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- (71) **Applicant (for all designated States except US):**
NELLCOR PURITAN BENNETT LLC [US/US]; 6135
Gunbarrel Avenue, Boulder, CO 80301 (US).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** **MILNE, Gary**
[US/US]; 590 Spruce Circle, Louisville, CO 800278 (US).
HENSLEY, Kirk [US/US]; 7105 Timberview Drive, Dub-
lin, OH 43017 (US). **DOYLE, Peter** [US/US]; 1948 Cas-
ablanca Court, Vista, CA 92081 (US). **KIMM, Gardner**
[US/US]; 4319 Point Reyes Court, Carlsbad, CA 92010
(US).
- (74) **Agent:** **ANDERSON, Matthew**; 6135 Gunbarrel Avenue,
Boulder, CO 80301 (US).

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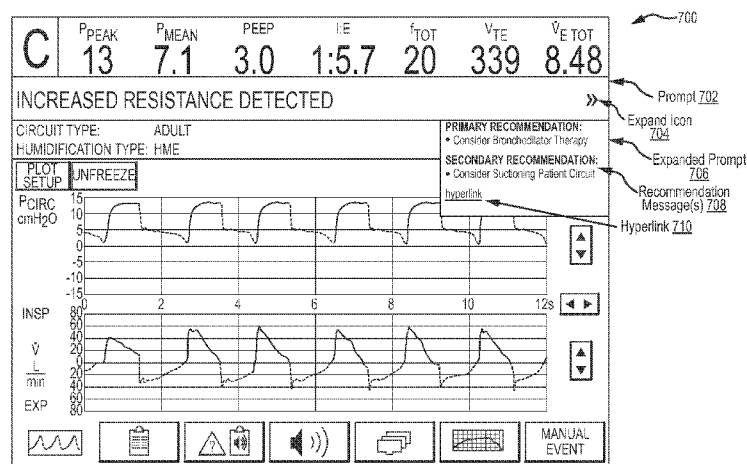


FIG. 7

(57) **Abstract:** This disclosure describes systems and methods for monitoring ventilatory parameters, analyzing ventilatory data as-
sociated with those parameters, and providing useful notifications and/or recommendations to clinicians. For example, many clini-
cians may not easily identify or recognize data patterns and correlations indicative of a fluctuation in resistance during mechanical
ventilation of a patient. Furthermore, clinicians may not easily determine potential causes for the fluctuation in resistance and/or
steps for mitigating the fluctuation in resistance. According to embodiments, a ventilator may be configured to monitor and evaluate
diverse ventilatory parameters to detect fluctuations in resistance and may issue suitable notifications and recommendations to the
clinician based on potential causes of the fluctuation, ventilatory and/or patient data, etc. The suitable notifications and recommenda-
tions may further be provided in a hierarchical format such that the clinician may selectively access information regarding the fluctu-
ation in resistance.

VENTILATOR-INITIATED PROMPT REGARDING DETECTION OF FLUCTUATIONS IN RESISTANCE

Introduction

A ventilator is a device that mechanically helps patients breathe by replacing
5 some or all of the muscular effort required to inflate and deflate the lungs. In recent
years, there has been an accelerated trend towards an integrated clinical environment.
That is, medical devices are becoming increasingly integrated with communication,
computing, and control technologies. As a result, modern ventilatory equipment has
become increasingly complex, providing for detection, monitoring, and evaluation of a
10 myriad of ventilatory parameters during ventilation of a patient. However, due to the
shear magnitude of available ventilatory data, many clinicians may not readily assess
and evaluate the available data to detect certain patient conditions and/or changes in
patient condition.

Specifically, fluctuations in resistance may be indicative of a number of disparate
15 patient and/or ventilator conditions. The location of a change in resistance may be an
important factor in determining the cause for the change. However, this may be
difficult for a clinician to determine as resistance may arise in the patient airway, the
artificial airway (endotracheal or tracheostomy tube), the inspiratory limb or the
expiratory limb of the ventilatory circuit, the expiratory filter, etc. For example, an
20 increase in resistance may be detrimental to patient condition due to an increase in the
work of breathing (WOB) and may lead to other adverse consequences such as Auto-
PEEP. Furthermore, an increase in resistance may be the result of a variety of diverse
causes including, *inter alia*, mucous buildup in the artificial airway, a kink or
obstruction in the ventilatory circuit, an obstructed expiratory filter, changing lung
25 conditions, poor patient position, etc. In contrast, a decrease in resistance may be
indicative of changing lung conditions, a leak in the ventilatory circuit, improved patient
position, etc. Fluctuations in resistance are difficult to detect because resistance is
generally not measured directly, but may be implicated by slight changes in a variety of
different parameters. Furthermore, due to the variety of potential causes, fluctuations in
30 resistance may be difficult for a clinician to efficiently and effectively address during the
ventilation of a patient.

Ventilator-Initiated Prompt Regarding Detection of Fluctuations in Resistance

This disclosure describes systems and methods for monitoring and evaluating ventilatory parameters, analyzing ventilatory data associated with those parameters, and providing useful notifications and/or recommendations to clinicians. Modern ventilators monitor, evaluate, and graphically represent a myriad of ventilatory parameters. However, many clinicians may not easily identify or recognize data patterns and correlations indicative of certain patient conditions, changes in patient condition, and/or effectiveness of ventilatory treatment. Further, clinicians may not readily determine appropriate ventilatory adjustments that may address certain patient conditions and/or the effectiveness of ventilatory treatment. Specifically, clinicians may not readily detect or recognize fluctuations in resistance during mechanical ventilation of a patient. According to embodiments, a ventilator may be configured to monitor and evaluate diverse ventilatory parameters to detect fluctuations in resistance and may issue suitable notifications and recommendations to the clinician depending on potential causes of the fluctuation, the magnitude of the fluctuation, ventilatory and/or patient data, etc. The suitable notifications and recommendations may further be provided in a hierarchical format such that the clinician may selectively access summarized and/or detailed information regarding the fluctuation in resistance. In more automated systems, recommendations may be automatically implemented to mitigate the detected fluctuation in resistance.

According to embodiments, a ventilator-implemented method is provided for issuing a prompt in response to detecting a fluctuation in resistance during ventilation of a patient. The method comprises retrieving ventilatory data and identifying a maximum threshold and a minimum threshold for resistance. Further, the method comprises trending resistance during ventilation of the patient and detecting a fluctuation in resistance when the trended resistance breaches one of the maximum threshold and the minimum threshold. Upon detection of the fluctuation in resistance, the method includes displaying a notification.

According to additional embodiments, a ventilatory system for issuing a prompt in response to detecting a fluctuation in resistance during ventilation of a patient is provided. The ventilatory system performs a method that comprises retrieving ventilatory data and identifying a maximum threshold and a minimum threshold for

resistance. Further, the method comprises trending resistance during ventilation of the patient and detecting a fluctuation in resistance when the trended resistance breaches one of the maximum threshold and the minimum threshold. Upon detection of the fluctuation in resistance, the method includes displaying a notification.

5 According to additional embodiments, a ventilator processing interface for displaying one or more prompts in response to detecting a fluctuation in resistance is provided. The ventilator processing interface comprises a means for retrieving at least some ventilatory data, a means for determining the fluctuation in resistance, and means for displaying a prompt comprising a notification of the fluctuation in resistance.

10 According to additional embodiments, a graphical user interface for displaying one or more prompts in response to detecting a fluctuation in resistance is provided. The graphical user interface comprising at least one window, the at least one window having one or more elements comprising at least one prompt element for communicating information regarding detection of a fluctuation in resistance. For example, the at least
15 one prompt element displays a notification regarding the fluctuation in resistance.

 These and various other features as well as advantages which characterize the systems and methods described herein will be apparent from a reading of the following detailed description and a review of the associated drawings. Additional features are set forth in the description which follows, and in part will be apparent from the description,
20 or may be learned by practice of the technology. The benefits and features of the technology will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

 It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to
25 provide further explanation of the claims.

Brief Description of the Drawings

 The following drawing figures, which form a part of this application, are illustrative of described technology and are not meant to limit the scope of the claims in any manner, which scope shall be based on the claims appended hereto.

30 FIG. 1 is a diagram illustrating an embodiment of an exemplary ventilator connected to a human patient.

FIG. 2 is a block-diagram illustrating an embodiment of a ventilatory system for monitoring and evaluating ventilatory parameters associated with fluctuations in resistance.

FIG. 3 is a flow chart illustrating an embodiment of a method for issuing a
5 prompt upon detecting an increase or a decrease in resistance.

FIG. 4 is a flow chart illustrating an embodiment of a method for issuing a prompt upon determining one or more potential causes for an increase or a decrease in resistance.

FIG. 5 is a flow chart illustrating an embodiment of a method for issuing a
10 prompt upon determining one or more recommendations for mitigating an increase or a decrease in resistance.

FIG. 6 is an illustration of an embodiment of a graphical user interface displaying a prompt comprising an increased resistance notification and a recommendation for mitigating the increased resistance.

FIG. 7 is an illustration of an embodiment of a graphical user interface displaying a prompt comprising an increased resistance notification and an expanded prompt comprising one or more recommendations for mitigating the increase in resistance during ventilation of a patient.

FIG. 8 is an illustration of an embodiment of a graphical user interface displaying
20 a prompt comprising an increased resistance notification and a potential cause notification and an expanded prompt comprising one or more recommendations for mitigating the increased resistance during ventilation of a patient.

Detailed Description

Although the techniques introduced above and discussed in detail below may be
25 implemented for a variety of medical devices, the present disclosure will discuss the implementation of these techniques for use in a mechanical ventilator system. The reader will understand that the technology described in the context of a ventilator system could be adapted for use with other therapeutic equipment for alerting and advising clinicians regarding change in patient condition.

30 According to embodiments, the ventilator may be configured to collect ventilatory data by monitoring and evaluating diverse ventilatory parameters and/or patient physiological data. Based on the ventilatory data, the ventilator may issue

suitable notifications and recommendations to the clinician upon detecting a fluctuation in resistance. That is, the ventilator may detect an increase or a decrease in resistance based on, *inter alia*, ventilatory data (e.g., flow, volume, pressure, compliance, ventilator setup data, etc.), patient data (e.g., a patient body weight, a patient diagnosis, a patient gender, a patient age, etc.) and/or any suitable protocol, equation, etc. The ventilator may also detect an increase or a decrease in resistance at a particular location within the ventilatory system, e.g., expiratory limb, patient airway, etc. Furthermore, the ventilator may detect one or more projected causes of the increase or the decrease in resistance (e.g., clogged expiratory filter, leak in the ventilatory circuit, condensate accumulation in the ventilatory circuit, mucous plugging of the patient airway, etc.) based on whether an increase or decrease in resistance was detected, a location of the increase or decrease, patient data, etc. Based on the one or more projected causes of the fluctuation, the ventilator may be configured to provide a notification and/or one or more recommendations for mitigating the detected fluctuation in resistance.

These and other embodiments will be discussed in further detail with reference to the following figures.

Ventilator System

FIG. 1 is a diagram illustrating an embodiment of an exemplary ventilator connected to a human patient.

FIG. 1 illustrates ventilator **100** connected to a human patient **150**. Ventilator **100** includes a pneumatic system **102** (also referred to as a pressure generating system **102**) for circulating breathing gases to and from patient **150** via the ventilation tubing system **130**, which couples the patient to the pneumatic system via an invasive (e.g., endotracheal tube, as shown) or a non-invasive (e.g., nasal mask) patient interface.

Ventilation tubing system **130** may be a two-limb (shown) or a one-limb circuit for carrying gases to and from the patient **150**. In a two-limb embodiment, a fitting, typically referred to as a “wye-fitting” **170**, may be provided to couple a patient interface **180** (as shown, an endotracheal tube) to an inspiratory limb **132** and an expiratory limb **134** of the ventilation tubing system **130**.

Pneumatic system **102** may be configured in a variety of ways. In the present example, system **102** includes an expiratory module **108** coupled with the expiratory limb **134** and an inspiratory module **104** coupled with the inspiratory limb **132**.

Compressor **106** or other source(s) of pressurized gases (e.g., air, oxygen, and/or helium) is coupled with inspiratory module **104** to provide a gas source for ventilatory support via inspiratory limb **132**.

The pneumatic system **102** may include a variety of other components, including
5 mixing modules, valves, sensors, tubing, accumulators, filters, etc. Controller **110** is operatively coupled with pneumatic system **102**, signal measurement and acquisition systems, and an operator interface **120** that may enable an operator to interact with the ventilator **100** (e.g., change ventilator settings, select operational modes, view monitored parameters, etc.). Controller **110** may include memory **112**, one or more processors **116**,
10 storage **114**, and/or other components of the type commonly found in command and control computing devices. In the depicted example, operator interface **120** includes a display **122** that may be touch-sensitive and/or voice-activated, enabling the display to serve both as an input and output device.

The memory **112** includes non-transitory, computer-readable storage media that
15 stores software that is executed by the processor **116** and which controls the operation of the ventilator **100**. In an embodiment, the memory **112** includes one or more solid-state storage devices such as flash memory chips. In an alternative embodiment, the memory **112** may be mass storage connected to one or more processors **116** through a mass storage controller (not shown) and a communications bus (not shown). Although the
20 description of computer-readable media contained herein refers to a solid-state storage, it should be appreciated by those skilled in the art that computer-readable storage media can be any available media that can be accessed by the one or more processors **116**. That is, computer-readable storage media includes non-transitory, volatile and non-volatile, removable and non-removable media implemented in any method or technology for
25 storage of information such as computer-readable instructions, data structures, program modules or other data. For example, computer-readable storage media includes RAM, ROM, EPROM, EEPROM, flash memory or other solid state memory technology, CD-ROM, DVD, or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to
30 store the desired information and which can be accessed by the computer.

Communication between components of the ventilatory system or between the ventilatory system and other therapeutic equipment and/or remote monitoring systems

may be conducted over a distributed network, as described further herein, via wired or wireless means. Further, the present methods may be configured as a presentation layer built over the TCP/IP protocol. TCP/IP stands for “Transmission Control Protocol/Internet Protocol” and provides a basic communication language for many local networks (such as intra- or extranets) and is the primary communication language for the Internet. Specifically, TCP/IP is a bi-layer protocol that allows for the transmission of data over a network. The higher layer, or TCP layer, divides a message into smaller packets, which are reassembled by a receiving TCP layer into the original message. The lower layer, or IP layer, handles addressing and routing of packets so that they are properly received at a destination.

Ventilator Components

FIG. 2 is a block-diagram illustrating an embodiment of a ventilatory system for monitoring and evaluating ventilatory parameters associated with fluctuations in resistance.

