimal parameters for the treatment of the patient.

[0006] Obstructive and central sleep apnea are discriminated in known devices by injecting a 1 cm peak-to-peak 4 Hz oscillation into the treatment pressure waveshape and measuring the resulting 4 Hz flow. The phasic difference in the flow to the pressure waveshape is indicative of the compliance of the load which is then used to deduce if the upper airway is opened or closed. However, this method is uncomfortable for the patient as 4 Hz is easily within the frequency band that can be perceived by the patient. Also, this method does not give any information on events that include upper airway narrowing/closure and simultaneous central sleep apnea.

[0007] Obstructive and central sleep apnea are also discriminated in known device by detecting the cardiogenic flow. The cardiogenic flow is the airflow induced in the lungs during a heart beat due to the proximity of the lungs to the heart. During OSA, there is therefore never any cardiogenic flow. Like the previous solution, it is also unable to determine if CSA and OSA have occurred concurrently.

[0008] Another existing problem for known devices includes inferring high patient respiratory effort. Patient respiratory effort is a key indicator used by clinicians when evaluating the acute state of a patient in a number of diseases including sleep apnea, obstructive lung disease, and various restrictive diseases. Despite its known value, it has not enjoyed widespread use as either an input to flow generator titration algorithms or as a recorded clinical parameter due to the inconvenience or impracticality of the transducers involved.

[0009] The "gold standard" in terms of accuracy for monitoring effort is an oesophageal catheter which a patient is required to swallow. Unfortunately, this is uncomfortable and awkward for a patient and not practical outside a clinic. Respiratory bands around the patient's chest and abdomen are known to monitor effort. Suprasternal notch effort sensors are also known, as well as the use of EMG and ECG sensors. These techniques are all unsuitable for home use.

[0010] Another existing problem for known devices includes measuring and storing vaso-specific parameters, such as cardiac afterload, vascular tone, heart rate variability, sympathetic nervous system activity in general, and/or central venous pressure. If

these parameters were available in real-time in a flow generator, they could be used to (a) contribute to auto-titration algorithms and (b) be recorded with respiratory specific parameters to allow physicians to observe long-term trends and have a richer data set to determine the long term management of the patient.

[0011] Yet another existing problem for known devices includes limiting the mean mask pressure. Auto-titrating CPAP algorithms aimed at eliminating OSA or upper airway resistance syndrome (UARS) may use breath flow analysis to limit upper airway narrowing. Pressure beyond certain levels may, in some patients, be deleterious to cardiac function. Equally, a lower pressure may be beneficial to cardiac function provided it did not result in complete closure of the upper airway. It is desirable to include cardiovascular parameters in auto-titration schemes such that respiratory therapy (e.g., CPAP pressure) can be continuously optimised. Such parameters may include cardiac afterload, vascular tone, heart rate variability, sympathetic nervous system activity in general, and/or central venous pressure if they could be acquired non-invasively and conveniently.

[0012] ResMed's AutoSet CS and AutoSet CS2 devices specifically target patients with heart disease. These devices address the 'excessive CPAP pressure' problem by imposing a maximum average pressure of 15cmH_2O.

[0013] Another known sensor is a suprasternal notch effort sensor. See U.S. Patent No. 6,445,942 (Berthon-Jones). Other known techniques for monitoring apneas and hypopneas are described in U.S. Patent Nos. 6,091,973 (Colla et al.) and 6,363,270 (Colla et al.). Another related U.S. patent is U.S. Patent No. 5,704,345 (Berthon-Jones) which describes distinguishing open and closed airway apneas amongst other things. U.S. Patent No. 6,484,719 (Berthon-Jones) describes a servo-ventilator which uses a flow sensor. The contents of all these patents are hereby expressly incorporated by cross-reference.

SUMMARY

[0014] In accordance with a first aspect of the invention, ventilator settings are adjusted in accordance with a parameter derived from pulse oximeter plethysmography. Ventilator settings that are adjusted include one of more of expiratory pressure, the level of support, rise-time and the ventilator wave-shape can be adjusted. Parameters derived from pulse oximeter plethysmography include one or more of pulse rate, effort, cardiac afterload,

vascular tone, heart rate variability, sympathetic nervous system activity in general, and central venous pressure. In one form, ventilator mean treatment pressure is modulated in accordance with a parameter derived from pulse oximeter plethsmography. In another form, ventilator mean treatment pressure is decreased when pulse oximeter plethysmography indicates that a patient's vascular system is becoming stressed.

[0015] In accordance with a second aspect of the invention, pulse oximeter plethysmography is used to determine patient effort and the patient effort signal is used as an input to a feedback controller, the controller controlling positive pressure therapy delivered to the patient.

[0016] In accordance with a third aspect of the invention, pulse oximetry is used in conjunction with an airflow signal to distinguish open and closed airway apneas.

[0017] In accordance with a fourth aspect of the invention, a measure of patient effort is derived from a pulse oximeter plethysmograph signal, and the measure of effort is used as a control variable in a servo-ventilator. When the measure of patient effort increases, pressure support is reduced and when the measure of patient effort decreases, pressure support is increased.

[0018] Another aspect of the invention relates to a passive, non-invasive and convenient method of discriminating between obstructive and central sleep apnea, inferring high patient respiratory effort, measuring and storing vaso-specific parameters, and limiting mean mask pressure.

[0019] Yet another aspect of the invention relates to an air delivery system including a controllable flow generator operable to generate a supply of pressurized breathable gas to be provided to a patient for treatment and a pulse oximeter plethysmograph configured to determine a measure of patient effort during a treatment period and provide a patient effort signal for input to control operation of the flow generator.

[0020] Still another aspect of the invention relates to a method for treating sleep disordered breathing. The method includes providing a supply of pressurized breathable gas to a patient for treatment, using a pulse oximeter plethysmograph to determine a measure of patient effort during a treatment period and provide a patient effort signal, and controlling the supply of pressurized breathable gas based on input from the patient effort signal.

[0021] Parameters of interest (e.g., cardiac afterload, vascular tone, heart rate variability, and/or central venous pressure) can be estimated from a pulse oximeter plethysmograph. Currently, pulse oximeters are primarily employed for monitoring SpO2 and heart-rate. Some pulse oximeters display a plethysmograph, but as far as is known, none of the information present in the plethysmograph is used as input to auto-titrate respiratory or cardiovascular therapies. Peripheral Arterial Tone (PAT) is a novel multi-cell finger plethysmography system that focuses specifically on arterial tone. This technology may be an alternative to pulse oximetry as the sensing modality. Pulse-transit time (PTT) also contains information on autonomic activity and arterial tone.

[0022] Each aspect can be manifested in the form of a method and/or apparatus for non-invasive monitoring of one or more parameters relating to the diagnosis of a patient's health disorder, e.g., sleep disordered breathing, congestive heart failure, stroke, etc., and/or controlling a ventilator or other respiratory therapy device in accordance with the monitored parameter and/or the derived diagnosis.

[0023] Another aspect of the invention is to monitor a patient using pulse oximeter plethysmography without treating them.

[0024] Further aspects of the invention are set out in the attached claims.

[0025] Other aspects, features, and advantages of this invention will become apparent from the following detailed description when taken in conjunction with the accompanying drawings, which are a part of this disclosure and which illustrate, by way of example, principles of this invention.

BRIEF DESCRIPTION OF THE FIGURES

[0026] The accompanying drawings facilitate an understanding of the various embodiments of this invention. In such drawings:

[0027] Fig. 1 shows a pulse oximeter waveform transformed into an effort signal.

[0028] Fig. 2 shows a range of pulse oximetry applications in accordance with various embodiments of the invention.

[0029] Fig 3 shows a therapy system in accordance with an embodiment of the invention.

[0030] Fig. 3A is a schematic diagram of a monitoring system according to an embodiment of the present invention.

[0031] Fig. 4 shows an algorithm for Upper-airway obstruction (inspiratory flow limitation) and Auto-EEP / AutoCPAP in accordance with an embodiment of the invention.

[0032] Fig. 5 shows an algorithm for Auto-EEP titration / Automated Pressure Support titration in accordance with an embodiment of the invention.

[0033] Fig. 6 shows an algorithm for Detection of elevated Sympathetic Nervous System (SNS) or reduced cardiac output – cardiac patients on CPAP/AutoCPAP/Comfort (fixed low-support bilevel) devices in accordance with an embodiment of the invention.

[0034] Fig. 7 shows an algorithm for AutoCPAP on cardiac patients in accordance with an embodiment of the invention.

[0035] Fig. 8 is a block diagram illustrating a procedure for initializing NPPV therapy rate settings, based on respiratory rate information, in accordance with an embodiment of the present invention.

[0036] Fig. 9 is a block diagram illustrating a procedure for initializing NPPV therapy trigger threshold settings, based on positively identifying cardiogenic flow amplitude, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF ILLUSTRATED EMBODIMENTS

[0037] Pulse oximeter plethysmography (sometimes referred to simply as "pulse oximetry" or "photo-plethysmogram") is a standard method of obtaining blood oxygenation data in a non-invasive and continuous manner. Oximeters use two wavelengths of light to solve for hemoglobin saturation. The waveforms are created by the absorption produced by pulsatile arterial blood volume, which represents the alternating current (AC) signal. The absorption produced by nonpulsatile blood, venous and capillary blood, and tissue absorption is depicted by the direct current (DC) signal. See Hartert et al, *Use of Pulse Oximetry to Recognize Severity of Airflow Obstruction in Obstructive Airway Disease, Correlation with*

Pulsus Paradoxus, **Chest 1999:115:475-481**. A pulse oximeter signal from Hartert et al. is shown in Fig. 1.

[0038] Currently pulse oximeters are primarily employed for monitoring SpO_2 and heart-rate, however in accordance with an embodiment of the invention, the pulse oximeter is used as an indication of patient effort in a respiratory therapy device. Respiratory effort can be seen in the arterial blood pressure waveform as variation in the peak-to-peak amplitude. This is caused by the effect of the respiratory pleural pressure swings on cardiac output throughout the breathing cycle. Inspiration is associated with reduced systolic blood pressure, and this respiratory effect on blood pressure is referred to as 'pulsus paradoxus'.

[0039] This effect has been proposed as a measure of respiratory loading in various areas (asthma exacerbation, obstructive lung disease), where a variation of >10mmHg is associated with high respiratory effort. The reference standard for measuring arterial blood pressure is invasive (catheter), so indirect methods are desired. One such method is pulse-transit time (PTT), where the variation in blood pressure causes a variation in vascular compliance, transduced as the propagation time of the pulse from the heart to the periphery. Another method is the oximeter plethysmographic waveform, which relates the volume of arterial blood in the tissue bed being sensed (usually finger or ear). Changes in cardiac output throughout the respiratory cycle may be seen as variation in the plethysmogram's peak-to-peak amplitude, consistent with the arterial blood pressure observations. This variation in cardiac output, combined with the variation in central venous pressure due to respiration, also induces changes in the baseline/offset of the PPG signal synchronous with breathing. A third factor seen in the PPG is affected by breathing: the heart period is also modulated somewhat by respiration, primarily via the respiratory neural outflow, and to a lesser extent in response to the arterial pressure variations induced by respiration.