Ventilatory system **200** includes ventilator **202** with its various modules and components. That is, ventilator **202** may further include, *inter alia*, memory **208**, one or more processors **206**, user interface **210**, and ventilation module **212** (which may further include an inspiration module **214** and an exhalation module **216**). According to embodiments, the exhalation module **216** may be associated with an expiratory filter for preventing mucous and other debris from passing into the ventilator. Memory **208** is defined as described above for memory **112**. Similarly, the one or more processors **206** are defined as described above for one or more processors **116**. Processors **206** may further be configured with a clock whereby elapsed time may be monitored by the system **200**.

The ventilatory system **200** may also include a display module **204** communicatively coupled to ventilator **202**. Display module **204** may provide various input screens, for receiving clinician input, and various display screens, for presenting useful information to the clinician. The display module **204** is configured to communicate with user interface **210** and may include a graphical user interface (GUI). The GUI may be an interactive display, e.g., a touch-sensitive screen or otherwise, and may provide various windows and elements for receiving input and interface command operations. Alternatively, other suitable means of communication with the ventilator

202 may be provided, for instance by a wheel, keyboard, mouse, or other suitable interactive device. Thus, user interface 210 may accept commands and input through display module 204. Display module 204 may also provide useful information in the form of various data regarding the physical condition of a patient and/or a prescribed
 5 respiratory treatment. The useful information may be based on data collected by monitor module 218 or data derived or otherwise processed by data processing module 220, and the useful information may be displayed to the clinician in the form of graphs, wave representations, pie graphs, or other suitable forms of graphic display. For example, one or more smart prompts may be displayed on the GUI of display module
 10 204 upon detection of a fluctuation in resistance by the ventilator. Additionally or alternatively, one or more smart prompts may be communicated to a remote monitoring system coupled via any suitable means to the ventilatory system 200.

Equation of Motion

Ventilation module 212 may oversee ventilation of a patient according to prescribed ventilatory settings. By way of general overview, the basic elements
 15 impacting ventilation may be described by the following ventilatory equation (also known as the Equation of Motion):

$$P_m + P_v = V_T/C + R \cdot F$$

20 Here, P_m is a measure of muscular effort that is equivalent to the pressure generated by the muscles of a patient. If the patient's muscles are inactive, the P_m is equivalent to 0 cm H₂O. During inspiration, P_v represents the positive pressure delivered by a ventilator (generally in cm H₂O). V_T represents the tidal volume delivered based on the
 25 pressure supplied, C refers to the compliance, R represents the resistance, and F represents the gas flow during inspiration (generally in liters per min (L/m)). Alternatively, during exhalation, the Equation of Motion may be represented as:

$$P_a + P_t = V_{TE}/C + R \cdot F$$

30 Here, P_a represents the positive pressure existing in the lungs (generally in cm H₂O), P_t represents the transairway pressure, V_{TE} represents the tidal volume exhaled, C refers to the compliance, R represents the resistance, and F represents the gas flow during exhalation (generally in liters per min (L/m)).

Pressure

For positive pressure ventilation, pressure at the upper airway opening (e.g., in the patient's mouth) is positive relative to the pressure at the body's surface (i.e., relative to the ambient atmospheric pressure to which the patient's body surface is exposed, about 0 cm H₂O). As such, when P_v is zero, i.e., no ventilatory pressure is being delivered, the upper airway opening pressure will be equal to the ambient pressure (i.e., about 0 cm H₂O). However, when inspiratory pressure is applied (i.e., positive pressure), a pressure gradient is created that allows gases to flow into the airway and ultimately into the lungs of a patient during inspiration (or, inhalation) until the pressure is equalized. When an inspiratory volume (or V_T) has been delivered to the lungs such that the inspiratory pressure is achieved and maintained, pressure is equalized and gases no longer flow into the lungs (i.e., zero flow).

Flow and Volume

Volume refers to the amount of gas delivered to a patient's lungs, usually in liters (L). Flow refers to a rate of change in volume over time ($F = \Delta V / \Delta t$). Flow is generally expressed in liters per minute (L/m or lpm) and, depending on whether gases are flowing into or out of the lungs, flow may be referred to as inspiratory flow or expiratory flow, respectively. According to embodiments, the ventilator may control the rate of delivery of gases to the patient, i.e., inspiratory flow, and may control the rate of release of gases from the patient, i.e., expiratory flow.

As may be appreciated, volume and flow are closely related. That is, where flow is known or regulated, volume may be derived based on elapsed time. Indeed, volume may be derived by integrating the flow waveform. According to embodiments, a tidal volume, V_T , may be delivered upon reaching a set inspiratory time (T_I) at set inspiratory flow. Alternatively, set V_T and set inspiratory flow may determine the amount of time required for inspiration, i.e., T_I .

Compliance

Additional ventilatory parameters that may be measured and/or derived may include compliance and resistance, which refer to the load against which the patient and/or the ventilator must work to deliver gases to the lungs. Generally, compliance refers to a relative ease with which something distends and is the inverse of elastance, which refers to the tendency of something to return to its original form after being

deformed. As related to ventilation, compliance refers to the lung volume achieved for a given amount of delivered pressure ($C = \Delta V / \Delta P$). Increased compliance may be detected when the ventilator measures an increased volume relative to the given amount of delivered pressure. Some lung diseases (e.g., acute respiratory distress syndrome (ARDS)) may decrease compliance and, thus, require increased pressure to inflate the lungs. Alternatively, other lung diseases may increase compliance, e.g., emphysema, and may require less pressure to inflate the lungs.

Resistance

Resistance refers to frictional forces that resist airflow, e.g., due to synthetic structures (e.g., endotracheal tube, expiratory valve, etc.), anatomical structures (e.g., bronchial tree, esophagus, etc.), or viscous tissues of the lungs and adjacent organs. Resistance is highly dependant on the diameter of the airway. That is, a larger airway diameter entails less resistance and a higher concomitant flow. Alternatively, a smaller airway diameter entails higher resistance and a lower concomitant flow. In fact, decreasing the diameter of the airway results in an exponential increase in resistance (e.g., two-times reduction of diameter increases resistance by sixteen times). As may be appreciated, resistance may also increase due to a restriction of the airway that is the result of, *inter alia*, increased secretions, bronchial edema, mucous plugs, brochospasm, and/or kinking of the patient interface (e.g., invasive endotracheal or tracheostomy tubes).

Airway resistance may further be represented mathematically as:

$$R = P_t / F$$

Where P_t refers to the transairway pressure and F refers to the flow. That is, P_t refers to the pressure necessary to overcome resistive forces of the airway. Resistance may be expressed in centimeters of water per liter per second (i.e., cm H₂O/L/s).

Pulmonary Time Constant

As discussed above, compliance refers to the lung volume achieved for a given amount of delivered pressure ($C = \Delta V / \Delta P$). That is, stated differently, volume delivered is equivalent to the compliance multiplied by the delivered pressure ($\Delta V = C * \Delta P$). However, as the lungs are not perfectly elastic, a period of time is needed to deliver the volume ΔV at pressure ΔP . A pulmonary time constant, τ , may represent a

time necessary to inflate or exhale a given percentage of the volume at delivered pressure ΔP . The pulmonary time constant, τ , may be calculated by multiplying the resistance by the compliance ($\tau = R \cdot C$) for a given patient and τ is generally represented in seconds, s. The pulmonary time constant associated with exhalation of the given
5 percentage of volume may be termed an expiratory time constant and the pulmonary time constant associated with inhalation of the given percentage of volume may be termed an inspiratory time constant.

According to some embodiments, when expiratory resistance data is available, the pulmonary time constant may be calculated by multiplying expiratory resistance by
10 compliance. According to alternative embodiments, the pulmonary time constant may be calculated based on inspiratory resistance and compliance. According to further embodiments, the expiratory time, T_E , should be equal to or greater than a predetermined number of pulmonary time constants (e.g., about three pulmonary time constants) to ensure adequate exhalation. The predetermined number of pulmonary time
15 constants may be selected via any suitable means, e.g., a standard protocol, an institutional protocol, clinician input, etc. According to embodiments, for a triggering patient, T_E (e.g., determined by trending T_E or otherwise) should be equal to or greater than the predetermined number of pulmonary time constants. For a non-triggering patient, set RR should yield a T_E that is equal to or greater than the predetermined
20 number of pulmonary time constants.

Normal Resistance and Compliance

According to embodiments, normal resistance and compliance may be determined based on a patient's predicted body weight (PBW) (or ideal body weight (IBW)). That is, according to a standardized protocol or otherwise, patient data may be
25 compiled such that normal resistance and compliance values and/or ranges of values may be determined and provided to the ventilatory system. As such, a manufacturer, clinical facility, clinician, or otherwise, may configure the ventilator with normal resistance and compliance values and/or ranges of values based on PBWs (or IBWs) of a patient population. Thereafter, during ventilation of a particular patient, resistance and
30 compliance data may be trended for the patient and compared to normal values and/or ranges of values based on the particular patient's PBW (or IBW). According to embodiments, the ventilator may give an indication to the clinician regarding whether

the trended resistance and compliance data of the particular patient falls into normal ranges. According to some embodiments, data may be more readily available for trending resistance and compliance for non-triggering patients than for triggering patients.

5 According to further embodiments, a predicted T_E may be determined based on a patient's PBW (or IBW). That is, according to a standardized protocol or otherwise, patient population data may be compiled such that predicted T_E values and/or ranges of values may be determined based on PBWs (or IBWs) of the patient population and provided to the ventilatory system. Actual (or trended) T_E for a particular patient may
10 then be compared to the predicted T_E . As noted previously, increased resistance and/or compliance may result in an actual T_E that is longer than predicted T_E . However, when actual T_E is consistent with predicted T_E , this may indicate that resistance and compliance for the particular patient fall into normal ranges.

 According to further embodiments, a normal pulmonary time constant, τ , may be
15 determined based on a patient's PBW (or IBW). That is, according to a standardized protocol or otherwise, patient data may be compiled such that normal τ values and/or ranges of values may be determined based on PBWs (or IBWs) of a patient population and provided to the ventilatory system. A calculated τ may be determined for a particular patient by multiplying resistance by compliance (as described above,
20 resistance and compliance data may be more readily available for a non-triggering patient). As the product of resistance and compliance results in τ , increased resistance and/or compliance may result in an elevated τ value. However, when the calculated τ value for the particular patient is consistent with the normal τ value, this may indicate that the resistance and compliance of the particular patient fall into normal ranges.

25 **Patient Data**

 According to embodiments, patient data may be received by the ventilator **202**. Patient data (including a patient diagnosis, a patient disability, a patient post-operative condition, a patient body weight, a patient gender, a patient age, etc.) may influence the ventilator's determination of the one or more causes for fluctuations in resistance.
30 Furthermore, patient data may influence the ventilator's determination of one or more appropriate recommendations for mitigating the fluctuation in resistance. As such, according to some embodiments, the ventilator may take into consideration patient data

when determining potential causes and/or recommendations for fluctuations in resistance.

Some patients may exhibit certain characteristics associated with various conditions and diseases, e.g., COPD, ARDS, post-operative condition (single lung, cardiac surgery), etc. For example, patients diagnosed with COPD may exhibit chronic elevated resistance due to constricted and/or collapsed airways, while ARDS patients may exhibit chronic elevated resistance due to an inflammatory condition of the airways. In some cases, patients diagnosed with various conditions and diseases associated with an obstructive component may exhibit elevated resistance over many months or years. According to some embodiments, patients having these conditions may also exhibit elevated compliance.

According to embodiments described herein, a clinician may input a patient diagnosis, e.g., COPD, ARDS, emphysema, etc. The ventilator may associate the patient diagnosis with certain lung and airway characteristics. For example, if the ventilator receives a patient diagnosis of COPD, the ventilator may associate this patient diagnosis with elevated resistance. The ventilator may further associate this patient diagnosis with an obstructive component. Alternatively, if the ventilator receives a patient diagnosis of emphysema, the ventilator may associate this patient diagnosis with elevated compliance. Alternatively still, a patient diagnosis of ARDS may be associated with increased resistance and/or decreased lung compliance.

Inspiration

Ventilation module 212 may further include an inspiration module 214 configured to deliver gases to the patient according to prescribed ventilatory settings. Specifically, inspiration module 214 may correspond to the inspiratory module 104 or may be otherwise coupled to source(s) of pressurized gases (e.g., air, oxygen, and/or helium), and may deliver gases to the patient. Inspiration module 214 may be configured to provide ventilation according to various ventilatory modes, e.g., via volume-targeted, pressure-targeted, or via any other suitable mode of ventilation.

According to embodiments, the inspiration module 214 may provide ventilation via a form of volume ventilation. Volume ventilation refers to various forms of volume-targeted ventilation that regulate volume delivery to the patient. Different modes of volume ventilation are available depending on the specific implementation of volume

regulation. For example, for volume-cycled ventilation, an end of inspiration is determined based on monitoring the volume delivered to the patient. According to embodiments, during volume ventilation, as volume and flow are regulated by the ventilator, delivered V_T , flow waveforms (or flow traces), and volume waveforms may be constant and may not be affected by variations in lung or airway characteristics (e.g., compliance and/or resistance). Alternatively, pressure readings may fluctuate based on lung or airway characteristics. According to some embodiments, the ventilator may control the inspiratory flow and then derive volume based on the inspiratory flow and elapsed time. For volume-cycled ventilation, when the derived volume is equal to the prescribed V_T , the ventilator may initiate exhalation.

According to alternative embodiments, the inspiration module 214 may provide ventilation via a form of pressure ventilation. Pressure-targeted modes of ventilation may be provided by regulating the pressure delivered to the patient in various ways. For example, during pressure-cycled ventilation, an end of inspiration is determined based on monitoring the pressure delivered to the patient. According to embodiments, during pressure ventilation, the ventilator may maintain the same pressure waveform at the mouth, P_{mv} , regardless of variations in lung or airway characteristics, e.g., compliance and/or resistance. However, the volume and flow waveforms may fluctuate based on lung and airway characteristics. Under pressure-cycled ventilation, upon delivering the inspiratory pressure the ventilator may initiate exhalation.

As noted above, pressure delivered to the upper airway creates a pressure gradient that enables gases to flow into a patient's lungs. The pressure from which a ventilator initiates inspiration is termed the end-expiratory pressure (EEP) or "baseline" pressure. This pressure may be atmospheric pressure (about 0 cm H₂O), also referred to as zero end-expiratory pressure (ZEEP). However, commonly, the baseline pressure may be positive, termed positive end-expiratory pressure (PEEP). Among other things, PEEP may promote higher oxygenation saturation and/or may prevent airway collapse during exhalation.

According to still other embodiments, a combination of volume and pressure ventilation may be delivered to a patient, e.g., volume-targeted-pressure-controlled (VC+) ventilation. In particular, VC+ ventilation may provide benefits of setting a

target V_T , while also allowing for monitoring variations in flow. As will be detailed further below, variations in flow may be indicative of various patient conditions.

Exhalation

Ventilation module **212** may further include an exhalation module **216**
5 configured to release gases from the patient's lungs according to prescribed ventilatory settings. Specifically, exhalation module **216** may correspond to expiratory module **108** or may otherwise be associated with and/or controlling an expiratory valve for releasing gases from the patient. By way of general overview, a ventilator may initiate exhalation based on lapse of an inspiratory time setting (T_I) or other cycling criteria set by the
10 clinician or derived from ventilator settings (e.g., detecting delivery of prescribed V_T or prescribed inspiratory pressure based on a reference trajectory). Upon initiating the expiratory phase, exhalation module **216** may allow the patient to exhale by opening an expiratory valve. As such, exhalation is passive, and the direction of airflow, as described above, is governed by the pressure gradient between the patient's lungs
15 (higher pressure) and the ambient surface pressure (lower pressure). Although expiratory flow is passive, it may be regulated by the ventilator based on the size of the expiratory valve opening. According to some embodiments, the expiratory valve may be associated with an expiratory filter. The expiratory filter may function to prevent mucous and other debris from passing into the ventilator. However, when the expiratory
20 filter is obstructed, e.g., due to excess debris, mucous, etc., expiratory flow may be hindered. According to embodiments, the expiratory filter may be disposable or otherwise replaceable for eliminating excess debris, mucous, etc., that may increase resistance.

For a spontaneously breathing patient, expiratory time (T_E) is the time from the
25 end of inspiration until the patient triggers a next inspiration. For a non-triggering patient, it is the time from the end of inspiration until the next mandatory inspiration based on the set RR. In some cases, however, the time required to return to the functional residual capacity (FRC) or resting capacity of the lungs is longer than provided by T_E (e.g., because the pulmonary time constant has increased due to increased
30 resistance, the expiratory filter is clogged hindering expiratory flow, etc.). According to embodiments, e.g., when the ventilator detects that resistance has increased as a result of changing lung conditions, various ventilatory settings may be adjusted to better match

the time to reach FRC with the time available to reach FRC. For example, decreasing set T_I to thereby increase the amount of time available to reach FRC. Alternatively, inspiratory pressure may be decreased (decreasing V_T), resulting in less time required to reach FRC. According to alternative embodiments, e.g., when the ventilator detects that
5 the expiratory filter is clogged or that the patient airway may be obstructed by mucous, adjusting ventilatory settings may not be warranted. Rather, the ventilator may recommend to that the clinician change the expiratory filter or suction the patient airway.

As may be appreciated, at the point of transition between inspiration and exhalation, the direction of airflow may abruptly change from flowing into the lungs to
10 flowing out of the lungs or vice versa depending on the transition. Stated another way, inspiratory flow may be measurable in the ventilatory circuit until P_{Peak} is reached, at which point flow approximates zero. Thereafter, upon initiation of exhalation, expiratory flow is measurable in the ventilatory circuit until the pressure gradient between the lungs and the body's surface reaches zero (again, resulting in zero flow).
15 However, in some cases, as will be described further herein, expiratory flow may still be positive, i.e., measurable, at the end of exhalation (termed positive end-expiratory flow or positive EEF). In this case, positive EEF is an indication that the pressure gradient has not reached zero or, similarly, that the patient has not completely exhaled. Thus, a positive EEF may indicate that the T_E is not long enough for complete exhalation.
20 According to some embodiments, when the ventilator detects that the T_E is not long enough for complete exhalation, the ventilator may determine that the pulmonary time constant has increased due to increased resistance.

Ventilator Sensory Devices

The ventilatory system **200** may also include one or more distributed and/or
25 internal sensors communicatively coupled to ventilator **202**. Distributed sensors may communicate with various components of ventilator **202**, e.g., ventilation module **212**, internal sensors, monitor module **218**, data processing module **220**, and any other suitable components and/or modules. Distributed sensors may be placed in any suitable location, e.g., within the ventilatory circuitry or other devices communicatively coupled
30 to the ventilator. For example, sensors may be affixed to the ventilatory tubing or may be imbedded in the tubing itself. According to some embodiments, sensors may be provided at or near the lungs (or diaphragm) for detecting a pressure in the lungs.

Additionally or alternatively, sensors may be affixed or imbedded in or near wye-fitting **170** and/or patient interface **180**, as described above.

Distributed sensors may further include pressure transducers that may detect changes in circuit pressure (e.g., electromechanical transducers including piezoelectric, variable capacitance, or strain gauge). Distributed sensors may further include various flow sensors for detecting airflow. For example, some flow sensors may use obstructions to create a pressure decrease corresponding to the flow across the device (e.g., differential pressure pneumotachometers) and other flow sensors may use turbines such that flow may be determined based on the rate of turbine rotation (e.g., turbine flow sensors). Alternatively, sensors may utilize optical or ultrasound techniques for measuring changes in ventilatory parameters. A patient's blood parameters or concentrations of expired gases may also be monitored by sensors to detect physiological changes that may be used as indicators to study physiological effects of ventilation, wherein the results of such studies may be used for diagnostic or therapeutic purposes. Indeed, any distributed sensory device useful for monitoring changes in measurable parameters during ventilatory treatment may be employed in accordance with embodiments described herein.

Ventilator **202** may further include one or more internal sensors. Similar to distributed sensors, internal sensors may communicate with various components of ventilator **202**, e.g., ventilation module **212**, distributed sensors, monitor module **218**, data processing module **220**, and any other suitable components and/or modules. Internal sensors may employ any suitable sensory or derivative technique for monitoring one or more parameters associated with the ventilation of a patient. However, the one or more internal sensors may be placed in any suitable internal location, such as, within the ventilatory circuitry or within components or modules of ventilator **202**. For example, sensors may be coupled to the inspiratory and/or expiratory modules for detecting changes in, for example, circuit pressure and/or flow. Specifically, internal sensors may include pressure transducers and flow sensors for measuring changes in circuit pressure and airflow. Additionally or alternatively, internal sensors may utilize optical or ultrasound techniques for measuring changes in ventilatory parameters. For example, a patient's expired gases may be monitored by internal sensors to detect physiological changes indicative of the patient's condition and/or treatment, for example. Indeed,

internal sensors may employ any suitable mechanism for monitoring parameters of interest in accordance with embodiments described herein.

As should be appreciated, with reference to the Equation of Motion, ventilatory parameters are highly interrelated and, according to embodiments, may be either directly or indirectly monitored. For example, the distributed and internal sensors may provide raw data to the monitor module **218**. The raw data may further be provided to the data processing module **220** for processing and/or deriving ventilatory data. That is, parameters may be directly monitored by one or more sensors, as described above, or may be indirectly monitored by derivation according to the Equation of Motion or other equation, algorithm, etc.

Ventilatory Data

Ventilator **202** may further include a data processing module **220**. As noted above, distributed sensors and internal sensors may collect data regarding various ventilatory parameters. A ventilatory parameter refers to any factor, characteristic, or measurement associated with the ventilation of a patient, whether monitored by the ventilator or by any other device. Sensors may further transmit collected data to the monitor module **218** and/or the data processing module **220**. According to embodiments, the data processing module may **220** be configured to collect data regarding some ventilatory parameters, to derive data regarding other ventilatory parameters, and/or to transform the collected and/or derived ventilatory data into graphical data for display to the clinician and/or other modules of the ventilatory system. According to embodiments, the collected, derived, and/or graphically transformed data may be defined as ventilatory data. For example, data regarding end-expiratory flow (EEF), data regarding alveolar pressure P_a (e.g., via a breath-hold maneuver), P_{Peak} data, P_{Plat} data, volume data, flow trace data, EEP data, etc., may be collected, derived, and/or graphically represented by data processing module **220**. Thereafter, the ventilatory data may be utilized by the ventilator to detect a fluctuation, either an increase or a decrease, in resistance. Furthermore, the ventilatory data may be utilized by the ventilator to determine one or more potential causes for the fluctuation in resistance.

Furthermore, according to embodiments, ventilatory data may also include ventilator setup data. For example, ventilator setup data may include data regarding whether the ventilator is configured to use a heated or non-heated humidifier or a heat

and moisture exchanger (HME). Furthermore, ventilator setup data may include data regarding whether an inline nebulizer or closed suction catheter is being used for the patient. Indeed, ventilator setup data may include any data regarding the configuration of the ventilator, ventilator circuitry, patient interface, etc., that may be useful for
5 characterizing a detected fluctuation in resistance to determine one or more potential causes for the fluctuation in resistance. For example, ventilator setup data may be useful in determining whether condensate is likely to accumulate in the patient circuit, etc.

Upon detecting a fluctuation in resistance and one or more potential causes for the fluctuation, the ventilator may determine one or more recommendations for
10 mitigating the fluctuation in resistance based on, *inter alia*, ventilatory data, prescribed ventilatory settings, patient data, and/or any other suitable protocol, formula, equation, etc.

Flow Data

For example, according to embodiments, data processing module **220** may be
15 configured to monitor inspiratory and expiratory flow. Flow may be measured by any appropriate, internal or distributed device or sensor within the ventilatory system. As described above, flow sensors may be employed by the ventilatory system to detect circuit flow. However, any suitable device either known or developed in the future may be used for detecting airflow in the ventilatory circuit. Data processing module **220** may
20 be further configured to plot monitored flow data graphically via any suitable means. For example, according to embodiments, flow data may be plotted versus time (flow waveform), versus volume (flow-volume loop), or versus any other suitable parameter as may be useful to a clinician.

As may be appreciated, flow decreases as resistance increases, making it more
25 difficult to pass gases into and out of the lungs (i.e., $F = P_t / R$). For example, when a patient is intubated, i.e., having either an endotracheal or a tracheostomy tube in place, resistance may be increased as a result of the smaller diameter of the tube over a patient's natural airway. In addition, increased resistance may be observed in patients with obstructive disorders, such as COPD, asthma, etc. Higher resistance may
30 necessitate, *inter alia*, a higher inspiratory time setting (T_I) for delivering a prescribed pressure or volume of gases, a higher flow setting for delivering prescribed pressure or volume, a lower respiratory rate resulting in a higher expiratory time (T_E) for complete

exhalation of gases, etc. According to embodiments, an evaluation of a flow trace and/or an evaluation of end-expiratory flow (EEF) may be used to detect an increase in resistance, as described further herein.

Pressure Data

5 According to embodiments, data processing module 220 may be configured to monitor pressure. Pressure may be measured by any appropriate, internal or distributed device or sensor within the ventilatory system. For example, pressure may be monitored by proximal electromechanical transducers connected near the airway opening (e.g., on the inspiratory limb, expiratory limb, at the patient interface, etc.). Alternatively,
10 pressure may be monitored distally, at or near the lungs and/or diaphragm of the patient. As may be appreciated, an increase in transairway pressure may be indicative of an increase in resistance, while a decrease in transairway pressure may be indicative of an decrease in resistance (i.e., $R = P_t/F$)

 Data processing module 220 may be further configured to graphically plot
15 monitored pressure data via any suitable means. For example, according to embodiments, pressure data may be plotted versus time (pressure waveform), versus volume (pressure-volume loop or PV loop), or versus any other suitable parameter as may be useful to a clinician. According to embodiments, PV loops may provide useful clinical and diagnostic information to clinicians regarding the resistance or compliance
20 of a patient. Specifically, upon comparing PV loops from successive breaths, an increase in resistance may be detected when successive PV loops shorten and widen over time. That is, at constant pressure, less volume is delivered to the lungs when resistance is increasing, resulting in a shorter, wider PV loop. According to alternative embodiments, a PV loop may provide a visual representation, in the area between the
25 inspiratory plot of pressure vs. volume and the expiratory plot of pressure vs. volume, which is indicative of compliance. Further, PV loops may be compared to one another to determine whether compliance has changed. Additionally or alternatively, optimal compliance may be determined. That is, optimal compliance may correspond to the dynamic compliance determined from a PV loop during a recruitment maneuver, for
30 example.

Volume Data

According to embodiments, data processing module **220** may be configured to derive volume via any suitable means. For example, as described above, during volume ventilation, a prescribed V_T may be set for delivery to the patient. The actual volume delivered may be derived by monitoring the inspiratory flow over time (i.e., $V = F \cdot T$).
5 Stated differently, integration of flow over time will yield volume. According to embodiments, V_T is completely delivered upon reaching T_I . Similarly, the expiratory flow may be monitored such that expired tidal volume (V_{TE}) may be derived. That is, under ordinary conditions, upon reaching the T_E , the prescribed V_T delivered should be completely exhaled and FRC should be reached. However, under some conditions T_E is
10 inadequate for complete exhalation and FRC is not reached. Data processing module **220** may be further configured to graphically plot derived volume data via any suitable means. For example, according to embodiments, volume data may be plotted versus time (volume waveform), versus flow (flow-volume loop or FV loop), or versus any other suitable parameter as may be useful to a clinician.

15 **Resistance Fluctuation Detection**

Ventilator **202** may further include resistance detection module **222**. According to embodiments, resistance detection module **222** may evaluate, *inter alia*, the ventilatory data to detect a fluctuation in resistance. For example, based on PBW and/or other patient data, the resistance detection module **222** may identify a maximum
20 resistance threshold and a minimum resistance threshold (e.g., based on clinician input, a standardized protocol, institutional protocol, etc.). According to embodiments, the maximum and minimum resistance thresholds may define a range about a particular patient's measured and/or derived resistance. That is, for a patient exhibiting elevated resistance (e.g., a patient diagnosed with ARDS or COPD), the maximum and minimum
25 resistance thresholds may be higher than for a patient exhibiting normal resistance.

The resistance detection module **222** may further trend resistance values for the patient via any suitable means. "Trending," as used herein, means collecting and/or deriving data over a plurality of breaths (or at predetermined intervals of time). For example, according to embodiments, the resistance detection module **222** may trend
30 resistance by evaluating a plurality of successive PV loops. According to alternative embodiments, the resistance detection module **222** may trend resistance by trending flow data at a constant pressure (e.g., during successive maneuvers). In this case, where other

variables are known and/or constant, if flow decreases over time at constant pressure, resistance is increasing; whereas if flow is increasing over time at constant pressure, resistance is decreasing (i.e., $R = P_t / F$). According to alternative embodiments, a positive end expiratory flow may be indicative of increased resistance where expiratory time (T_E) is not sufficient to reach FRC. According to still other embodiments, resistance may be trended via any suitable means.

The trended resistance may be compared to the identified maximum and minimum threshold values to detect a fluctuation in resistance. When the trended resistance data breaches the maximum threshold value, the resistance detection module **222** may detect an increase in resistance. When the trended resistance data breaches the minimum threshold value, the resistance detection module **222** may detect a decrease in resistance.