[0040] Since the pulse oximeter plethysmogram is more related to volume of blood in the tissues, variation in the baseline/offset of the pulsatile component may be a more sensitive indicator of cardiopulmonary interaction than the cardiac output variation (Hartert et al.; Use of Pulse Oximetry to Recognize Severity of Airflow Obstruction in Obstructive Airway Disease – Correlation with Pulsus Paradoxis; Chest 1999; 115: 475-481).

[0041] Other factors (arterial tone, cardiac performance, postural changes) can also cause variations in the PPG, so processing is required to analyse the variation over the

respiratory frequencies, and may be aided further by correlating the variation with respiratory flow information provided by the flow generator. A progressive increase in PPpleth (pulsus paradoxus from the plethysmogram) may indicate increasing efforts associated with impending upper airway (UA) collapse. A dramatic increase in PPpleth might indicate UA obstruction.

[0042] The waveform may be characterised into the following categories:

(a) Pulsatile amplitude: The AC amplitude of the pulse is most indicative of vascular compliance, which is greatly affected by arterial tone/sympathetic nervous system activity when looked at over 20-30 seconds or greater. As such, it can indicate arousal from apnea, and over many days/weeks, may demonstrate the long-term benefits of abolishing OSA/UARS on SNS activity. The finger is the best site for detecting the effect of autonomic activity on vascular compliance. Pulse oximetry at the ear is less sensitive to autonomic activity, but may offer an estimation of relative blood pressure variation, given that vascular compliance exerts a lesser effect.

(b) Offset or baseline: Respiration induces a phasic variation in the pulse baseline (pulsus paradoxus) that varies in accordance with respiratory effort (the pressor response). This effect has been used to identify airway resistance (asthma) and obstruction (obstructive lung disease). See Comparison of traditional and plethysmographic methods for measuring pulsus paradoxus (Clark J et al. Arch Pediatr Adolesc Med 2004. 158: 48-51) and use of pulse oximetry to recognize severity of airflow obstruction in obstructive airway disease; correlation with pulsus paradoxus (Hartert et al. Chest 1999. 115: 475-481. Available online at http://www.chestjournal.org/cgi/reprint/115/2/475).

(c) Pulse rhythm: Irregular heart rhythm can be detected, particularly (but not exclusively) when combined with ECG activity. A beat-to-beat shifting of pulse amplitude after a pause can indicate irregular rhythm. Availability of ECG allows pulse-transit time to be calculated, another indicator of vascular tone, which may augment the sensitivity or specificity of any conclusions regarding arousal, respiratory effort, or sympathetic tone. Heart-rate variability indices can be calculated from the pulse period, inferring sympatho-vagal balance. Fractal components in the HRV data can distinguish sleep-wake state.

(d) Waveshape: The wave morphology contains similar information to that seen in arterial catheter pressure signals or applanation tonometry. For example, the position and

relative amplitude of the dicrotich notch can point to the degree and timing of pressure-wave reflections from the peripheral circulation, itself an indicator of vasomotor tone (SNS). Venous pulsation may also be apparent in the waveform, which represents interaction between a number of factors, but in our case may indicate the effect of excessive CPAP (increased central venous pressure) or improvement in congestive heart failure (reduced central venous pressure). The first-derivative of the plethysmogram is closely related to arterial flow to the area, while the second-derivative of the waveform has been proposed as an indicator of vasoactivity and arterial compliance.

[0043] Methods for extracting the above parameters from the raw PPG exist, for example, time-domain or frequency-domain signal processing techniques, or elements of both. One example are the methods taught in WO 03/00125 A1 and WO 2004/075746 A2, employing the continuous wavelet transform to extract the respiratory signals and arterial tone information from the raw PPG. Time-domain analysis of assessing baseline fluctuations from the PPG are summarised by Shamir et al, British Journal of Anaesthesia 1999, 82(2): 178-81.

[0044] Recent developments in oximeter signal processing has allowed device performance to be more robust when presented with movement and low perfusion. Modern embedded processors allow more sophisticated post-processing of plethysmographic waveforms, and even the most advanced oximeter technology is available as OEM module format. These technological advances, together with the underlying information present in the plethysmogram combined with information from the therapy device, may permit a respiratory device to employ an oximeter as part of a servo-controlled therapy.

[0045] The information present in the plethysmogram may be useful to diagnosis-only studies as well, since it can indicate arousals that may not be evident as a desaturation.

[0046] Respiratory effects can also be seen as variation in cardiac timing, termed 'respiratory sinus arrythmia', which may also be used to extract respiratory timing information.

[0047] An aspect of the invention relates to the combination of (1) oximeter plethysmograph-derived parameters with (2) respiratory flow information, to augment real-time control algorithms for a respiratory therapy device.

[0048] This arrangement may prove superior to current techniques if it permits a more thorough and timely estimate of the patient's acute condition allowing algorithms to

prescribe more appropriate therapy. The parameters are also optionally stored within the flow generator to give a physician a richer data set for long term patient management. This is superior to current technologies as it gives a physician data from flow generators used in an unsupervised environment similar to that gained in a sleep study.

[0049] Plethysmographic parameters useful for titration and long term patient management include all those noted above (patient effort, vascular compliance, heart rate variability, arrhythmia detection, venous pulsation, and SpO2).

[0050] In accordance with an embodiment of the invention, a pulse oximeter signal **10** is fed through signal processor **20**, for example, a low pass filter, peak detection, nadir detection or averaging. The filter is designed to remove signals indicative of heart rate and leave signals indicative of respiratory rate.

[0051] Once the effort signal is derived from the pulse oximeter, it may be used in a number of ways as shown in Fig. 2 and described in further detail below:

(i) Open-Closed Apnea Discrimination. The plethysmographically derived respiratory effort estimate can be used during episodes of apnea (using respiratory flow data) to indicate whether the apnea is opened (non-obstructed) or closed (obstructed), useful in automatic titration algorithm logic. For example, a low or zero flow signal is indicative of an apnea. If the apnea occurs in the absence of effort as measured by the pulse oximeter, then the apnea is regarded as being "open". However, if there is effort, then the apnea is regarded as being "closed".

(ii) High airway resistance. Similarly, a period of high respiratory effort derived from the oximeter plethysmograph combined with reduced respiratory flow or with flow limitation (inferred by flow waveshape) can imply the presence of significant airway resistance, be it due to expiratory flow limitation or upper-airway resistance. In both cases, the combination of high effort and low measured respiratory flow may be an indicator to increase applied PEEP.

(iii) Relative work of breathing: In the absence of respiratory flow limitation (adjudged from respiratory flow waveshape or estimated volumes), persistently high respiratory effort may indicate inadequate pressure support (under-ventilation).

(iv) Used in conjunction with a flow based measure of phase (such as described in U.S. Patent No. 6,484,719).

(v) Using the effort waveshape to augment ResMed's AutoSet CPAP algorithm. Increasing patient effort is indicative of impending upper-airway instability. AutoCPAP titration based on increased patient effort may be more pre-emptive of obstruction than the current flattening based algorithm.

(vi) Using the effort information as a basis for an algorithm in a ResMed's VPAP or AutoCS device to titrate applied PEEP. It is conceivable that titration algorithms based on inspiratory waveshape will be challenged when used in devices that change the pressure during the breath cycle. Changes in patient effort are not as dependent on intra-breath changes in pressure and hence should be more robust to these types of therapy.

(vii) Using the effort waveshape as an early indicator that a patient has been overventilated. This may be a possible consequence of inappropriate servo-ventilation, where a ventilator augments the patient's ventilation to achieve a target level. This indicator can be used to titrate the target ventilation.

(viii) Using venous pulsation as an input to ResMed's AUTOSET CPAP algorithms for patients with OSA and heart failure. Increases in venous pulsation can be used to limit the CPAP pressure applied to safer limits.

(ix) Using vascular compliance as an input to ResMed's CPAP algorithms. Changes in vascular compliance can be indicative of patient arousals. This can be used to augment the data currently used for automatically prescribing CPAP levels.

(x) Comparison of the respiratory effort estimate with the respiratory device's own estimate of breath phase (parameter used in ResMed's AutoCS2 and AutoVPAP) may allow a more robust breath-tracking scheme within the respiratory device; for example, it may improve leak rejection or leak estimation.

(xi) Sleep state – detection of non-REM sleep. REM sleep is similar to wake periods in the fractal component of HRV (see http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12059594; http://ajpheart.physiology.org/cgi/reprint/280/1/H17; http://ajpheart.physiology.org/cgi/reprint/283/1/H434), but the non-REM sleep stages differ significantly from awake. HRV data might be analysed to indicate sleep onset, since the patient must pass through non-REM sleep prior to achieving REM sleep. The PPG inherently monitors heart period, and provided this period information is not averaged, can be used to

conduct traditional HRV analyses. One method of discriminating sleep/wake from HRV is taught by Ivanov et al, Europhysics Letters 1999, 48(5): 594-6000.

[0052] Analysis of the plethysmographic waveshape, possibly in combination with other monitored variables, may be used to optimise CPAP or VPAP therapies to reduce arterial stiffness, independently associated with poor cardiovascular prognosis. For example:

(i) By combining the timing of the cardiogenic respiratory flow signal with the timing of the plethysmographic pulse it may be possible to calculate relative variations in pulse-transit time more accurately than traditional PTT (pulse transmission time) estimates. Traditional methods that employ the ECG for cardiac timing information include both the pre-ejection period and the pulse transit time. By contrast, cardiogenic flow is induced by the actual ventricular ejection. Accurate PTT estimation may offer additional information to that of the plethysmograph alone, contributing to the estimation of arterial tone/SNS activity and/or respiratory effort, and allowing closed-loop therapies aiming to optimise arterial compliance.

(ii) The morphology of the plethysmographic waveform may offer information directly associated with vascular compliance, for example, the position of the so-called 'diochrotic notch' relative to the initial systolic peak, allowing closed-loop therapies aiming to optimise arterial compliance.