Upon detection of a fluctuation in resistance, a potential cause determination module **224** may identify one or more potential causes for the fluctuation in resistance. For example, the potential cause determination module **224** may identify whether the fluctuation in resistance is an increase or a decrease. Furthermore, the potential cause determination module **224** may identify a location of the fluctuation in resistance. According to embodiments, the ventilator may be configured with one or more potential causes associated with an increase in resistance and with one or more potential causes associated with a decrease in resistance. Furthermore, the ventilator may be configured with one or more potential causes associated with a location of the fluctuation in resistance. For example, based on a protocol, standard, or otherwise, the ventilator may be configured to associate an increase in resistance with one or more of the following potential causes, among others: obstructed expiratory filter, obstructed ventilatory circuit (e.g., due to condensate accumulation, kinking, or otherwise), obstructed patient airway (e.g., due to mucus plugging), changing lung conditions (e.g., ARDS-related inflammatory response, asthma-related bronchial constriction, COPD-related airway constriction, bronchial edema, bronchospasm, infection and/or fluid, etc.), patient body position, poor internal placement of the ventilatory circuit, etc. For example, Indeed, the ventilator may be configured with any suitable number of potential causes associated with an increase in resistance. Furthermore, based on a protocol, standard, or otherwise, the ventilator may be configured to associate a decrease in resistance with one or more

of the following potential causes: a leak in the ventilatory circuit, changing lung conditions (e.g., bronchial relaxation after medication, reduced infection and/or fluid, etc.), improved body position, etc. As above, the ventilator may be similarly configured with any suitable number of potential causes associated with a decrease in resistance.

5 According to embodiments, upon a determination that the fluctuation in resistance is an increase or a decrease and identification of one or more potential causes for the increase or decrease in resistance, a likelihood determination module **226** may be configured to determine a relative likelihood for each of the one or more identified potential causes. For example, likelihood determination module **226** may determine a
10 relative likelihood for each of the one or more identified potential causes based on ventilatory data, patient data, sensory data, algorithms or other probability computations, etc. The likelihood determination module **226** may further rank or otherwise organize the one or more identified potential causes according to their relative likelihoods. For example, according to embodiments, the likelihood determination module **226** may be
15 configured to determine a relative likelihood of one or more identified potential causes based on a location of the fluctuation in resistance. For example, when increased resistance was detected in the expiratory limb, it may be more likely that condensate accumulation in the ventilatory circuit or a clogged expiratory filter may be potential causes. Furthermore, according to embodiments, the likelihood determination module
20 **226** may be configured to determine a relative likelihood that the expiratory filter is obstructed based on one or more of the following (among others): data from a sensory device at or near the expiratory valve, an evaluation of when the expiratory filter was last replaced, an evaluation of expiratory flow, etc. That is, according to embodiments, the ventilator may detect increased resistance in the expiratory limb of the ventilatory
25 circuit indicative of a clogged expiratory filter.

 According to embodiments, the ventilator may be further configured to determine a relative likelihood that the patient circuit is occluded. For example, an abrupt increase in resistance may be indicative of a ventilatory circuit that is kinked or otherwise temporarily occluded. In contrast, a gradual increase in resistance may be
30 indicative of mucous plugging (among other causes). For example, the ventilator may detect mucous plugging in the patient's airway via one or more distributed sensory devices, a length of time since the patient airway was last suctioned, increased resistance

to delivered flow to the patient, etc. According to other embodiments, the ventilator may be configured to determine a relative likelihood that decreased resistance is due to a leak in the ventilatory circuit. For instance, ventilator may evaluate one or more of the following (among others): whether delivered volume is less than the expired volume,
5 data collected by distributed sensors along the ventilatory circuit, trended flow data, etc.

According to some embodiments, the likelihood determination module 226 may further evaluate patient data and/or a patient diagnosis to determine whether certain changed lung conditions are likely responsible for a fluctuation in resistance. For example, if patient data indicates that the patient is asthmatic, the ventilator may
10 determine a higher relative likelihood that bronchial constriction is a potential cause for an increase in resistance. In contrast, if the patient has been diagnosed with ARDS, the ventilator may determine a higher relative likelihood that an increase in inflammation of the airways is a potential cause for the increase in resistance. Alternatively, if the patient was diagnosed with pneumonia, the ventilator may determine a higher relative
15 likelihood that a reduction in infection and/or fluid in the patient's lungs is a potential cause for a decrease in resistance (or that an increase in infection and/or fluid in the lungs is a potential cause for an increase in resistance). Indeed, each identified potential cause may be associated with a relative likelihood based on any available ventilatory data, sensory data, patient data, etc., retrieved by the ventilator. According to
20 embodiments, the ventilator may determine that more than one potential cause may have a same or similar relative likelihood for causing an increase or a decrease in resistance.

According to some embodiments, the ventilator may display each of the one or more identified potential causes to the clinician. According to other embodiments, the ventilator may only display a subset of the one or more identified potential causes, e.g.,
25 only potential causes having higher relative likelihoods. The ventilator may be configured to determine and display the subset of identified potential causes via any suitable means. For example, the ventilator may be configured to display a predetermined number of the most likely potential causes, e.g., the three most likely potential causes. In this case, the ventilator will display the three most likely potential
30 causes of three identified potential causes, of five identified potential causes, or of ten identified potential causes. As may be appreciated, any number of the most likely potential causes may be pre-configured, selected, or otherwise designated for display.

According to alternative embodiments, the ventilator may be configured to display a most likely percentage of identified potential causes. For example, the ventilator may be configured to display the most likely 40% of potential causes. In this case, the most likely 4 of 10 identified potential causes, the most likely 2 of 5 identified potential causes, etc. (here, the ventilator may be further configured to round up or down to the nearest whole number of potential causes for display). According to still other embodiments, each potential cause may be designated with a likelihood probability upon evaluation of ventilatory data, patient data, statistical analyses, etc. (e.g., a likelihood probability between 1 and 100) and the ventilator may be configured to display only those potential causes with a likelihood probability greater than some number (e.g., a likelihood probability of 50 or more). Indeed, any suitable method for ranking, organizing, or otherwise identifying and displaying one or more likely potential causes for an increase or a decrease in resistance may be employed within the spirit of the present disclosure.

15 **Prompt Generation**

Ventilator **202** may further include a prompt module **228**. The prompt module **228** may provide a prompt notifying a clinician of a detected increase or decrease in resistance. According to some embodiments, the prompt may be provided in a hierarchical format such that an initial prompt is displayed that provides a notification to the clinician that an increase or a decrease in resistance has been detected. The initial prompt may further provide an indication of the one or more identified potential causes for the increase or decrease in resistance. Alternatively, the initial prompt may only display a subset of the identified potential causes, i.e., the most likely potential causes. According to other embodiments, the initial prompt may only display a notification that an increase or a decrease in resistance has been detected and the one or more potential causes may be displayed on an expanded prompt.

According to embodiments, the prompt module **228** may provide the initial prompt as a tab, banner, dialog box, or other suitable type of display. The initial prompt may be provided along a border of the graphical user interface, near an alarm display or bar, or in any other suitable location. A shape and size of the initial prompt may further be optimized for easy viewing with minimal interference to other ventilatory displays. The initial prompt may be further configured with a combination of icons and text such

that the clinician may readily identify whether resistance has increased or decreased and, optionally, one or more potential causes for the increase or decrease in resistance.

According to some embodiments, the initial prompt may display only one or more potential causes having a higher relative likelihood for causing the increase or decrease
5 in resistance.

According to further embodiments, the prompt module **228** may provide an expanded prompt via any suitable means. For example, the expanded prompt may be selectably activated via any suitable means and may display the one or more identified potential causes and/or one or more recommendations for mitigating the increase or
10 decrease in resistance. The expanded prompt may further be provided adjacent to the prompt (i.e., initial prompt) along a border of the graphical user interface, near an alarm display or bar, or in any other suitable location. The shape and size of the expanded prompt may further be optimized for easy viewing with minimal interference to other ventilatory displays.

Prompt module **228** may also provide the initial prompt and/or expanded prompt as a partially transparent window or format. The transparency may allow for the initial prompt and/or expanded prompt to be displayed such that normal ventilator GUI and ventilatory data may be visualized behind the prompts. This feature may be particularly useful for displaying the expanded prompt. The initial prompt and/or expanded prompt
20 may further be displayed in areas of the user interface that are either blank or that cause minimal distraction from the ventilatory data and other graphical representations provided by the GUI. However, upon selective expansion of an initial prompt, data and graphs may be at least partially obscured. As a result, prompt module **228** may provide the expanded prompt such that it is partially transparent.

The prompt module **228** may further include a notification module **230**. The notification module **230** may identify a fluctuation in resistance via any suitable means. For example, the notification module **230** may be in communication with the resistance detection module **222**, the monitor module **218**, the data processing module **220**, and/or any other suitable module or sensory device to identify that a fluctuation in resistance
25 has been detected by the ventilator. Further, the notification module **230** may identify whether the fluctuation in resistance is an increase or a decrease and a location in the ventilatory system where the fluctuation in resistance was detected. According to

embodiments, the notification module **230** may further identify one or more potential causes for the increase or decrease in resistance. For example, the notification module **230** may be in communication with the potential cause determination module **224** or any other suitable module or sensory device. According to further embodiments, the notification module **230** may identify a relative likelihood of each of the one or more identified potential causes. For example, the notification module **230** may be in communication with the likelihood determination module **226** or any other suitable module or sensory device. According to embodiments, the notification module **230** may further provide an indication of the increase or decrease in resistance to the prompt module **228** for display on a prompt. According to additional embodiments, the notification module **230** may further provide an indication of the one or more potential causes for the increase or the decrease in resistance, or a subset thereof, to the prompt module **228** for display on a prompt.

The prompt module **228** may further include a recommendation module **232**. That is, according to embodiments, in addition to identifying one or more potential causes for an increase or a decrease in resistance, the ventilator may also determine one or more recommendations for mitigating the increase or decrease in resistance. For example, prompt module **228** may be configured to display the one or more recommendations on a prompt on user interface **204**, e.g., within a window of the GUI. According to additional embodiments, the prompt may be communicated to and/or displayed on a remote monitoring system communicatively coupled to ventilatory system **200**.

According to embodiments, the recommendation module **232** may retrieve one or more potential causes for the increase or decrease in resistance from the potential cause determination module **224** or, according to some embodiments, the recommendation module **232** may retrieve only one or more potential causes having a higher relative likelihood of causing the increase or decrease in resistance from the likelihood determination module **226**. As may be appreciated, the ventilator may be configured to associate some potential causes for an increase or a decrease in resistance with one or more appropriate recommendations for mitigating the increase or decrease in resistance. In contrast, for other potential causes, it may not be appropriate or necessary

to mitigate the increase or decrease in resistance (e.g., where a decrease in resistance is detected upon administration of medication for bronchial constriction).

According to embodiments, the recommendation module **232** may be configured to determine one or more appropriate recommendations for mitigating an increase or a decrease in resistance based on an evaluation of ventilatory data, patient data, sensory data, current ventilatory settings, and any suitable protocol, equation, etc. For example, the ventilator may evaluate each potential cause (or each of the more likely potential causes) in light of data known to the ventilator in order to determine one or more recommendations for mitigating the increase or decrease in resistance. That is, if the ventilator determines that it is relatively likely that a dirty expiratory filter caused an increase in resistance, the ventilator may determine that it is appropriate to recommend changing the expiratory filter. In contrast, if the ventilator determines that it is relatively likely that a kink or temporary occlusion of the ventilatory circuit caused an increase in resistance, the ventilator may determine that it is appropriate to recommend checking the ventilatory circuit for kinking. Alternatively, if the ventilator determines that it is relatively likely that bronchial constriction is a cause for an increase in resistance (e.g., for an asthmatic patient), the ventilator may determine that it is appropriate to recommend administration of medication to the patient (here, the ventilator may be further configured to evaluate the last time that medication was administered prior to determining the appropriate recommendation). In contrast, if the patient has been diagnosed with COPD, the ventilator may determine that it is appropriate to recommend increasing PEEP in order to promote bronchial patency.

As specified above, in some cases a recommendation may not be warranted. For example, if the ventilator determines that administration of medication is a likely cause of a decrease in resistance, the ventilator may not provide a recommendation but may merely notify the clinician of the decreased resistance. Similarly, if the ventilator senses a decrease in resistance following suctioning of the patient airway, the ventilator may merely notify the clinician of the decrease rather than offering a recommendation for mitigating the decrease in resistance. As may be appreciated, the one or more recommendations may be based on a variety of considerations, including whether the resistance increased or decreased, on potential causes for the increase or decrease in resistance, and on available ventilatory data, patient data, sensory data, and any suitable

protocol, equation, etc. Indeed, as should be appreciated, any number of appropriate recommendations may be determined based on each of a plurality of potential causes for the increase or decrease in resistance.

In order to accomplish the various aspects of the notification and/or recommendations display, the prompt module 228 may communicate with various other components and/or modules. For instance, prompt module 228 may be in communication with monitor module 218, data processing module 220, resistance detection module 224, potential cause determination module 224, likelihood determination module 226, notification module 230, recommendation module 232, and/or any other suitable module or component of the ventilatory system 200. That is, prompt module 228 may receive ventilatory data, sensory data, and information regarding any suitable protocol, equation, etc. Further, according to some embodiments, the prompt module 228 may have access to patient data, including a patient's diagnostic information (e.g., regarding whether the patient has ARDS, COPD, asthma, emphysema, or any other disease, disorder, or condition).

According to embodiments, upon viewing an initial prompt and/or expanded prompt in response to detection of an increase or decrease in resistance, the initial prompt and/or expanded prompt may be cleared from the graphical user interface.

Methods of Prompt Generation

FIG. 3 is a flow chart illustrating an embodiment of a method for issuing a prompt upon detecting an increase or a decrease in resistance.

As should be appreciated, the particular steps and methods described herein are not exclusive and, as will be understood by those skilled in the art, the particular ordering of steps as described herein is not intended to limit the method, e.g., steps may be performed in differing order, additional steps may be performed, and disclosed steps may be excluded without departing from the spirit of the present methods.

Method 300 begins with an initiate ventilation operation 302. Initiate ventilation operation 302 may further include various additional operations. For example, initiate ventilation operation 302 may include receiving one or more ventilatory settings associated with ventilation of a patient. As such, the ventilatory settings and/or input received may include, *inter alia*, an inspiratory pressure (or target inspiratory pressure), a tidal volume (V_T), a respiratory rate (RR), an I:E ratio, a % O_2 , etc. Additionally,

during ventilation, ventilatory settings may be adjusted and accepted. In addition, during initiate ventilation operation **302**, patient data may be received. Patient data may refer to any data particular to a patient, for example, a predicted or ideal body weight (PBW or IBW), a patient diagnosis, a patient age, a patient disability, a patient post-operative condition, etc. A patient diagnosis may include, *inter alia*, ARDS, COPD, emphysema, asthma, etc. Upon initiating ventilation, the ventilator may further monitor ventilatory parameters and collect and/or derive ventilatory data.

At retrieve operation **304**, the ventilator may retrieve ventilatory data, patient data, etc. The ventilatory data may include data collected while monitoring various ventilatory parameters, including volume, pressure, flow, etc. The ventilatory data may further include data that is calculated or otherwise derived from the collected data, e.g., via the Equation of Motion or otherwise. For example, resistance may be calculated or otherwise derived from collected data such as flow, pressure, or volume (e.g., $R = P_t / F$; $R = \tau \Delta P / \Delta V$; etc.) Furthermore, resistance may be derived at over a plurality of breaths or at predetermined intervals of time. The patient data may include, *inter alia*, any data particular to a patient as described above.

At identify operation **306**, the ventilator may identify a maximum resistance threshold and a minimum resistance threshold. For example, the maximum resistance threshold and a minimum resistance threshold may be based on PBW and/or other patient data (e.g., based on clinician input, a standardized protocol, institutional protocol, etc.). According to alternative embodiments, the maximum and minimum resistance thresholds may be defined for a particular patient. That is, based on an initial calculation of a particular patient's resistance, the maximum threshold may be set at a certain amount or percentage above the initial calculation and the minimum threshold may be set at a certain amount or percentage below the initial calculation. In this case, for a patient exhibiting elevated resistance (e.g., a patient diagnosed with ARDS or COPD), the maximum and minimum resistance thresholds may be higher than for a patient exhibiting normal resistance. According to alternative embodiments, the maximum and minimum resistance thresholds may be based at least in part on a patient diagnosis (e.g., based on clinician input, a standardized protocol, institutional protocol, etc.). In this case, as with the example above, the maximum and minimum resistance

thresholds may be higher for a patient diagnosed with COPD than for a patient exhibiting normal resistance.

At trend operation **308**, the ventilator may trend resistance. As described above, according to embodiments, the ventilator may trend resistance by evaluating a plurality of successive PV loops. As described above, an increase in resistance may be detected when successive PV loops shorten and widen over time. That is, at constant pressure, less volume is delivered to the lungs when resistance is increasing, resulting in a shorter, wider PV loop. According to alternative embodiments, the ventilator may trend resistance by trending flow data at a constant pressure (e.g., during successive maneuvers). In this case, where other variables are known and/or constant, if flow decreases over time at constant pressure, resistance is increasing; whereas if flow is increasing over time at constant pressure, resistance is decreasing (i.e., $R = P_f / F$). According to alternative embodiments, a positive end expiratory flow may be indicative of increased resistance where expiratory time (T_E) is not sufficient to reach FRC.

According to other embodiments, calculated values for resistance may be trended over a period of time or over a number of breaths. According to still other embodiments, resistance may be trended via any suitable means. According to alternative embodiments, the ventilator may trend resistance values associated with a location. For example, the ventilator may monitor and trend resistance at or near the expiratory valve, within the expiratory limb or the inspiratory limb of the ventilatory circuit, within the patient airway, etc. According to some embodiments, different maximum and minimum resistance thresholds may apply based on the monitored location.

At determination operation **310**, the ventilator may compare the trended resistance with the maximum threshold. If the trended resistance breaches the maximum threshold, the ventilator may detect an increase in resistance at detect operation **312**.

According to embodiments, the ventilator may further associate the increase in resistance with a location, e.g., patient airway, expiratory limb, etc.

At determination operation **314**, the ventilator may compare the trended resistance with the minimum threshold. If the trended resistance breaches the minimum threshold, the ventilator may detect a decrease in resistance at detect operation **316**. According to embodiments, the ventilator may further associate the decrease in resistance with a location, e.g., patient airway, expiratory limb, etc.

At issue prompt operation **318**, the ventilator may issue a prompt providing a notification that an increase or a decrease in resistance was detected by any suitable means. For example, the ventilator may generate an alert or other notification in text form. For example, the notification may provide: "Increased Resistance Detected" or
5 "Decreased Resistance Detected." According to alternative embodiments, the prompt may provide a notification via an abbreviated alert, an icon, or any other suitable method of notifying the clinician that an increase or a decrease in resistance was detected by the ventilator. As described above, the prompt may be displayed by any suitable means in any suitable location on the ventilator or a remote monitor. For example, the prompt
10 may be displayed as a tab, banner, dialog box, or other suitable type of display, along a border of the graphical user interface, near an alarm display or bar, or in any other suitable location. The prompt may further be displayed in areas of the user interface that are either blank or that cause minimal distraction from the ventilatory data and other graphical representations provided by the GUI. The prompt may be provided in a
15 transparent form, or otherwise, for minimizing distraction, and may be cleared upon clinician viewing.

FIG. 4 is a flow chart illustrating an embodiment of a method for issuing a prompt upon determining one or more potential causes for an increase or a decrease in resistance.

20 As should be appreciated, the particular steps and methods described herein are not exclusive and, as will be understood by those skilled in the art, the particular ordering of steps as described herein is not intended to limit the method, e.g., steps may be performed in differing order, additional steps may be performed, and disclosed steps may be excluded without departing from the spirit of the present methods.

25 Method **400** begins with detect fluctuation operation **402**, wherein the ventilator detects a fluctuation in resistance, either an increase or a decrease, as described above with reference to method **300**.

At determination operation **404**, the ventilator may determine whether the fluctuation in resistance is an increase, as described above with reference to method **300**.

30 Upon a determination that there was an increase in resistance, the method may proceed to retrieve operation **406**. At retrieve operation **406**, the ventilator may retrieve ventilatory data, patient data, and/or any other data, equation, protocol, standard, etc., as

described with reference to operation **304**. Furthermore, at identify operation **408**, the ventilator may identify one or more potential causes for the increase in resistance. As described above, the ventilator may be configured with one or more potential causes associated with an increase in resistance. For example, based on a protocol, standard, or otherwise, the ventilator may be configured to associate an increase in resistance with one or more of the following potential causes, among others: obstructed expiratory filter, obstructed ventilatory circuit (e.g., due to condensate accumulation, kinking, or otherwise), obstructed patient airway (e.g., due to mucous plugging), changing lung conditions (e.g., asthma-related bronchial constriction, COPD-related airway constriction, ARDS-related inflammatory response, bronchial edema, bronchospasm, infection and/or fluid, etc.), poor patient body position, improper internal placement of the ventilatory circuit, etc. Indeed, the ventilator may be configured with any suitable number of potential causes associated with an increase in resistance.

Upon a determination that there was not an increase in resistance, the method may proceed to detect operation **410**. At detect operation **410**, the ventilator may determine that a decrease in resistance was detected.

Upon a determination that there was a decrease in resistance, the method may proceed to retrieve operation **412**. At retrieve operation **412**, the ventilator may retrieve ventilatory data, patient data, and/or any other data, equation, protocol, standard, etc., as described with reference to operation **304**. Furthermore, at identify operation **414**, the ventilator may identify one or more potential causes for the decrease in resistance. As described above, the ventilator may be configured with one or more potential causes associated with a decrease in resistance. For example, based on a protocol, standard, or otherwise, the ventilator may be configured to associate a decrease in resistance with one or more of the following potential causes: a leak in the ventilatory circuit, changing lung conditions (e.g., bronchial relaxation after medication, reduced infection and/or fluid, etc.), improved body position, etc. As above, the ventilator may be similarly configured with any suitable number of potential causes associated with a decrease in resistance.

At optional determine operation **416** (identified by dashed lines), the ventilator may optionally determine a relative likelihood for each of the one or more identified potential causes for the increase or the decrease in resistance, e.g., based on ventilatory

data, patient data, sensory data, algorithms, statistical analyses, etc. For example, according to embodiments, the ventilator may be configured to determine a relative likelihood that the expiratory filter is obstructed based on one or more of the following (among others): data from a sensory device at or near the expiratory valve, an evaluation of when the expiratory filter was last replaced, an evaluation of expiratory flow, etc. According to some embodiments, the ventilator may detect an increase in expiratory limb resistance indicative of a clogged expiratory filter. The ventilator may be further configured to determine a relative likelihood that the ventilatory circuit is occluded. For example, an abrupt increase in resistance may be indicative of a ventilatory circuit that is kinked or otherwise temporarily occluded, and if so, the ventilator may be further configured to identify whether the inspiratory or expiratory limb is occluded. In contrast, a gradual increase in resistance may be indicative of mucous plugging in the patient airway or condensate accumulation in the ventilatory circuit. For example, the ventilator may detect mucous plugging in the patient airway via one or more distributed sensory devices, a length of time since the patient airway was last suctioned, increased resistance in the patient airway, etc. Alternatively, the ventilator may detect condensate accumulation in the ventilatory circuit via one or more distributed sensory devices, a length of time since the ventilatory circuit was drained of condensate, a type of humidifier utilized (e.g., heated or not), etc. As may be appreciated, the ventilator may be configured to determine a relative likelihood for each of the one or more potential causes for the increase or the decrease in resistance via any suitable means.

According to some embodiments, the ventilator may also evaluate patient data, including a patient diagnosis, to determine relative likelihoods for the one or more identified potential causes. For example, if the patient data indicates that the patient is asthmatic, the ventilator may determine a higher relative likelihood that bronchial constriction is a potential cause for an increase in resistance. In contrast, if the patient has been diagnosed with ARDS, the ventilator may determine a higher relative likelihood that an increase in inflammatory response is a potential cause for the increase in resistance. Alternatively, if the patient was diagnosed with pneumonia, the ventilator may determine a higher relative likelihood that a reduction in infection and/or fluid in the patient's lungs is a potential cause for a decrease in resistance (or that an increase in infection and/or fluid in the lungs is a potential cause for an increase in resistance).

Indeed, each identified potential cause may be associated with a relative likelihood based on the specific ventilatory data, sensory data, patient data, etc., retrieved by the ventilator. According to embodiments, the ventilator may determine that more than one potential cause may have a same or similar relative likelihood for causing an increase or
5 a decrease in resistance.

At optional determine operation **418** (identified by dashed lines), the ventilator may optionally rank or otherwise organize the one or more identified potential causes according to their relative likelihoods. For example, based on algorithms, statistical analyses, probability theorem, or otherwise, the ventilator may determine a probability
10 that each of the one or more identified potential causes led to the increase or the decrease in resistance. For instance, according to embodiments, each potential cause may be designated with a likelihood probability upon evaluation of ventilatory data, patient data, computations, etc. (e.g., a likelihood probability between 1 and 100). According to alternative embodiments, the ventilator may simply rank each of the one or
15 more identified potential causes according to their relative likelihoods, e.g., for 5 identified potential causes, the ventilator may rank each potential cause from 1, most likely, to 5, least likely. For potential causes that are determined to have a statistically equivalent likelihood, the ventilator may assign the same ranking. Indeed, the ventilator may be configured to rank or organize each of the identified potential causes for the
20 increase or the decrease in resistance via any suitable means.

At issue prompt operation **420**, the ventilator may issue a prompt displaying one or more potential causes for the increase or decrease in resistance via any suitable means. For example, the prompt may provide: "Increased Resistance Likely Due to Clogged Expiratory Filter," "Increased Resistance Likely Due to Bronchial
25 Constriction," or "Decreased Resistance Likely Due to Response to Bronchodilator Therapy," etc. According to embodiments, the prompt may display one or more of the identified potential causes but less than all of the identified potential causes for the increase or the decrease in resistance. For example, according to some embodiments, the ventilator may display only a most likely potential cause on the prompt. For
30 example, where the ventilator determines that an increase in resistance may be due to condensate accumulation in the ventilatory circuit or to a clogged expiratory filter, but where condensate accumulation is more likely, the prompt may display only: "Increase

Resistance Detected, Condensate Accumulation Likely.” According to alternative embodiments, the ventilator may be configured to display a predetermined number of the most likely potential causes, e.g., the three most likely potential causes. According to still alternative embodiments, the ventilator may be configured to display a most
5 likely percentage of identified potential causes, e.g., the most likely 40% of potential causes. According to still alternative embodiments, the ventilator may be configured to display only those potential causes with a likelihood probability greater than some number (e.g., a likelihood probability of 50 or more). Indeed, the ventilator may be configured to display the one or more potential causes for the increase or decrease in
10 resistance, or a subset thereof, according to any suitable method. According to at least some embodiments, the ventilator may determine one or more potential causes for the increase or decrease in resistance but may not display the one or more potential causes to the clinician.

As described above, the prompt may be displayed by any suitable means in any
15 suitable location on the ventilator or a remote monitor. For example, the prompt may be displayed as a tab, banner, dialog box, or other suitable type of display, along a border of the graphical user interface, near an alarm display or bar, or in any other suitable location. The prompt may further be displayed in areas of the user interface that are either blank or that cause minimal distraction from the ventilatory data and other
20 graphical representations provided by the GUI. The prompt may be provided in a transparent form, or otherwise, for minimizing distraction, and may be cleared upon clinician viewing.

According to some embodiments, the ventilator may display the one or more potential causes for the increase or decrease in resistance, or a subset thereof, on an
25 expanded prompt. For example, the ventilator may notify the clinician of an increase or a decrease in resistance on an initial prompt. The initial prompt may provide an icon or other selectable control such that upon clinician selection the one or more potential causes for the increase or decrease in resistance may be displayed on an expanded prompt. The expanded prompt may further be provided adjacent to the initial prompt
30 along a border of the graphical user interface, near an alarm display or bar, or in any other suitable location. The shape and size of the expanded prompt may further be optimized for easy viewing with minimal interference to other ventilatory displays. The

initial prompt and/or expanded prompt may be provided in a transparent form, or otherwise, for minimizing distraction, and may be cleared upon clinician viewing.

FIG. 5 is a flow chart illustrating an embodiment of a method for issuing a prompt upon determining one or more recommendations for mitigating an increase or a decrease in resistance.

As should be appreciated, the particular steps and methods described herein are not exclusive and, as will be understood by those skilled in the art, the particular ordering of steps as described herein is not intended to limit the method, e.g., steps may be performed in differing order, additional steps may be performed, and disclosed steps may be excluded without departing from the spirit of the present methods.

Method **500** begins with detect operation **502**, wherein the ventilator detects a fluctuation (either an increase or a decrease) in resistance, as described above with reference to method **300**.

At retrieve operation **504**, the ventilator may retrieve ventilatory data, patient data, and/or any other data, equation, protocol, standard, etc., as described with reference to operation **304**.

At identify operation **506**, the ventilator may identify one or more potential causes for the fluctuation in resistance, as described above with reference to method **400**.