[0053] With reference to Fig. 3-7 it is noted that:

THERAPY ALGORITHM adjustments may include:

- Level of PEEP/CPAP
- Level of Pressure support

[0054] Concerning the two feedback signals F/B1 and F/B2 it is noted that:

F/B 1 (Airflow-inferred patient parameter) may include any or all of the following:

- Minute ventilation estimate
- Inspiratory airflow limitation (e.g., UA flattening index)
- Expiratory airflow limitation (e.g., expiratory flow waveform morphology)
- Tidal volume
- Leak

- Cardiac timing (time of systolic ejection, extracted from cardiogenic flow)
- Respiratory phase

[0055] F/B 2 (PPG-inferred patient parameter) may include any or all of the following:

- Relative indication of respiratory effort (e.g., high effort leads to increased respiratory baseline variation of PPG, pulsus paradoxus)
- Absolute indication of respiratory rate
- Patterns of respiratory effort and rate indicative of respiratory control anomalies or apnea type (crescendo/decrescendo in breathing effort, statistical derivations from respiratory patterns)
- Indication of respiratory rate (e.g., variation of PPG amplitude and timing parameters)
- Relative indication of worsening cardiac function (e.g., cardiac decompensation results in increased respiratory baseline variation of PPG, pulsus paradoxus)
- Relative indication of venous congestion (e.g., degree of venous pulsation in PPG – morphological analysis)
- Relative variation in sympathetic nervous system activity or arterial compliance (e.g., variation of PPG pulse amplitude over >20-30 second timescale, or shift in location of dicrotic notch)
- Standard pulse oximetry (SpO_2)
- Arrival time of systolic pulse at periphery (e.g., systolic rise in PPG).
- Pulse rate

[0056] CLINICAL TARGETS may include:

- Minimum ventilation (e.g., Respiratory Insufficiency, Obesity Hypoventilation patients)
- Nominal ventilation (e.g., Cheyne-Stokes Respiration patients)
- Optimal synchrony
- Sleep quality (all patients)
- Long-term cardiac function (e.g., CHF/CSR/hypertensive patients).
- Anticipation/prediction of cardiac decompensation (e.g., CHF patients)
- Optimal arterial compliance

- Minimum CPAP/EEP/PEEP
- Maximum CPAP/EEP/PEEP
- Minimum Pressure Support
- Maximum Pressure
- Maximum Average Pressure

[0057] Figure 3A is a schematic diagram for a monitoring system according to an embodiment of the present invention. Concerning the feedback signals F/B1 and F/B2, and the "Combined Processing" box, it is noted that:

- **F/B 1** (Airflow-inferred patient parameter) may include any or all of the following:
- Inspiratory airflow limitation (e.g., UA flattening index)
- Expiratory airflow limitation (e.g., expiratory flow waveform morphology)
- Cardiac timing (time of systolic ejection, extracted from cardiogenic flow)
- Respiratory phase
- Time course of breath amplitude and derived statistics

[0058] **F/B 2** (PPG-inferred patient parameter) may include any or all of the following:

- Relative indication of respiratory effort (e.g., high effort leads to increased respiratory baseline variation of PPG, pulsus paradoxus)
- Absolute indication of respiratory rate.
- Relative indication of worsening cardiac function (e.g., cardiac decompensation results in increased respiratory baseline variation of PPG, pulsus paradoxus)
- Relative indication of venous congestion (e.g., degree of venous pulsation in PPG – morphological analysis)
- Relative variation in sympathetic nervous system activity or arterial compliance (e.g., variation of PPG pulse amplitude over >20-30 second timescale, or shift in location of dicrotic notch)
- Standard pulse oximetry (SpO_2)
- Arrival time of systolic pulse at periphery (e.g., systolic rise in PPG).
- Pulse rate

[0059] **COMBINED PROCESSING** may include:

- Delay between respiration changes (F/B 1) and blood gas adjustments (F/B 2), eg to

infer circulatory delay.

- Pulse transit time (PTT) indicated by delay between cardiogenic flow pulses (F/B 1) and arrival of the pulse at the periphery (F/B 2).

[0060] CLINICAL MONITORING TARGETS may include:

- Assessment of SDB
- Assessment of sleep quality (all patients)
- Assessment of cardiac function (e.g., CHF/CSR/hypertensive patients) as an adjunct to patient management.

[0061] Figures 4-7 show a number of algorithms performing various embodiments of the invention. Embodiments of the invention may take the form of a method and/or apparatus to monitor, in a non-invasive manner, one or more parameters, e.g., pulse oximetry and/or air flow, relating, e.g., to a patient's breathing and/or heart activity.

[0062] The monitored parameter or parameters may be used for diagnostic purposes, e.g., to log data, to produce a report or an alarm or otherwise signal a physician. In addition, or in the alternative, the values of the monitored parameter(s) may be used to control, e.g., stop, start or vary, the delivery of pressurized gas (e.g., timing, flow pressure) from a blower, ventilator or the like, to the patient.

[0063] Fig. 4 shows an open/closed airway apnea algorithm. An airflow signal is analysed and a determination is made as to whether it is within normal bounds. If it is then CPAP/EPAP therapy is maintained at its current level. If the airflow signal is not normal, for example low indicative of an apnea, then the effort signal is analysed. If the effort is high then an obstructive apnea may be indicated and the appropriate therapy is to increase the treatment pressure.

[0064] Fig. 5 shows an algorithm for patients suffering general respiratory insufficiency. The algorithm defines when pressure support, or End Expiratory Pressure (EEP) should be varied.

[0065] Fig. 6 shows an algorithm which may be part of a monitoring system for evaluating cardiac performance. A cardiac patient may be receiving CPAP therapy and have an additional monitoring device with the algorithm of Fig. 6. Alternatively the CPAP device may incorporate the pulse oximeter. The two signals F/B/1 and F/B/2 are analysed. Where the values are indicative of elevated levels of SNS activity, or decompensation (poor cardiac

performance) an alert is generated. The alert may be in the form of an audible alarm, or part of a messaging system which reports to a physician.

[0066] Fig. 7 depicts an algorithm for cardiac patients on CPAP therapy. The algorithm is similar to that in Fig. 4. However, it has the additional step that venous congestion is monitored through the pulse oximeter. If venous congestion is worsening, then CPAP pressure will not be increased, but restored to a previous level.

[0067] Fig. 8 depicts a procedure for initializing NPPV therapy rate settings, based on respiratory rate information. Preferably, this is performed after attaching oximeter probe (F/B2), but can be attached prior to commencing ventilation.

[0068] Fig. 9 depicts a procedure for initializing NPPV therapy trigger threshold settings, based on positively identifying cardiogenic flow amplitude. Preferably, this is performed once ventilation is initiated, e.g., so a respiratory flow signal is available.

[0069] The combination of traditional oximetry data (saturation, heart rate, pulse timing information) and respiratory timing and effort information (inferred from additional processing of a PPG and/or from the addition of a nasal or oronasal cannulae data) may permit new diagnostic possibilities. For example:

- Circulatory delay (delay between breathing changes and saturation changes), possibly an indicator of heart-failure severity or cardiac decompensation.
- 'True' Pulse Transit Time (PTT), via the delay between cardiogenic flow pulses seen by the nasal pressure transducer at end-expiration (seen at the nares) and the arrival of pulse at the periphery (from the oximeter plethysmogram). PTT measurement is an indicator of arousal (transient increases in sympathetic outflow and BP) and possibly an indicator of average BP/average sympathetic activation when viewed over longer periods. Traditionally, PTT is calculated based on the ECG for central cardiac timing (systole) and the PPG for peripheral pulse timing. Using cardiogenic flow for central cardiac timing may have advantage over ECG-derived PTT in that the cardiogenic flow (CGF) represents mechanical ejection (with a fixed propagation delay from lung to nares) rather than electrical activation of the left-ventricle, so removes the pre-ejection period from the measurement. The pre-ejection period is known to sometimes detract from the sensitivity of the ECG-derived PTT measurement. By acquiring the CGF at a consistent portion of the respiratory cycle (end expiration, when it is most readily seen), the respiratory-induced fluctuations in PTT may be

ignored. That leaves just the PTT variations due to either BP variation or increased arterial tone (sympathetic activation), both of which shorten the PTT, and both of which are associated with arousal, thereby offering another important SBD parameter.

By extracting respiratory effort information from the raw PPG (pulsus paradoxus) a simple diagnostic system may offer all the key information required for SBD screening except sleep staging: breathing pattern, oxygen saturation, arousal (PTT) or increased SVR, and high effort periods (apnea discrimination and RERA classification). This system may or may not include a nasal pressure transducer, depending on the relative importance of the derived signals. Nasal airflow combined with respiratory effort permits straight-forward discrimination between central and obstructive apneas, but signal processing may glean the same information from combining information from the PPG, e.g., time course of breathing effort compared to time course of desaturations, or statistical analysis of the time course of breathing effort.

[0070] Other specific examples of where aspects of the invention may be used include:

(a) Using respiratory-related cardiac variations (e.g., "respiratory sinus arrhythmia") to track and predict breath-phase, and to use the prediction for ventilator triggering. Such variations may conveniently be detected in the PPG, but may also be detected by other cardiac monitoring devices such as ECG electrodes. Typically the respiratory variation imposed on cardiac performance occurs too late to be used as a ventilator trigger; ventilators ideally offer respiratory support coincident with early inspiration, preferably within 100msec of the patient's initial inspiratory effort. Ventilators typically monitor inspiratory flow or airway pressure variations as a trigger. In severe obstructive respiratory disorders (e.g., COPD) the respiratory flow or pressure information is a poor indicator of inspiratory timing. In such disorders, an alternative 'window' into respiratory activity may offer superior results. Respiration, particularly laboured respiration, is known to affect cardiac timing and cardiac output. By monitoring cardiac performance over previous breath cycles, and deriving a respiratory phase signal from cardiac information, it is proposed that the timing of the next inspiratory effort may be predicted, provided the latency of extracting the respiratory signal is not excessive (e.g., more than 1 breath delayed). The central-to-peripheral propagation time for the pulse is typically around 200msec (the "pulse transit time"), and at best the cardiac cycle would offer a low sample-rate estimate of breath

phase (about 4-6 beats per breath). So it is unlikely that a prediction of breath phase could occur sooner than 0.5 breaths in advance, and thus may not offer precise inspiratory timing. However, such a method may still offer significant utility in disease states such as COPD, where ventilator synchronisation via respiratory flow is traditional very delayed, and where breath timing may be more entrained than in normal breathing (and therefore predictability being potentially greater).

(b) Using HRV analysis to infer sleep onset within a screener device, or sleep structure within a therapy device.

(c) In a ventilator system equipped with customised PPG monitoring, detecting dramatic drop in cardiac output (inferred from PPG amplitude reductions), and asserting an alarm. A drop in cardiac output may be a consequence of many clinically relevant circumstances, e.g., applying excessive positive pressure in a patient with hypovolemia (Yamakage, Can J Anesth 2005 52(2): 207), excessive dynamic hyperinflation / air trapping (Perel, BJA 76(1):168-169) (Conacher, Lancet 1995 346:448).

[0071] Advantages for the patient include, for example, more comfort and ease of use. Aspects of the invention provide optimal therapy without being festooned with sensors, e.g., a finger or ear probe is sufficient. Advantages for the physician include, for example, ease to administer. Aspects of the invention provide simple application, automated therapies, and long term patient management feedback. Other advantages include less expensive and improved therapy.

[0072] Although the invention has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the application of the principles of the invention. Numerous modifications may be made therein and other arrangements may be devised without departing from the spirit and scope of the invention. For example, those skilled in the art recognise that there are other indications of upper airway instability, resistance or obstruction which are not necessarily accompanied by or associated with flow flattening.