At determine operation **508**, the ventilator may determine one or more recommendations for mitigating the fluctuation in resistance. According to embodiments, based on each of the one or more potential causes and the retrieved ventilatory data, patient data, etc., the ventilator may determine one or more appropriate recommendations. For example, if one of the identified potential causes for an increase in resistance is a clogged expiratory filter, the ventilator may determine an appropriate recommendation for mitigating the increased resistance includes checking and/or changing the expiratory filter. Alternatively, if one of the identified potential causes for an increase in resistance is improper patient position, the ventilator may determine an appropriate recommendation for mitigating the increased resistance includes repositioning the patient. Alternatively still, if one of the identified potential causes for an increase in resistance is bronchial constriction, the ventilator may evaluate available ventilatory data, patient data, etc., and may determine that the patient is diagnosed with

asthma and that an appropriate recommendation for mitigating the increased resistance includes suggesting administration of a bronchodilator. Alternatively still, if one of the identified potential causes for an increase in resistance is an inflammatory response, the ventilator may evaluate available ventilatory data, patient data, etc., and may determine
5 that the patient is diagnosed with ARDS and that an appropriate recommendation for mitigating the increased resistance includes suggesting bronchodilator therapy or suctioning the patient airway. Alternatively still, if one of the identified potential causes for a decrease in resistance is a leak in the ventilatory circuit, the ventilator may determine an appropriate recommendation for mitigating the decreased resistance
10 includes suggesting checking the ventilatory circuit. As should be appreciated, any number of appropriate recommendations for mitigating a fluctuation in resistance may be determined based on a particular potential cause of the fluctuation and available ventilatory data, patient data, etc. Furthermore, according to embodiments, one or more recommendations may be determined for each of the identified one or more potential
15 causes for a fluctuation in resistance.

At issue prompt operation **510**, the ventilator may issue a prompt displaying the one or more recommendations for mitigating the fluctuation in resistance via any suitable means. For example, the recommendation may provide: "Increased Resistance Detected, Check Expiratory Filter," "Increased Resistance Detected, Consider
20 Bronchodilator Therapy," "Increased Resistance Detected, Consider Suctioning Patient Airway," or "Decreased Resistance Detected, Suggest Checking Ventilatory Circuit for Leak," etc. As described above, the prompt may be displayed by any suitable means in any suitable location on the ventilator or a remote monitor. For example, the prompt may be displayed as a tab, banner, dialog box, or other suitable type of display, along a
25 border of the graphical user interface, near an alarm display or bar, or in any other suitable location. The prompt may further be displayed in areas of the user interface that are either blank or that cause minimal distraction from the ventilatory data and other graphical representations provided by the GUI. The prompt may be provided in a transparent form, or otherwise, for minimizing distraction, and may be cleared upon
30 clinician viewing.

According to some embodiments, the ventilator may display the one or more recommendations for mitigating the increase or decrease in resistance on an expanded

prompt. That is, according to embodiments, the ventilator may notify the clinician of an increase or a decrease in resistance on an initial prompt. For example, the notification may display: "Increased Resistance Detected" or "Decreased Resistance Detected." The initial prompt may provide an icon or other selectable control such that upon clinician
5 selection the one or more recommendations for mitigating the increase or decrease in resistance may be displayed on an expanded prompt. According to embodiments, the one or more recommendations for mitigating the increase or decrease in resistance may be displayed along with each of one or more potential causes (or a subset thereof) on the expanded prompt. According to alternative embodiments, only the one or more
10 recommendations for mitigating the increase or the decrease in resistance may be displayed on the expanded prompt. According to some embodiments, a recommendation associated with a more likely potential cause may be displayed as a primary recommendation and a recommendation associated with a less likely potential cause may be displayed as a secondary recommendation. For example, the initial
15 prompt may display "Increased Resistance Detected" or "Increased Resistance Detected, Condensate Accumulation Likely," and, upon selection of an expand icon or otherwise, the expanded prompt may display a primary recommendation of: "Consider Draining Condensate from Circuit" and a secondary recommendation of: "Consider Changing Expiratory Filter."

20 The expanded prompt may be provided adjacent to the initial prompt along a border of the graphical user interface, near an alarm display or bar, or in any other suitable location. The shape and size of the expanded prompt may further be optimized for easy viewing with minimal interference to other ventilatory displays. The initial prompt and/or expanded prompt may be provided in a transparent form, or otherwise,
25 for minimizing distraction, and may be cleared upon clinician viewing.

Ventilator GUI Display of Prompt

FIG. 6 is an illustration of an embodiment of a graphical user interface displaying a prompt comprising an increased resistance notification and a recommendation for mitigating the increased resistance.

30 Graphical user interface 600 may display various monitored and/or derived data to the clinician during ventilation of a patient. In addition, graphical user interface 600

may display various messages to the clinician (e.g., alarm messages, etc.). Specifically, graphical user interface **600** may display a prompt as described herein.

According to embodiments, the ventilator may monitor and evaluate various ventilatory parameters based on one or more predetermined thresholds to detect a fluctuation in resistance. In some cases, the ventilator may determine that the fluctuation in resistance is a decrease in resistance. In other cases, the ventilator may determine that the fluctuation in resistance is an increase in resistance. For example, a detection of positive end-expiratory flow (EEF) may be indicative of an increase in resistance. As illustrated, a flow waveform may be generated and displayed by the ventilator on graphical user interface **600**. As further illustrated, the flow waveform may be displayed such that inspiratory flow **602** is represented in a different color (e.g., green) than expiratory flow **604** (e.g., yellow). Although expiratory flow may preferably approximate zero at the end of expiration, in some instances EEF may not reach zero before inspiration begins, as illustrated by positive EEF **606**. According to embodiments, positive EEF may be identified by a positive EEF icon **608**, or other identifier, such that a clinician may readily identify positive EEF on the flow waveform. Additionally or alternatively, the flow waveform may be frozen for a period of time such that the clinician may be alerted as to the position in time of the incidence of positive EEF along the flow waveform. According to some embodiments, when positive EEF is detected, the ventilator may make a determination that resistance has increased by evaluating additional ventilatory data such as trended resistance, evaluation of PV loops, etc.

Upon a determination that resistance has increased, the graphical user interface **600** may display a prompt, e.g., prompt **610**.

According to embodiments, prompt **610** may be displayed in any suitable location such that a clinician may be alerted regarding the detected increase in resistance, but while allowing other ventilatory displays and data to be visualized substantially simultaneously. As illustrated, prompt **610** is presented as a bar or banner across an upper region of the graphical user interface **600**. However, as previously noted, prompt **610** may be displayed as a tab, icon, button, banner, bar, or any other suitable shape or form. Further, prompt **610** may be displayed in any suitable location within the graphical user interface **600**. For example, prompt **610** may be located along any border

region of the graphical user interface **600** (e.g., top, bottom, or side borders) (not shown), across an upper region (shown), or in any other suitable location. Further, as described herein, prompt **610** may be partially transparent (not shown) such that ventilatory displays and data may be at least partially visible behind prompt **610**.

5 Specifically, prompt **610** may alert the clinician that increased resistance has been detected, for example by notification message **612**. As described herein, notification message **612** may alert the clinician of an increase in resistance via any suitable means, e.g., “Increased Resistance Detected.” Prompt **610** may further include information regarding one or more potential causes for the increased resistance. For
10 example, if the ventilator determined that the increased resistance was likely caused by a clogged expiratory filter, this information may be provided to the clinician (e.g., “Increased Resistance Detected, Expiratory Filter Likely Clogged”) (not shown). Prompt **610** may further include information regarding one or more recommendations for mitigating the increased resistance. With reference to the above example, if the
15 ventilator determined that the increased resistance was likely caused by a clogged expiratory filter, the ventilator may provide a recommendation to the clinician (e.g., “Increased Resistance Detected, Check Expiratory Filter”) (shown). According to the illustrated embodiment, recommendation message **614** is provided along with the notification message **612** in a banner. According to alternative embodiments, the
20 notification message **612** alone may be provided on an initial prompt (not shown).

 As may be appreciated, the disclosed data, graphics, and smart prompt illustrated in graphical user interface **600** may be arranged in any suitable order or configuration such that information and alerts may be communicated to the clinician in an efficient and orderly manner. The disclosed data, graphics, and smart prompt are not to be
25 understood as an exclusive array, as any number of similar suitable elements may be displayed for the clinician within the spirit of the present disclosure. Further, the disclosed data, graphics, and smart prompt are not to be understood as a necessary array, as any number of the disclosed elements may be appropriately replaced by other suitable elements without departing from the spirit of the present disclosure. The illustrated
30 embodiment of the graphical user interface **600** is provided as an example only, including potentially useful information and alerts that may be provided to the clinician

to facilitate communication of the detected fluctuation in resistance in an orderly and informative way, as described herein.

FIG. 7 is an illustration of an embodiment of a graphical user interface displaying a prompt comprising an increased resistance notification and an expanded prompt comprising one or more recommendations for mitigating the increase in resistance during ventilation of a patient.

Graphical user interface **700** may display various monitored and/or derived data to the clinician during ventilation of a patient, as described with reference to graphical user interface **600**.

According to embodiments, the ventilator may monitor and evaluate various ventilatory parameters based on one or more predetermined thresholds to detect a fluctuation in resistance. In some cases, the ventilator may determine that the fluctuation in resistance is a decrease in resistance. In other cases, the ventilator may determine that the fluctuation in resistance is an increase in resistance. For example, a detection of positive end-expiratory flow (EEF) may be indicative of an increase in resistance. However, according to some embodiments, when positive EEF is detected, the ventilator may make a determination that resistance has increased by evaluating additional ventilatory data such as trended resistance, evaluation of PV loops, evaluation of ventilator setup data, etc. Upon a determination that resistance has increased, the graphical user interface **700** may display a prompt, e.g., prompt **702**.

According to embodiments, prompt **702** may be displayed in any suitable location such that a clinician may be alerted regarding the detected increase in resistance, but while allowing other ventilatory displays and data to be visualized substantially simultaneously, as described above with reference to prompt **610**.

Specifically, prompt **702** may alert the clinician that increased resistance has been detected, for example by a notification message (e.g., "Increased Resistance Detected").

According to embodiments, prompt **702** may be expanded to provide additional information and/or recommendations to the clinician regarding the detected fluctuation in resistance (e.g., increase in resistance). For example, an expand icon **704** may be provided within a suitable area of the prompt **702**. According to embodiments, upon selection of the expand icon **704** via any suitable means, the clinician may optionally

expand prompt **702** to acquire additional information and/or recommendations for mitigating the detected increase in resistance, e.g. expanded prompt **706**. As described above for prompt **610**, expanded prompt **706** may be displayed as a tab, icon, button, banner, bar, or any other suitable shape or form. Further, expanded prompt **706** may be displayed in any suitable location within the graphical user interface **700**. For example, expanded prompt **706** may be displayed below (shown) prompt **702**, to a side (not shown) of prompt **702**, or otherwise logically associated with prompt **702**. According to other embodiments, an initial prompt may be hidden (not shown) upon displaying expanded prompt **706**. Expanded prompt **706** may also be partially transparent (not shown) such that ventilatory displays and data may be at least partially visible behind expanded prompt **706**.

According to embodiments, expanded prompt **706** may comprise additional information (not shown) and/or one or more recommendation messages **708** regarding a detected fluctuation in resistance (e.g., an increase in resistance). For example, the one or more recommendation messages **708** may include one or more primary recommendation messages and one or more secondary recommendation messages. According to embodiments, the one or more primary recommendation messages may provide one or more suggestions for mitigating the increase in resistance based on more likely potential causes for the increase in resistance. The one or more secondary recommendation messages may provide one or more suggestions for mitigating the increase in resistance based on less likely potential causes for the increase in resistance. For example, if an increase in resistance was likely caused by inflammation of the airways and the patient was diagnosed with ARDS, a primary recommendation message may include: "Consider Bronchodilator Therapy." Additionally, according to embodiments, a secondary recommendation message may include: "Consider Suctioning Patient Airway."

According to embodiments, expanded prompt **706** may also include one or more hyperlinks **710**, which may provide immediate access to the display and/or settings screens associated with a detected fluctuation in resistance. For example, associated parameter settings screens may be accessed from expanded prompt **706** via hyperlink **710** such that the clinician may address the detected fluctuation in resistance by adjusting one or more parameter settings as necessary. Alternatively, associated parameter display

screens may be accessed such that the clinician may view clinical data associated with the detected fluctuation in resistance in the form of charts, graphs, or otherwise. That is, according to embodiments, the clinician may access the ventilatory data that implicated the detected fluctuation in resistance for verification purposes.

5 As may be appreciated, the disclosed data, graphics, and smart prompt illustrated in graphical user interface **700** may be arranged in any suitable order or configuration such that information and alerts may be communicated to the clinician in an efficient and orderly manner. The disclosed data, graphics, and smart prompt are not to be understood as an exclusive array, as any number of similar suitable elements may be
10 displayed for the clinician within the spirit of the present disclosure. Further, the disclosed data, graphics, and smart prompt are not to be understood as a necessary array, as any number of the disclosed elements may be appropriately replaced by other suitable elements without departing from the spirit of the present disclosure. The illustrated embodiment of the graphical user interface **700** is provided as an example only,
15 including potentially useful information and alerts that may be provided to the clinician to facilitate communication of the detected fluctuation in resistance in an orderly and informative way, as described herein.

FIG. 8 is an illustration of an embodiment of a graphical user interface displaying a prompt comprising an increased resistance notification and a potential
20 cause notification and an expanded prompt comprising one or more recommendations for mitigating the increased resistance during ventilation of a patient.

As described above with reference to FIG. 7, graphical user interface **800** may display various monitored and/or derived data to the clinician during ventilation of a patient. In addition, graphical user interface **800** may display a prompt **802** including a
25 notification message regarding a detected fluctuation in resistance, e.g., “Increased Resistance Detected” (shown) or “Decreased Resistance Detected” (not shown). According to some embodiments, one or more potential causes for the fluctuation in resistance may be displayed on prompt **802**, e.g., “Mucous Plugging Likely” (shown), “Bronchospasm Likely” (not shown), “Expiratory Filter Likely Clogged” (not shown),
30 etc. According to embodiments, only a most likely potential cause may be displayed on prompt **802**. According to alternative embodiments, one or more potential causes for a

fluctuation in resistance may be determined by the ventilator, but may not be displayed to the clinician.

According to embodiments, as described above, an expand icon **804** may be provided within a suitable area of prompt **802**. Upon selection of the expand icon **804**, the clinician may optionally expand prompt **802** to acquire additional information and/or recommendations for mitigating a fluctuation in resistance. For example, expanded prompt **806** may be provided upon selection of expand icon **804**. As described above for prompts **610** and **706**, expanded prompt **806** may be displayed in any suitable shape or form in any suitable location within the graphical user interface **800**.

According to embodiments, expanded prompt **806** may comprise additional information (not shown) and/or one or more recommendation messages **808** regarding a detected fluctuation in resistance (e.g., an increase in resistance). For example, the one or more recommendation messages **808** may include one or more primary recommendation messages and one or more secondary recommendation messages.

According to embodiments, the one or more primary recommendation messages may provide one or more suggestions for mitigating the increase in resistance based on more likely potential causes for the increase in resistance. For example, if the ventilator determined that mucous plugging is a likely cause for the increase in resistance, a primary recommendation message may provide: "Consider Suctioning Patient Airway" (shown). The one or more secondary recommendation messages may provide one or more suggestions for mitigating the increase in resistance based on less likely potential causes for the increase in resistance. For example, if the ventilator determined that a clogged expiratory filter is a less likely cause for the increase in resistance, a secondary recommendation message may provide: "Consider Changing Expiratory Filter" (shown).

As described above, according to embodiments, expanded prompt **806** may also include one or more hyperlinks **810**, which may provide immediate access to the display and/or settings screens associated with the detected fluctuation in resistance. For example, associated parameter settings screens may be accessed from expanded prompt **806** via hyperlink **810** such that the clinician may address the detected fluctuation in resistance by adjusting one or more parameter settings as necessary. Alternatively, associated parameter display screens may be accessed such that the clinician may view

clinical data associated with the detected fluctuation in resistance in the form of charts, graphs, or otherwise.

As may be appreciated, the disclosed prompt and recommendation messages illustrated in graphical user interface **800** may be arranged in any suitable order or configuration such that information and alerts may be communicated to the clinician in an efficient and orderly manner. Indeed, the illustrated embodiment of the graphical user interface **800** is provided as an example only, including potentially useful information and recommendations that may be provided to the clinician to facilitate communication of suggestions for mitigating the detected fluctuation in resistance in an orderly and informative way, as described herein.

It will be clear that the systems and methods described herein are well adapted to attain the ends and advantages mentioned as well as those inherent therein. Those skilled in the art will recognize that the methods and systems within this specification may be implemented in many manners and as such is not to be limited by the foregoing exemplified embodiments and examples. In other words, functional elements being performed by a single or multiple components, in various combinations of hardware and software, and individual functions can be distributed among software applications at either the client or server level. In this regard, any number of the features of the different embodiments described herein may be combined into one single embodiment and alternative embodiments having fewer than or more than all of the features herein described are possible.

While various embodiments have been described for purposes of this disclosure, various changes and modifications may be made which are well within the scope of the present disclosure. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the disclosure and as defined in the appended claims.

Claims

What is claimed is:

1. A ventilator-implemented method for issuing a prompt in response to
5 detecting a fluctuation in resistance during ventilation of a patient, the method comprising:
 - retrieving ventilatory data;
 - identifying a maximum threshold and a minimum threshold for resistance;
 - trending resistance during ventilation of the patient;
 - 10 detecting a fluctuation in resistance when the trended resistance breaches one of the maximum threshold and the minimum threshold; and
 - displaying a notification regarding detection of the fluctuation in resistance.
2. The method of claim 1, further comprising retrieving patient data,
15 wherein the patient data comprises at least one of: a patient diagnosis, a patient predicted body weight (PBW), and a patient gender.
3. The method of claim 1, further comprising:
 - determining one or more potential causes for the fluctuation in resistance based
20 at least in part on the retrieved ventilatory data.
4. The method of claim 2, further comprising:
 - determining one or more potential causes for the fluctuation in resistance based
at least in part on the retrieved patient data.
- 25 5. The method of claim 3, further comprising:
 - determining one or more recommendations for mitigating the fluctuation in resistance based on the determined one or more potential causes and at least some ventilatory data; and
 - 30 displaying the one or more recommendations.

6. The method of claim 4, further comprising:
determining one or more recommendations for mitigating the fluctuation in resistance based on the determined one or more potential causes and at least some patient data; and
5 displaying the one or more recommendations.

7. The method of claim 5, wherein displaying further comprises:
displaying an icon for accessing the one or more recommendations, wherein upon activating the icon the one or more recommendations are displayed.
10

8. The method of claim 5, further comprising:
displaying the notification regarding detection of the fluctuation in resistance on an expandable prompt; and
displaying an icon for expanding the prompt to display one or more of: the one
15 or more potential causes for the fluctuation in resistance and the one or more recommendations for mitigating the fluctuation in resistance.

9. A ventilatory system for issuing a prompt in response to detecting a fluctuation in resistance during ventilation of a patient, comprising:
20 at least one processor; and
at least one memory, communicatively coupled to the at least one processor and containing instructions that, when executed by the at least one processor, perform a method comprising:
retrieving ventilatory data;
25 identifying a maximum threshold and a minimum threshold for resistance;
trending resistance during ventilation of the patient;
detecting a fluctuation in resistance when the trended resistance breaches one of the maximum threshold and the minimum threshold; and
30 displaying a notification regarding detection of the fluctuation in resistance.

10. The ventilatory system of claim 9, further comprising:
determining one or more potential causes for the fluctuation in resistance based
at least in part on the retrieved ventilatory data.
- 5 11. The ventilatory system of claim 10, further comprising:
determining one or more recommendations for mitigating the fluctuation in
resistance based on the determined one or more potential causes and at least some
ventilatory data; and
displaying the one or more recommendations.
- 10 12. The ventilatory system of claim 10, displaying further comprises:
displaying an icon for accessing the one or more potential causes, wherein upon
activating the icon the one or more potential causes are displayed.
- 15 13. The ventilatory system of claim 11, wherein displaying further
comprises:
displaying an icon for accessing the one or more recommendations, wherein
upon activating the icon the one or more recommendations are displayed.
- 20 14. A graphical user interface for displaying one or more prompts in response
to detecting a fluctuation in resistance, the ventilator configured with a computer having
a user interface including the graphical user interface, the graphical user interface
comprising:
at least one window; and
25 one or more elements within the at least one window comprising at least one
prompt element for communicating information regarding detection of a fluctuation in
resistance, wherein the at least one prompt element displays a notification regarding the
fluctuation in resistance.
- 30 15. The graphical user interface of claim 14, wherein the at least one prompt
element displays one or more potential causes for the fluctuation in resistance.

16. The graphical user interface of claim 14, wherein the at least one prompt element displays one or more recommendations for mitigating the fluctuation in resistance.

5 17. The graphical user interface of claim 14, wherein the at least one prompt element is an expandable prompt element, the expandable prompt element further comprising:

a selectable icon, wherein upon selection the expandable prompt element displays one or more potential causes for the fluctuation in resistance.

10

18. The graphical user interface of claim 14, wherein the at least one prompt element is an expandable prompt element, the expandable prompt element further comprising:

15 a selectable icon, wherein upon selection the expandable prompt element displays one or more recommendations for mitigating the fluctuation in resistance.

19. A ventilator processing interface for displaying one or more prompts in response to detecting a fluctuation in resistance, comprising:

20 means for retrieving at least some ventilatory data;
means for determining the fluctuation in resistance; and
means for displaying a prompt comprising a notification of the fluctuation in resistance.

25 20. The ventilator processing interface of claim 19, wherein the prompt further comprises one or more recommendations for mitigating the fluctuation in resistance.

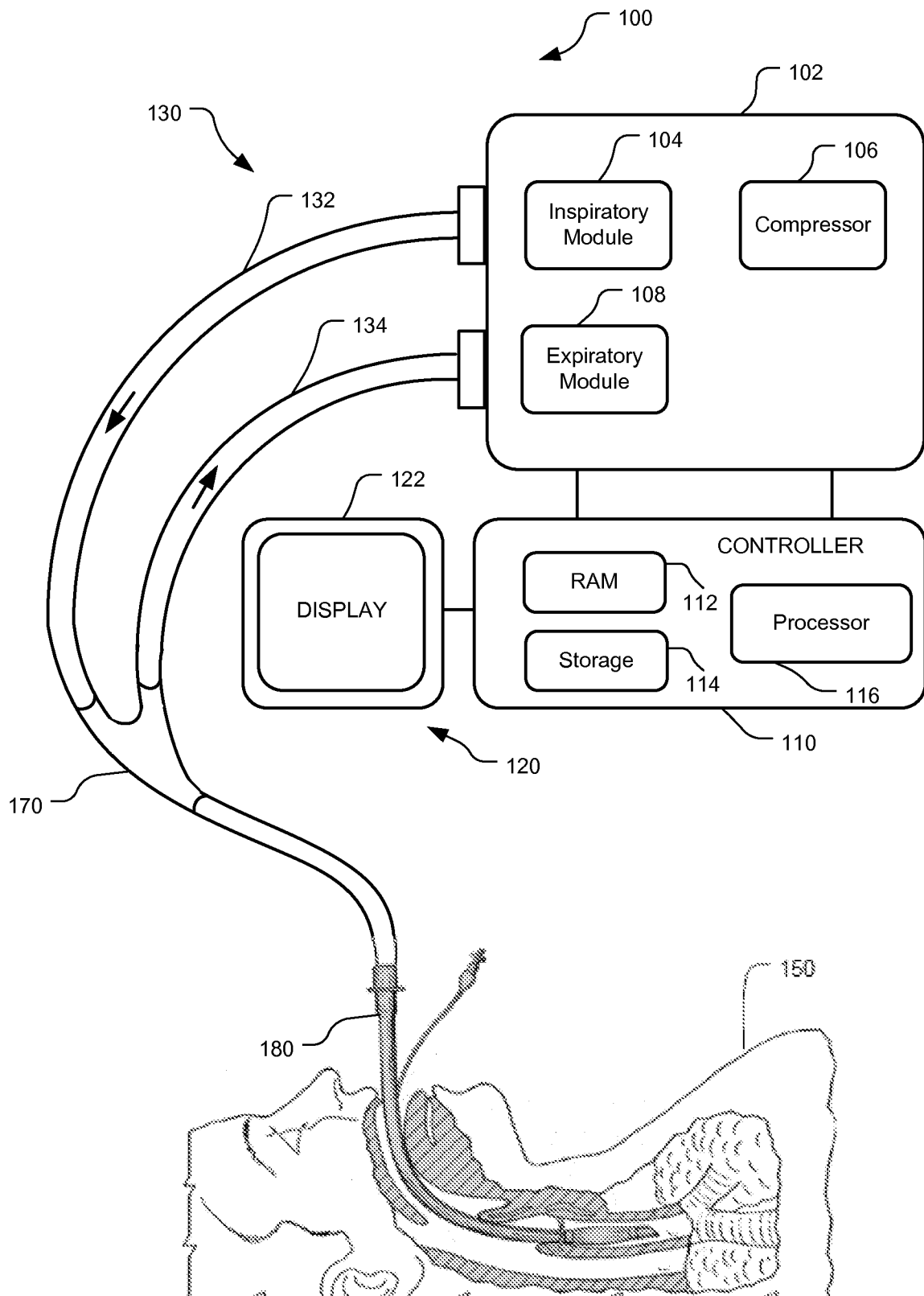


FIG. 1

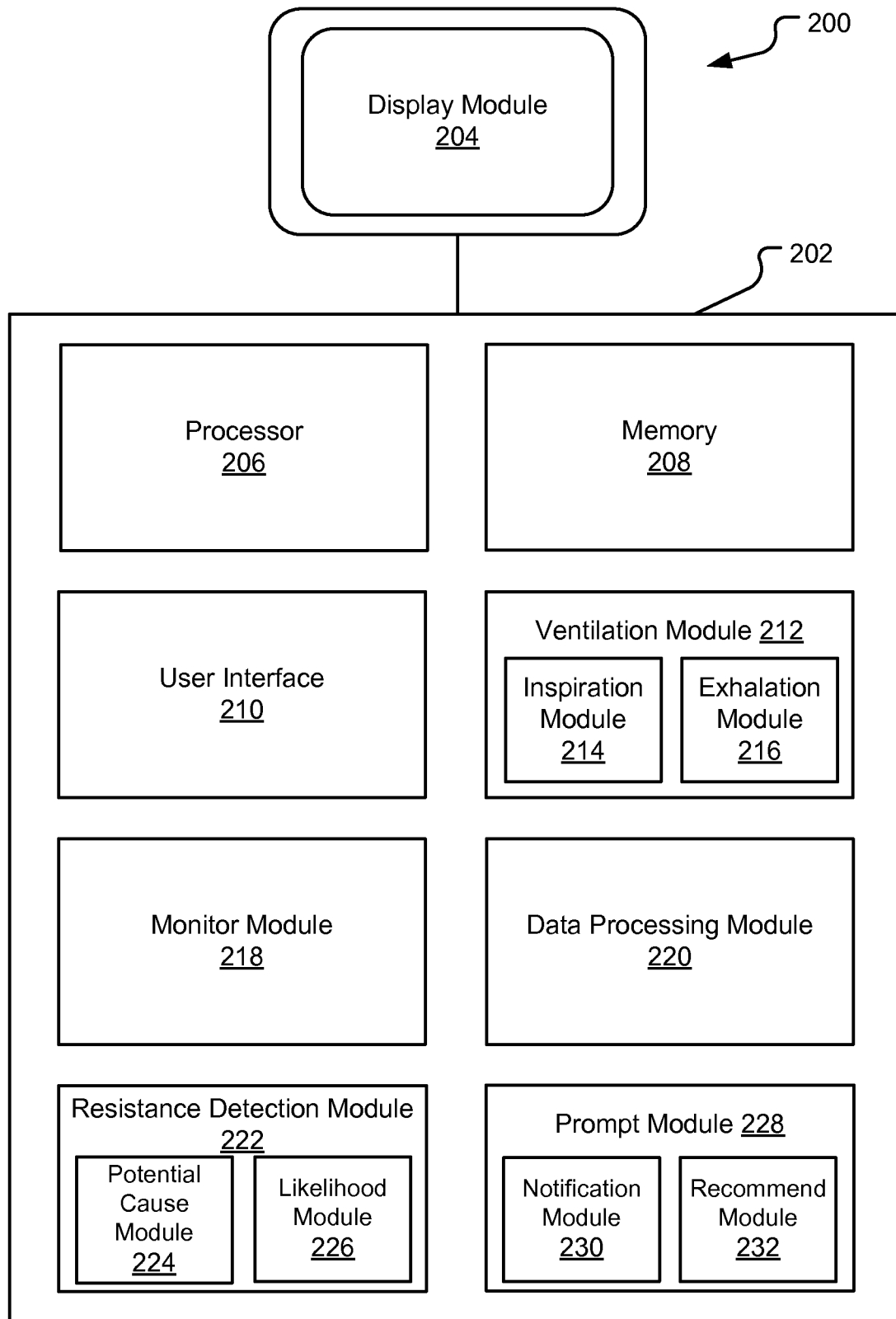
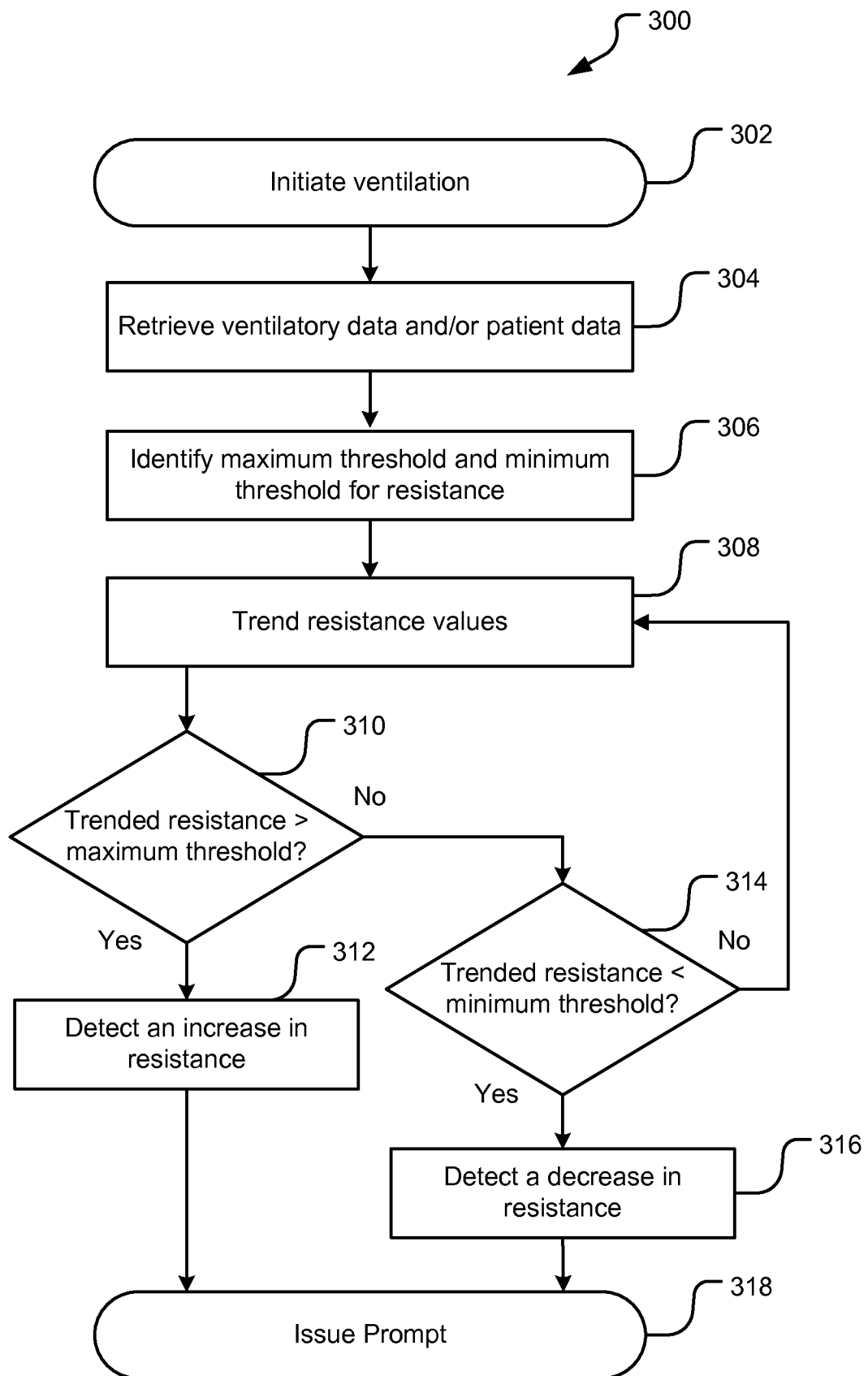