[0073] Also, the various embodiments described above may be implemented in conjunction with other embodiments, e.g., aspects of one embodiment may be combined with aspects of another embodiment to realize yet other embodiments. In addition, while the invention has particular application to patients who suffer from OSA, it is to be appreciated

that patients who suffer from other illnesses (e.g., congestive heart failure, diabetes, morbid obesity, stroke, barriatric surgery, etc.) can derive benefit from the above teachings. Moreover, the above teachings have applicability with patients and non-patients alike in non-medical applications.

CLAIMS

1. An air delivery system, comprising:

a controllable flow generator operable to generate a supply of pressurized breathable gas to be provided to a patient for treatment; and

a pulse oximeter configured to determine a measure of patient effort during a treatment period and provide a patient effort signal for input to control operation of the flow generator.

2. The air delivery system according to claim 1, wherein the measure of patient effort is derived from a pulse oximeter signal.

3. The air delivery system according to any one of claims 1-2, wherein the patient effort signal is used to at least one of discriminate between open-closed apnea, determine high airway resistance, determine relative work of breathing, augment control algorithms for the flow generator, determine overventilation, and determine sleep state.

4. The air delivery system according to any one of claims 1-3, wherein the patient effort signal is used in conjunction with an airflow signal to distinguish between open and closed airway apneas.

5. The air delivery system according to any one of claims 1-4, wherein pressure support is reduced when the measure of patient effort increases, and pressure support is increased when the measure of patient effort decreases.

6. A method for treating sleep disordered breathing, comprising:

providing a supply of pressurized breathable gas to a patient for treatment;

using a pulse oximeter to determine a measure of patient effort during a treatment period and provide a patient effort signal; and

controlling the supply of pressurized breathable gas based on input from the patient effort signal.

7. The method according to claim 6, further comprising deriving the measure of patient effort from a pulse oximeter signal.

8. The method according to any one of claims 6-7, further comprising using the patient effort signal to at least one of discriminate between open-closed apnea, determine high airway resistance, determine relative work of breathing, augment control algorithms for the flow generator, determine overventilation, and determine sleep state.

9. The method according to any one of claims 6-8, further comprising using the patient effort signal in conjunction with an airflow signal to distinguish between open and closed airway apneas.

10. The method according to any one of claims 6-9, further comprising reducing pressure support when the measure of patient effort increases, and increasing pressure support when the measure of patient effort decreases.

11. A respiratory effort monitoring apparatus, comprising:

a pulse oximeter configured to derive a pulse oximeter signal; and

a signal processor configured to receive the pulse oximeter signal and generate a patient effort signal indicative of respiratory rate.

12. The respiratory effort monitoring apparatus according to claim 11, wherein the patient effort signal is used as input to control operation of a controllable flow generator operable to generate a supply of pressurized breathable gas to be provided to a patient for treatment.

13. A method for treating sleep disordered breathing, comprising:

deriving a pulse oximeter signal; and

processing the pulse oximeter signal to generate a patient effort signal indicative of respiratory rate.

14. The method according to claim 13, further comprising controlling a supply of pressurized breathable gas to a patient for treatment based on input from the patient effort signal.

15. A method of controlling a ventilator comprising the steps of monitoring a patient using pulse oximeter plethysmography, deriving a patient parameter from said pulse oximeter plethysmography, and controlling the ventilator by adjusting a ventilator setting in accordance with said patient parameter.

16. A method as claimed in claim 15 wherein said ventilator setting is one or more of expiratory pressure, pressure support, rise time and wave-shape.

17. A method as claims in claim 15 wherein mean treatment pressure is modulated in accordance with said patient parameter.

18. A method as claimed in claim 15 wherein said patient parameter is one or more of pulse rate, effort, cardiac afterload, vascular tone, heart rate variability, sympathetic nervous system activity in general, and central venous pressure.

19. A method as claimed in claim 15 wherein mean treatment pressure is decreased when said parameter indicates that a patient's vascular system is becoming stressed.

20. A method of monitoring a patient respiratory parameter comprising the steps of monitoring a patient using pulse oximeter plethysmography and determining a patient respiratory parameter from said pulse oximeter plethysmograph.

21. A method as claimed in claim 20 wherein said respiratory parameter is monitored while the patient is sleeping.

22. A method as claimed in claim 20 wherein said parameter is a parameter indicative of the extent to which the patient is suffering from sleep disordered breathing.

23. A method as claimed in claim 22 wherein said parameter is a parameter indicative of upper airway obstruction.

24. A method for delivering positive pressure therapy by a CPAP ventilator to a patient having a health disorder comprising

analyzing a signal from a pulse oximeter to determine patient effort and forming a patient effort signal,

inputting the patient effort signal to a feedback controller of the ventilator that controls positive pressure therapy to the patient.

25. The method of delivering positive pressure therapy of claim 24 wherein the health disorder is sleep disordered breathing, congestive heart failure, or stroke.

26. The method of delivering positive pressure therapy of claim 24 wherein a pulse oximeter signal is processed to remove signals indicative of heart rate and leave signals indicative of respiratory rate.

27. The method of delivering positive pressure therapy of claim 26 wherein the processing employs a low pass filter, peak detector, nadir detector or averaging.

28. The method of delivering positive pressure therapy of claim 24 wherein in the absence of respiratory flow limitation, persistently high respiratory effort indicates inadequate pressure support.

29. The method of delivering positive pressure therapy of claim 24 wherein the effort information in a VPAP or AutoCS device is used to titrate applied PEEP.

30. The method of delivering positive pressure therapy of claim 24 wherein a measure of effort waveshape is used as an indicator that a patient has been overventilated.

31. The method of delivering positive pressure therapy of claim 30 further comprising the step of using the indicator to titrate the target ventilation.

32. The method of delivering positive pressure therapy of claim 24 further comprising the step of determining venous pulsation as an input to a CPAP algorithm for patients with OSA and heart failure.

33. The method of delivering positive pressure therapy of claim 24 further comprising the step of limiting the CPAP pressure applied in response to increases in venous pulsation .

34. The method of delivering positive pressure therapy of claim 24 further comprising the step of determining vascular compliance as an input to a CPAP algorithm.

35. The method of delivering positive pressure therapy of claim 34 wherein changes in vascular compliance are indicative of patient arousals.

36. The method of delivering positive pressure therapy of claim 35 further comprising the step of augmenting the data for prescribing CPAP levels.

37. A method for delivering positive pressure therapy by a CPAP ventilator to a patient having a health disorder comprising

combining a signal from a pulse oximeter with an airflow signal to distinguish open and closed airway apneas.

38. The method for delivering positive pressure therapy of claim 37 wherein respiratory effects are seen as variation in cardiac timing and respiratory timing information is extracted.

39. The method for delivering positive pressure therapy of claim 37 wherein the health disorder is sleep disordered breathing, congestive heart failure, or stroke.

40. The method for delivering positive pressure therapy of claim 37 wherein the pulse oximeter is used as an indication of patient effort in a respiratory therapy device.

41. The method for delivering positive pressure therapy of claim 40 wherein respiratory effort is seen in the arterial blood pressure waveform as variation in the peak-to-peak amplitude.

42. The method for delivering positive pressure therapy of claim 41 wherein inspiration is associated with reduced systolic blood pressure.

43. The method for delivering positive pressure therapy of claim 37 wherein a plethysmographically derived respiratory effort estimate is used during episodes of apnea to indicate whether the apnea is opened or closed.

44. The method for delivering positive pressure therapy of claim 43 wherein the indication of apnea type is used in automatic titration algorithm logic.

45. The method for delivering positive pressure therapy of claim 44 wherein a low or zero flow signal is indicative of an apnea.

46. The method for delivering positive pressure therapy of claim 45 wherein if the apnea occurs in the absence of effort as measured by the pulse oximeter, then the apnea is regarded as being open.

47. The method for delivering positive pressure therapy of claim 45 wherein if there is effort, then the apnea is regarded as being closed.

48. The method for delivering positive pressure therapy of claim 37 wherein a period of high respiratory effort derived from an oximeter plethysmograph combined with reduced respiratory flow or with flow limitation implies the presence of significant airway resistance.

49. The method for delivering positive pressure therapy of claim 48 wherein the combination of high effort and low measured respiratory flow is an indicator to increase applied PEEP (Positive End Expiratory Pressure).

50. The method for delivering positive pressure therapy of claim 37 further comprising the step of combining a flow based measure of phase.

51. The method for delivering positive pressure therapy of claim 37 further comprising the step of using a measure of effort waveshape in a CPAP algorithm, wherein increasing patient effort is indicative of impending upper-airway instability.

52. A method for delivering positive pressure therapy by a servo-ventilator to a patient having a health disorder comprising

deriving a measure of patient effort from a pulse oximeter signal,

using the measure of patient effort as a control variable in the servo-ventilator, wherein when the measure of patient effort increases, pressure support is reduced and when the measure of patient effort decreases, pressure support is increased.

53. The method for delivering positive pressure therapy of claim 52 wherein the health disorder is sleep disordered breathing, congestive heart failure, or stroke.

54. A therapy system for a patient having a pulse oximeter and receiving a flow of pressurized air via a patient interface, wherein a therapy algorithm receiving input of clinical targets determines a therapy pressure that a flow meter measures and communicates via an airflow signal to a signal processor, said processor inputting a first feedback signal to the therapy algorithm and wherein the pulse oximeter emits a photo-plethysmograph signal to a signal processor that inputs a second feedback signal to the therapy algorithm, wherein the therapy algorithm adjusts a level of PEEP/CPAP or a level of pressure support received by the patient.

55. The therapy system of claim 54, wherein the first feedback signal is selected from the group consisting of minute ventilation estimate, inspiratory airflow limitation, expiratory airflow limitation, tidal volume, leak, cardiac timing and respiratory phase.

56. The therapy system of claim 54, wherein the second feedback signal is selected from the group consisting of a relative indication of respiratory effort, an absolute indication of respiratory rate, patterns of respiratory effort and rate indicative of respiratory control anomalies or apnea type, an indication of respiratory rate, relative indication of worsening cardiac function, relative indication of venous congestion, relative variation in sympathetic nervous system activity, standard pulse oximetry, arrival time of systolic pulse at periphery, and pulse rate.

57. The therapy system of claim 54, wherein the clinical targets are selected from the group consisting of minimum ventilation, nominal ventilation, optimal synchrony, sleep quality, long-term cardiac function, anticipation/prediction of cardiac decompensation, minimum CPAP/EEP/PEEP, maximum CPAP/EEP/PEEP, minimum pressure support, maximum pressure, and maximum average pressure.

58. A monitoring system for a patient having a pulse oximeter and a pressure sensor receiving nasal or oro-nasal flow sensed by cannula, wherein the pressure sensor communicates via an airflow signal to a signal processor, said processor inputting a first feedback signal to a combined processing system and wherein the pulse oximeter emits a photo-plethysmograph signal to a signal processor that inputs a second feedback signal to the combined processing system,

wherein the first feedback signal is selected from the group consisting of inspiratory airflow limitation, expiratory airflow limitation, cardiac timing, respiratory phase, time course of breath amplitude and derived statistics,

wherein the second feedback signal is selected from the group consisting of relative indication of respiratory effort, absolute indication of respiratory rate, relative indication of worsening cardiac function, relative indication of venous congestion, relative variation in sympathetic nervous system activity, standard pulse oximetry, arrival time of systolic pulse at periphery, and pulse rate, and

the combined processing system determines quantities from the group consisting of delay between respiration changes and blood gas adjustments, circulatory delay, and pulse transit time (PTT) indicated by delay between cardiogenic flow pulses and arrival of the pulse at the periphery.

59. A method to monitor, in a non-invasive manner, pulse oximetry and/or air flow, relating to a patient's breathing and/or heart activity wherein the monitored parameter is used for diagnostic purposes to log data, to produce a report or an alarm or otherwise signal a physician, and wherein the value of the monitored parameter may be used to control the delivery of pressurized gas from a blower, ventilator or the like, to the patient.

60. An open/closed airway apnea algorithm wherein

an airflow signal is analyzed,

a determination is made as to whether it is within normal bounds,

if within normal bounds then CPAP/EPAP therapy is maintained at its current level

if not within normal bound the effort signal is analyzed,

if the effort is high then an obstructive apnea is indicated and the appropriate therapy is to increase the treatment pressure.

61. The therapy system of claim 54 for patients suffering general respiratory insufficiency, wherein the algorithm defines when pressure support, or End Expiratory Pressure (EEP) should be varied.

62. The monitoring system of claim 58, wherein the two feedback signals are analyzed, and where if the analysis is indicative of elevated levels of SNS activity, or decompensation an alert is generated.

63. The open/closed airway apnea algorithm of claim 60 further having the additional step that venous congestion is monitored through the pulse oximeter such that if venous congestion is worsening, then CPAP pressure will not be increased, but restored to a previous level.

64. The therapy system of claim 54, wherein therapy rate settings are initialized based on respiratory rate information.

65. The therapy system of claim 54, wherein therapy trigger threshold settings, are initialized based on positively identifying cardiogenic flow amplitude.

66. A method for delivering positive pressure therapy by a CPAP ventilator to a patient having a health disorder comprising the combination of oximetry data and respiratory timing and effort information inferred from additional processing of a PPG and/or from the addition of a nasal or oronasal cannulae data.

67. The method for delivering positive pressure therapy of claim 66 wherein circulatory delay is an indicator of heart-failure severity or cardiac decompensation.

68. The method for delivering positive pressure therapy of claim 66 wherein true Pulse Transit Time (PTT) variations due to either BP variation or increased arterial tone (sympathetic activation) is obtained via the delay between cardiogenic flow pulses seen by a nasal pressure transducer at end-expiration and the arrival of pulse at the periphery from an oximeter plethysmogram.

69. The method of claim 68, wherein the CGF is acquired at a consistent portion of the respiratory cycle, and an SBD parameter is provided.

70. The method of claim 66, further comprising extracting respiratory effort information from the raw PPG (pulsus paradoxus) for SBD screening.

71. The method of claim 72 further comprising using a nasal pressure transducer for discrimination between central and obstructive apneas.

72. The method of claim 71 further comprising signal processing for discrimination between central and obstructive apneas from combining information from the PPG, e.g., time course of breathing effort compared to time course of desaturations, or statistical analysis of the time course of breathing effort.

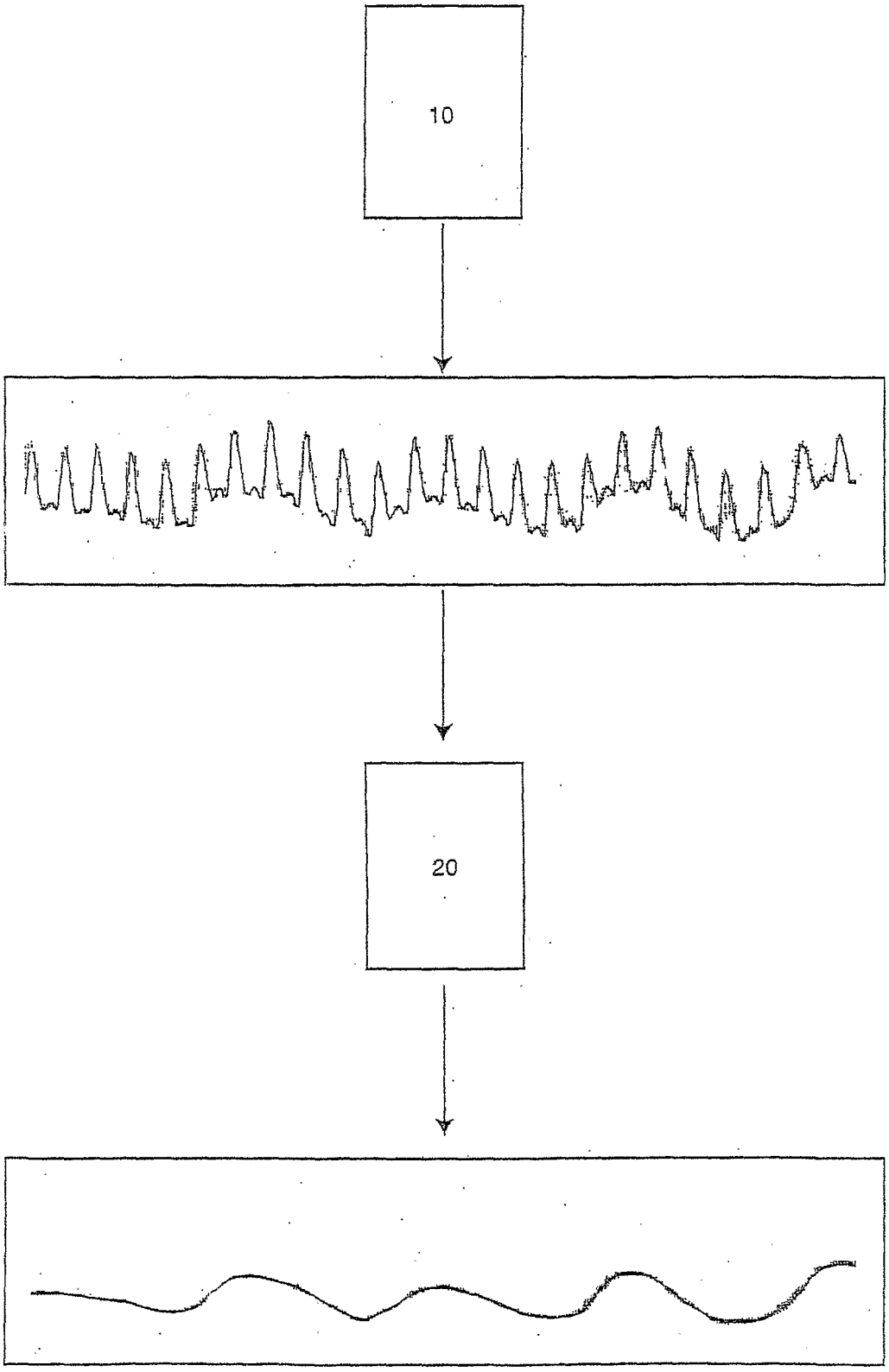

Fig. 1

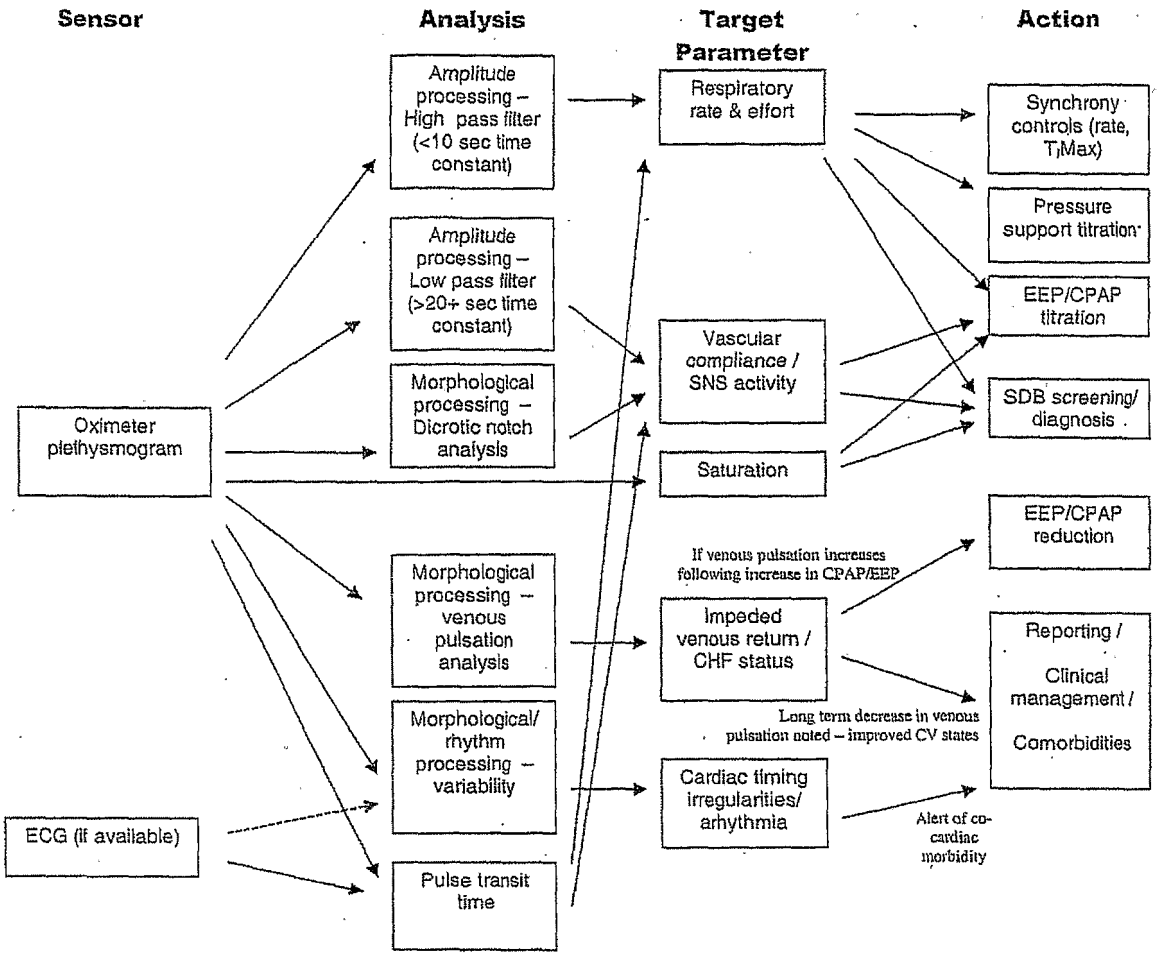
Sensor
Analysis
Target Parameter
Action
Amplitude processing – High pass filter (<10 sec time constant)
Amplitude processing – Low pass filter (>20+ sec time constant)
Morphological processing – Dicrotic notch analysis
Oximeter plethysmogram
Morphological processing – venous pulsation analysis
Morphological/ rhythm processing – variability
ECG (if available)
Pulse transit time
Respiratory rate & effort
Vascular compliance / SNS activity
Saturation
Impeded venous return / CHF status
Cardiac timing irregularities/ arhythmia
If venous pulsation increases following increase in CPAP/EEP
Long term decrease in venous pulsation noted – improved CV states
Alert of co-cardiac morbidity
Synchrony controls (rate, TiMax)
Pressure support titration
EEP/CPAP titration
SDB screening/ diagnosis
EEP/CPAP reduction
Reporting / Clinical management / Comorbidities

FIG. 2

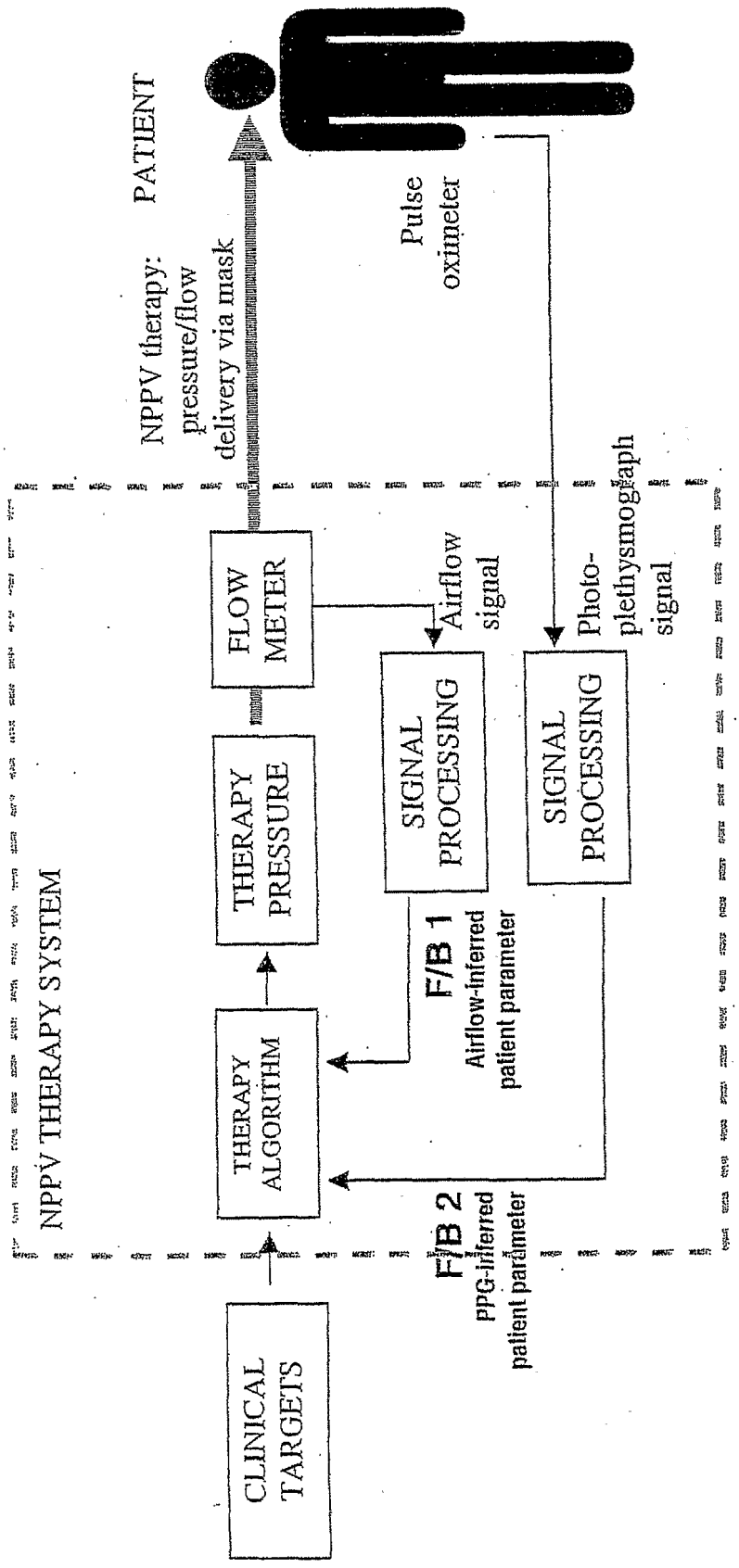
NPPV THERAPY SYSTEM
CLINICAL TARGETS
THERAPY ALGORITHM
THERAPY PRESSURE
FLOW METER
NPPV therapy: pressure/flow delivery via mask
PATIENT
Pulse oximeter
SIGNAL PROCESSING
Airflow signal
SIGNAL PROCESSING
Photo-plethysmograph signal
F/B 1
Airflow-inferred patient parameter
F/B 2
PPG-inferred patient parameter

Fig. 3

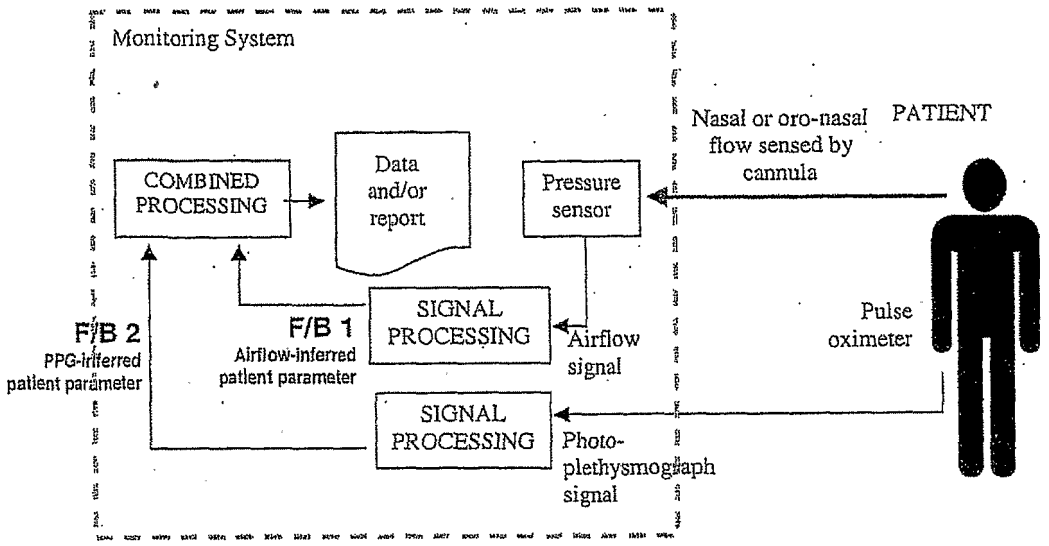
Monitoring System
COMBINED PROCESSING
Data and/or report
Pressure sensor
Nasal or oro-nasal flow sensed by cannula
PATIENT
SIGNAL PROCESSING
Airflow signal
Pulse oximeter
F/B 2
PPG-inferred patient parameter
F/B 1
Airflow-inferred patient parameter
SIGNAL PROCESSING
Photo-plethysmograph signal

FIG. 3A

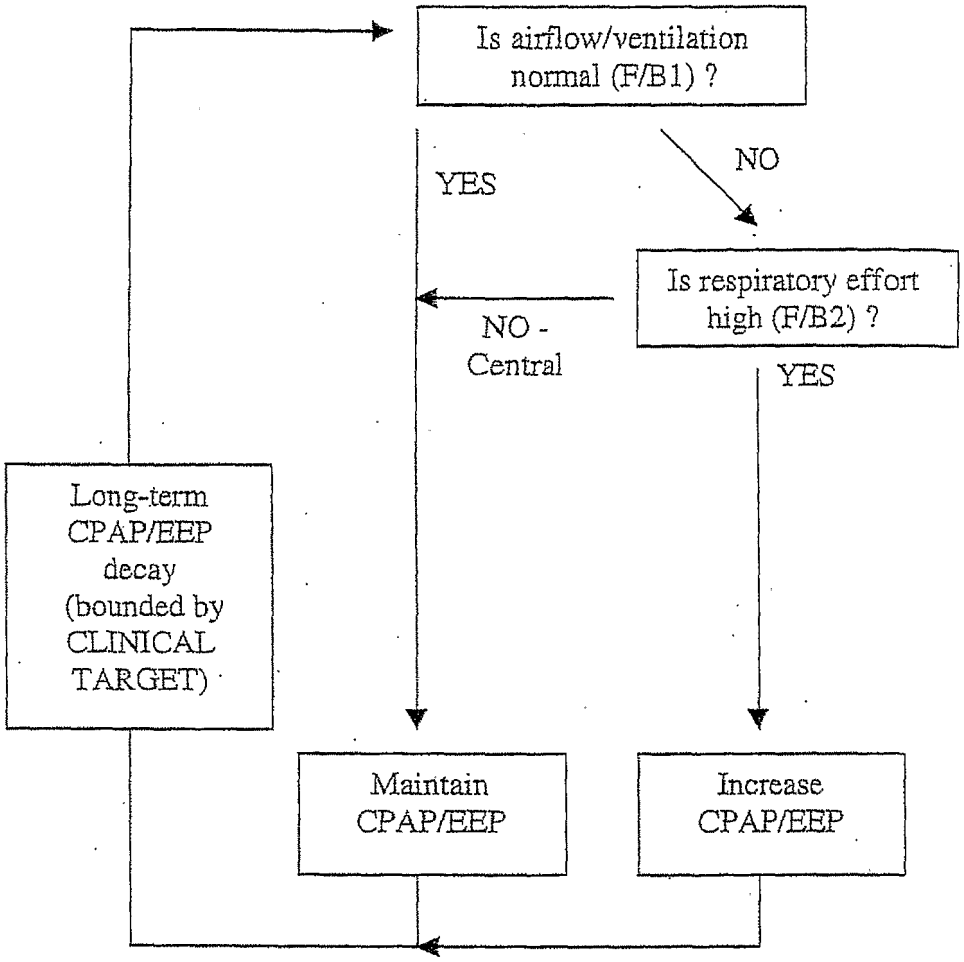
Is airflow/ventilation normal (F/B1) ?
YES
NO
Is respiratory effort high (F/B2) ?
NO - Central
YES
Long-term CPAP/EEP decay (bounded by CLINICAL TARGET)
Maintain CPAP/EEP
Increase CPAP/EEP

Fig. 4

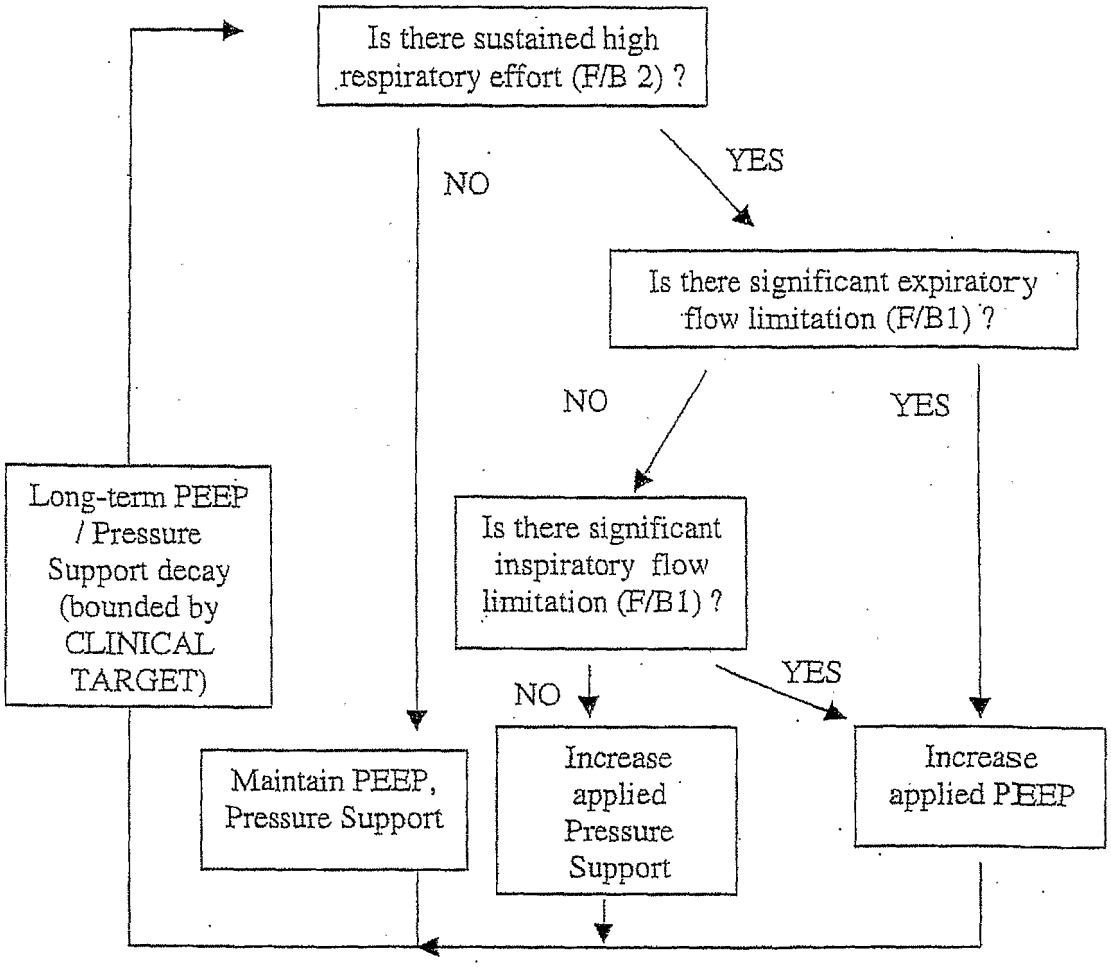
Is there sustained high respiratory effort (F/B 2) ?
NO
YES
Is there significant expiratory flow limitation (F/B1) ?
NO
YES
Long-term PEEP / Pressure Support decay (bounded by CLINICAL TARGET)
Is there significant inspiratory flow limitation (F/B1) ?
NO
YES
Maintain PEEP, Pressure Support
Increase applied Pressure Support
Increase applied PEEP

Fig. 5

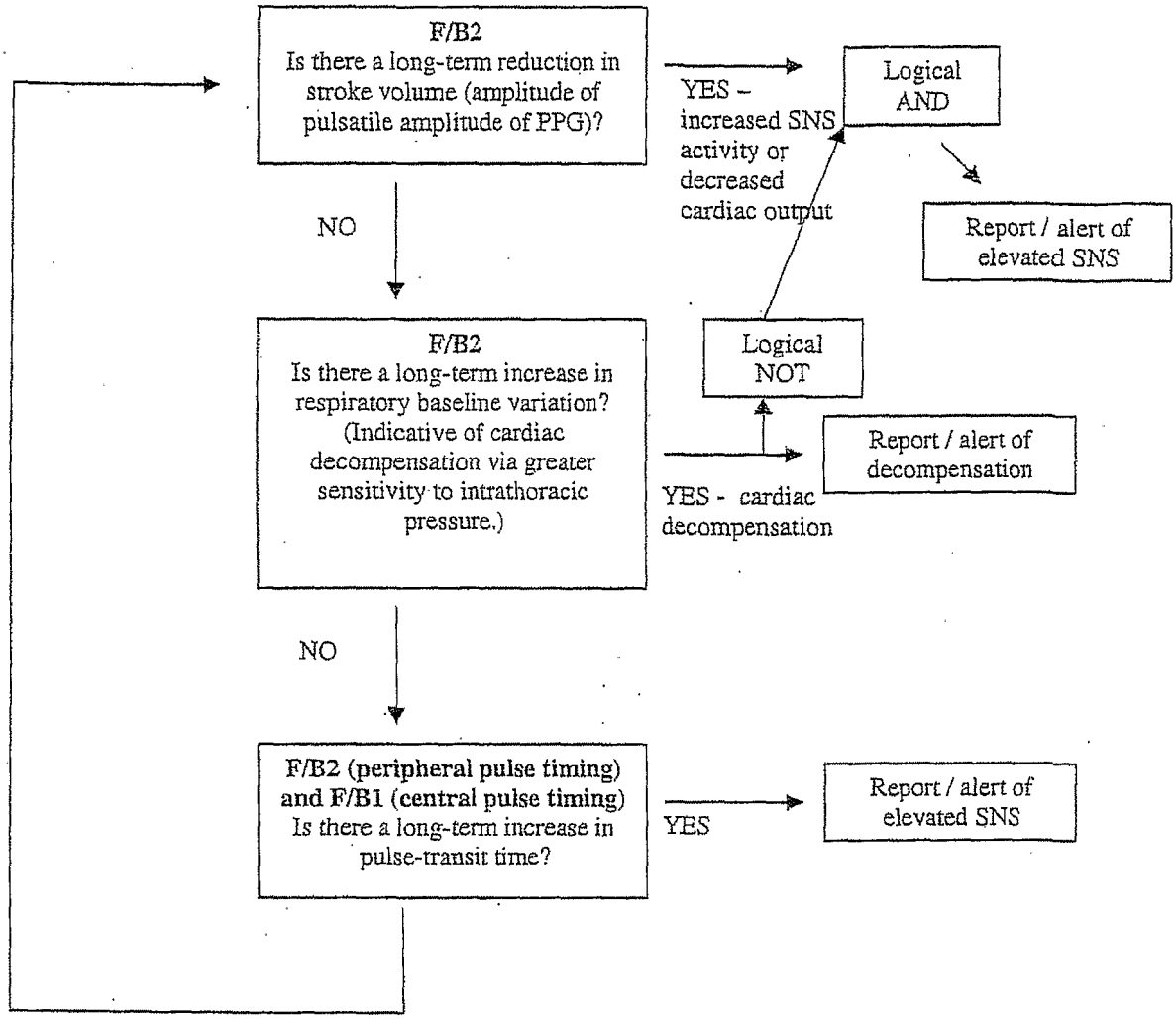
F/B2
Is there a long-term reduction in stroke volume (amplitude of pulsatile amplitude of PPG)?
YES – increased SNS activity or decreased cardiac output
Logical AND
Report / alert of elevated SNS
NO
F/B2
Is there a long-term increase in respiratory baseline variation? (Indicative of cardiac decompensation via greater sensitivity to intrathoracic pressure.)
Logical NOT
Report / alert of decompensation
YES - cardiac decompensation
NO
F/B2 (peripheral pulse timing) and F/B1 (central pulse timing)
Is there a long-term increase in pulse-transit time?
YES
Report / alert of elevated SNS

Fig. 6

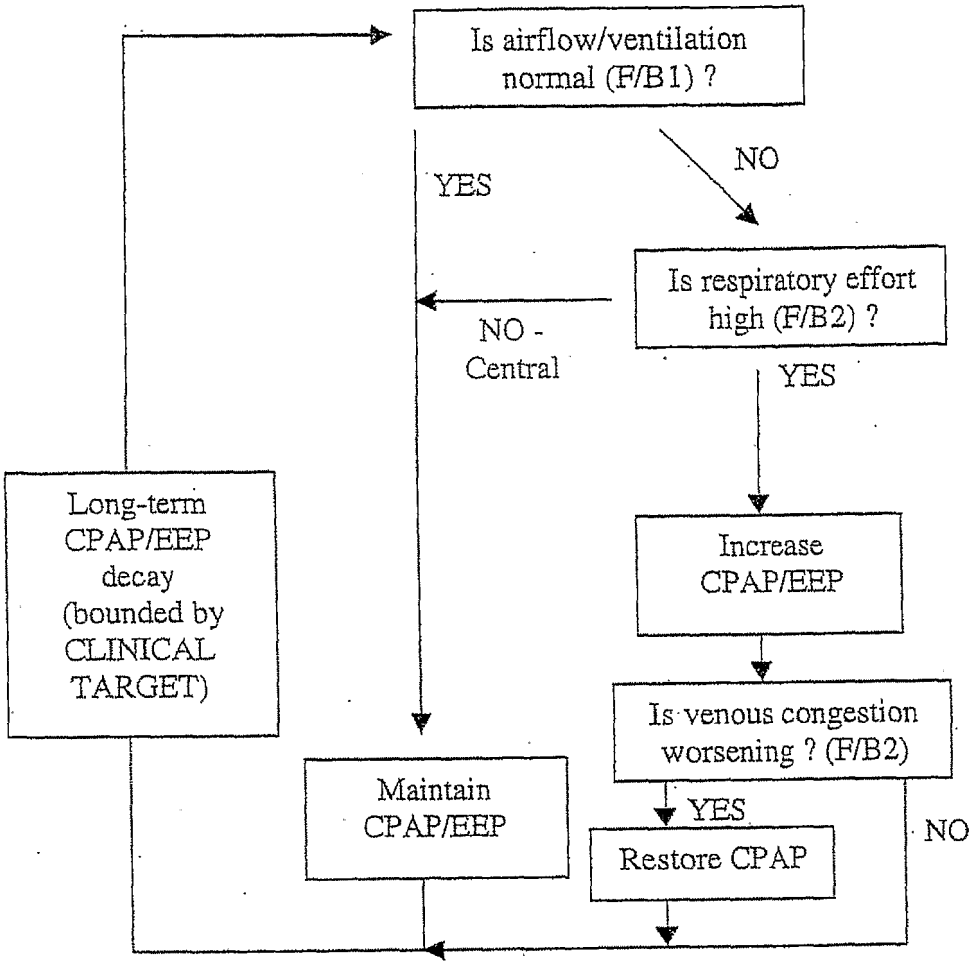
Is airflow/ventilation normal (F/B1) ?
YES
NO
Is respiratory effort high (F/B2) ?
NO - Central
YES
Long-term CPAP/EEP decay (bounded by CLINICAL TARGET)
Increase CPAP/EEP
Is venous congestion worsening ? (F/B2)
Maintain CPAP/EEP
YES
NO
Restore CPAP

Fig. 7

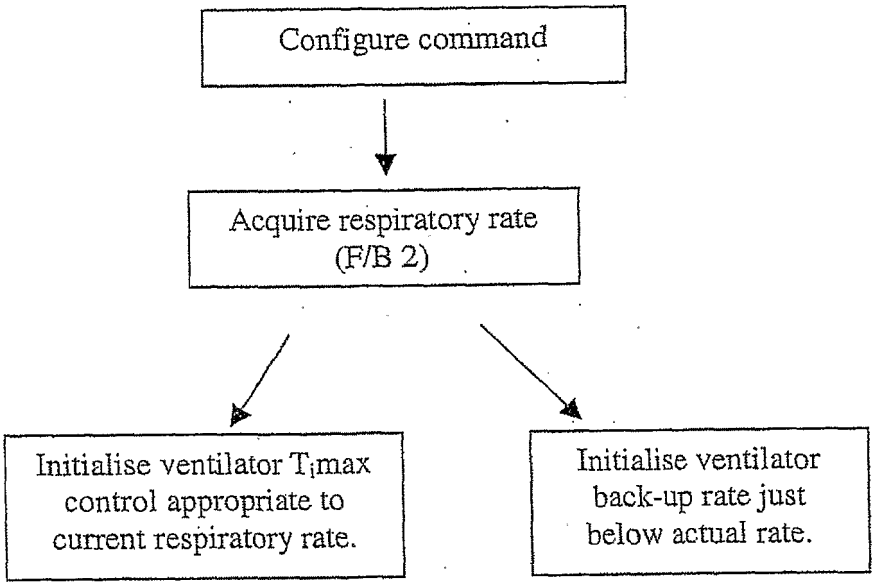
Configure command
Acquire respiratory rate (F/B 2)
Initialise ventilator $T_i$max control appropriate to current respiratory rate.
Initialise ventilator back-up rate just below actual rate.

FIG. 8

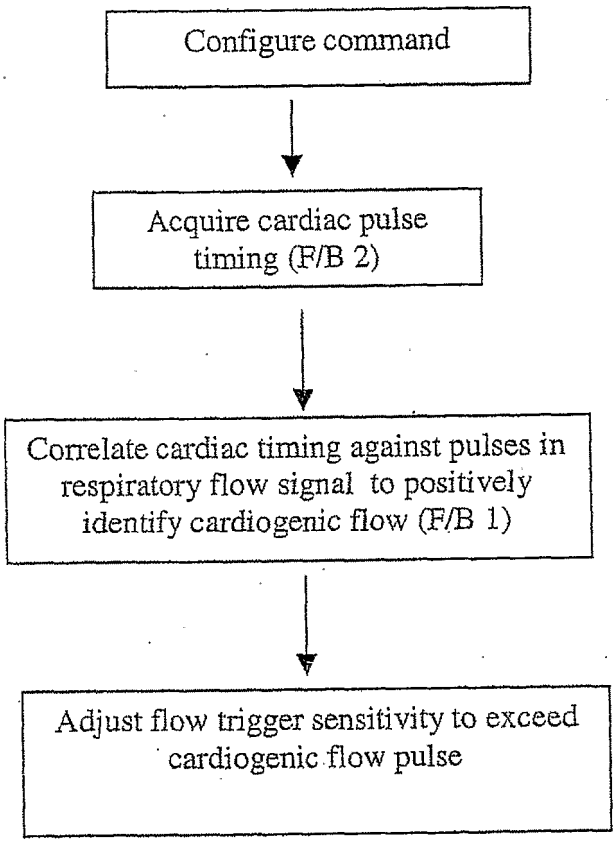
Configure command
Acquire cardiac pulse timing (F/B 2)
Correlate cardiac timing against pulses in respiratory flow signal to positively identify cardiogenic flow (F/B 1)
Adjust flow trigger sensitivity to exceed cardiogenic flow pulse

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2005/001543

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: A61M 16/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI and keywords: A61M 16/- and oximet+ and effort and control and apnea and obstruct and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6325761 B1 (JAY) 4 December 2001 Column 1 lines 25 to 35 Column 3 lines 19 to 31	1-3,5-8,10-19, 24-31,52, 53,66
Y		4,9,37-51, 70-72
Y	US 6702752 B2 (DEKKER) 9 March 2004 Column 1 lines 7 to 14 Column 4 lines 12 to 14	1-19,24-31, 37-53,66, 70-72
P,A	US 2005/0061319 A1 (HARTLEY et al.) 24 March 2005 Whole document	1

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
2 December 2005

Date of mailing of the international search report
07 DEC 2005

Name and mailing address of the ISA/AU

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2005/001543

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2001/000264 A1 (UNIVERSITY OF FLORIDA) 4 January 2001 Page 12 line 26 to page 13 line 15	15-19,54-57, 61,64,66
X	WO 2000/045883 A1 (VERSAMED MEDICAL SYSTEMS LTD) 10 August 2000 Page 12 line 24 to page 13 line 4	15-19,54-57, 61,64,66
X	WO 2002/065901 A2 (ARES MEDICAL, INC.) 29 August 2002 Page 20 lines 10 to 14 Page 50 lines 17 to 21	15-19,54-57, 61,64,66
X Y	US 5954050 A (CHRISTOPHER) 21 September 1999 Column 8 lines 33 to 57	60 1-19,24-31, 37-53,66, 70-72
X Y	US 6675797 B1 (BERTHON-JONES) 13 January 2004 Column 1 lines 32 to 40	60 1-19,24-31, 37-53,66, 70-72
X Y	WO 2001/078601 A1 (RESMED LIMITED) 25 October 2001 Page 25 lines 1 to 9 Page 26 lines 20 to 28	60 1-19,24-31, 37-53,66, 70-72

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2005/001543

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: **20 – 23, 58, 59 and 62**
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

See additional sheet.

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See additional sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2005/001543

Supplemental Box
(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box No:

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion the International Searching Authority has found that there are different inventions as follows:

1. Claims 1 – 14, 24 – 36, 52, and 53 directed to deriving a measure of respiratory effort from the output signal of a pulse oximeter. It is considered that using a pulse oximeter to derive such a measure comprises a first "special technical feature".

2. Claims 15 – 19, 37 – 51, 54 – 57, 61 and 64 – 72 directed to controlling a ventilator using pulse oximeter data. It is considered that controlling a ventilator in this way comprises a second "special technical feature".

3. Claims 60 and 63 directed to a method of determining whether an airway is open or closed using an effort signal. It is considered that use of the effort signal comprises a third "special technical feature".

Since the abovementioned groups of claims do not share any of the technical features identified, a "technical relationship" between the inventions, as defined in PCT rule 13.2 does not exist. Accordingly the international application does not relate to one invention or to a single inventive concept, a prior.

As the search and examination for the additional inventions will each require more than a little additional search and examination effort over that for the first invention and each other, four additional search fees are warranted.

Claims 20 – 23, 58, 59 and 62 are not considered searchable as their scopes are not able to be clearly determined. For claims 20 – 23, the term "patient respiratory parameter" is too vague and it is not clear what it is intended to include. Claim 58 defines a monitoring system with a first feedback signal selected from many possibilities, a second feedback signal again selected from a range of possibilities, and a processing system which can calculate one of several values. Due to the many possibilities in inputs and outputs for claim 58, the full scope of the claim is not clear enough to enable a search to be performed. Similarly for claim 59, wherein the two "and/or"s in the claim render the claim unsearchable.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU2005/001543

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	6325761	AU	60347/99	CA	2343092	EP	1112023
		US	6129675	WO	0015106		
US	6702752	AU	2003217564	CN	1646055	EP	1485009
		US	6709402	US	6805673	US	6896661
		US	2003163033	US	2003163034	US	2003163050
		US	2003163054	US	2004260186	WO	03071938
US	2005061319	US	2004204728	US	2004204734	US	2004204735
		US	2004215239	US	2004215240	US	2004215258
		US	2004220626	US	2004220628	US	2004220629
		US	2004220633	US	2004220641	US	2004225329
		US	2004230128	US	2004230129	US	2004230229
		US	2004230230	US	2004230243	US	2004230249
		US	2004230272	US	2004230273	US	2004230274
		US	2004230279	US	2004230280	US	2004230281
		US	2004230282	US	2005004615	US	2005038350
		US	2005039745	US	2005042589	US	2005043644
		US	2005043652	US	2005043772	US	2005061315
		US	2005061320	US	2005061323	US	2005065447
		US	2005065448	US	2005065560	US	2005065566
		US	2005065567	US	2005065572	US	2005074741
		US	2005076905	US	2005076908	US	2005076909
		US	2005080348	US	2005080461	US	2005080463
		US	2005081847	US	2005085738	US	2005107838
		US	2005109338	US	2005109339	US	2005113710
		US	2005115561	US	2005119708	US	2005142070
		US	2005145246	WO	2004091715	WO	2004091717
		WO	2004091719	WO	2004091720	WO	2005018737
		WO	2005028029	WO	2005089638	WO	2005102450
WO	0100264	AU	60640/00	AU	60645/00	EP	1189649
		EP	1586344	US	6796305	US	2004003813
		US	2005098178	WO	0100265		
WO	0045883	AU	25063/00				

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU2005/001543

WO	02065901	AU	2002246880	EP	1353594	US	6811538
		US	2002165462	US	2005027207		
US	5954050	AU	10856/99	CA	2305189	EP	1056498
		WO	9920332				
US	6675797	AU	36787/99	AU	55382/98	AU	55383/98
		AU	77641/94	EP	0651971	EP	0920845
		EP	0927538	EP	0934723	EP	1488743
		US	5704345	US	6029665	US	6138675
		US	6363933	US	2004123866		
WO	0178601	AU	42752/00	US	6840907		

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX

专利名称(译)	用于在睡眠呼吸紊乱中无创监测呼吸参数的方法和装置		
公开(公告)号	EP1804873A4	公开(公告)日	2017-07-19
申请号	EP2005791284	申请日	2005-10-06
[标]申请(专利权)人(译)	雷斯梅德有限公司		
申请(专利权)人(译)	瑞思迈有限公司		
当前申请(专利权)人(译)	瑞思迈有限公司		
发明人	OATES, JOHN DAVID, RESMED LIMITED MARTIN, DION CHARLES CHEWE, RESMED LIMITED		
IPC分类号	A61M16/00 A61B5/00 A61B5/08 A61B5/087 A61B5/1455		
CPC分类号	A61B5/0826 A61B5/087 A61B5/1455 A61B5/7278 A61B5/7282 A61M16/0051 A61M16/026 A61M2016/0039 A61M2230/04 A61M2230/205 A61M16/0003 A61M16/0057 A61M2016/003 A61M2230/005 A61M2230/42		
优先权	60/615961 2004-10-06 US 60/629612 2004-11-22 US		
其他公开文献	EP1804873A1		
外部链接	Espacenet		

摘要(译)

空气输送系统包括可控流量发生器，其可操作以产生待提供给患者以进行治疗的加压可呼吸气体供应;以及脉冲血氧计，其配置成确定治疗期间患者努力量的度量并提供患者努力信号用于输入控制流量发生器的操作。