FIG. 2

**FIG. 3**

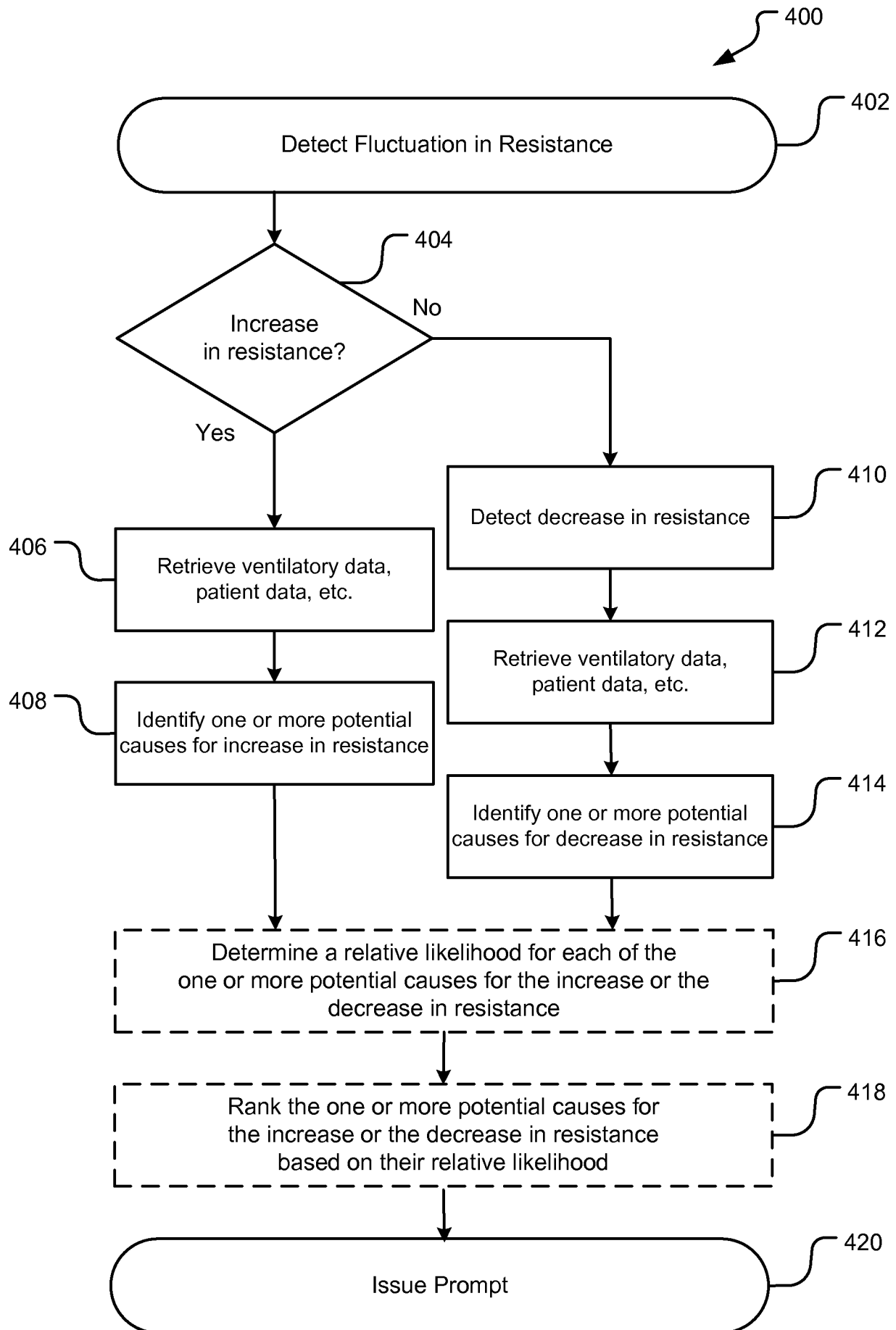
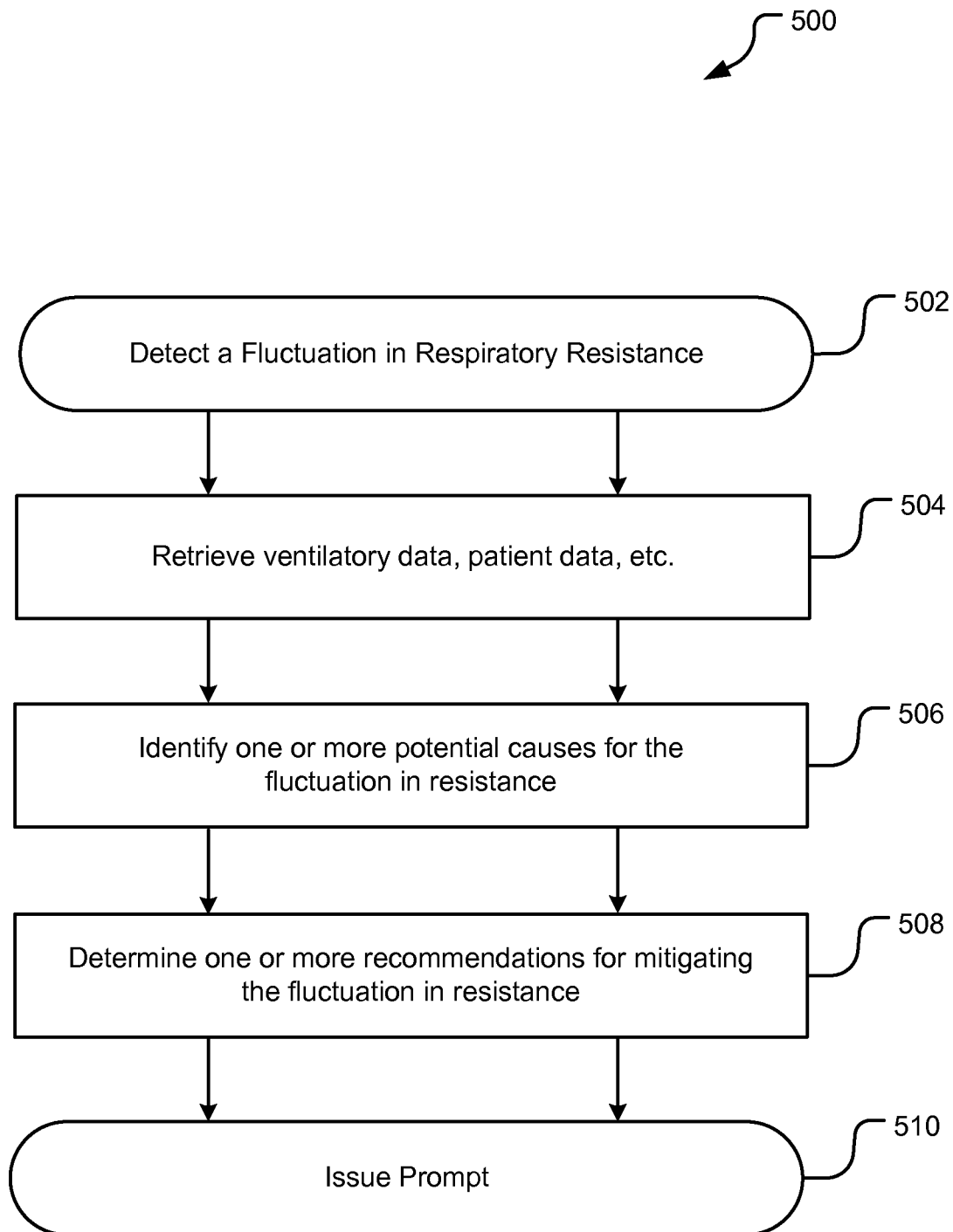


FIG. 4

**FIG. 5**

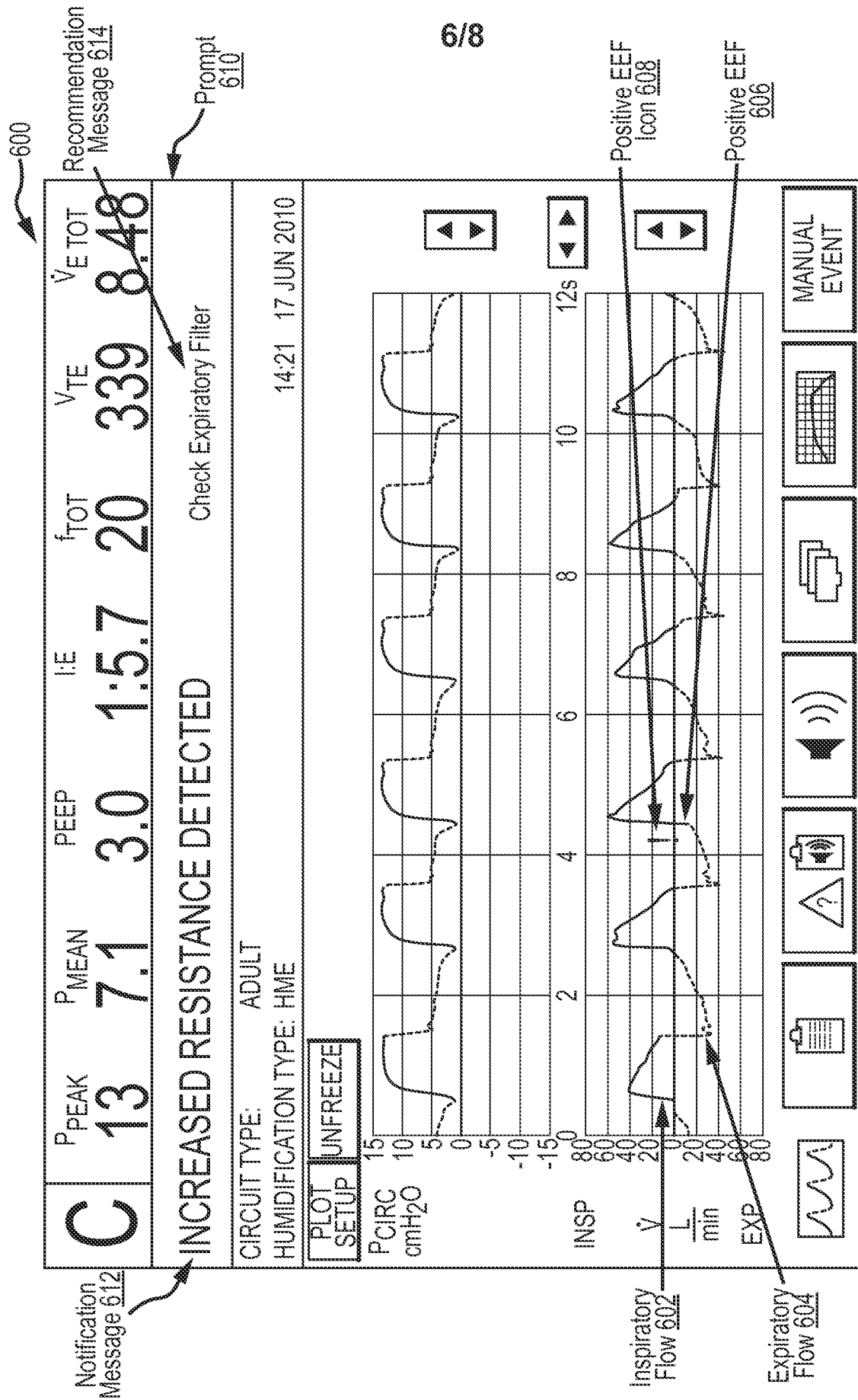


FIG.6

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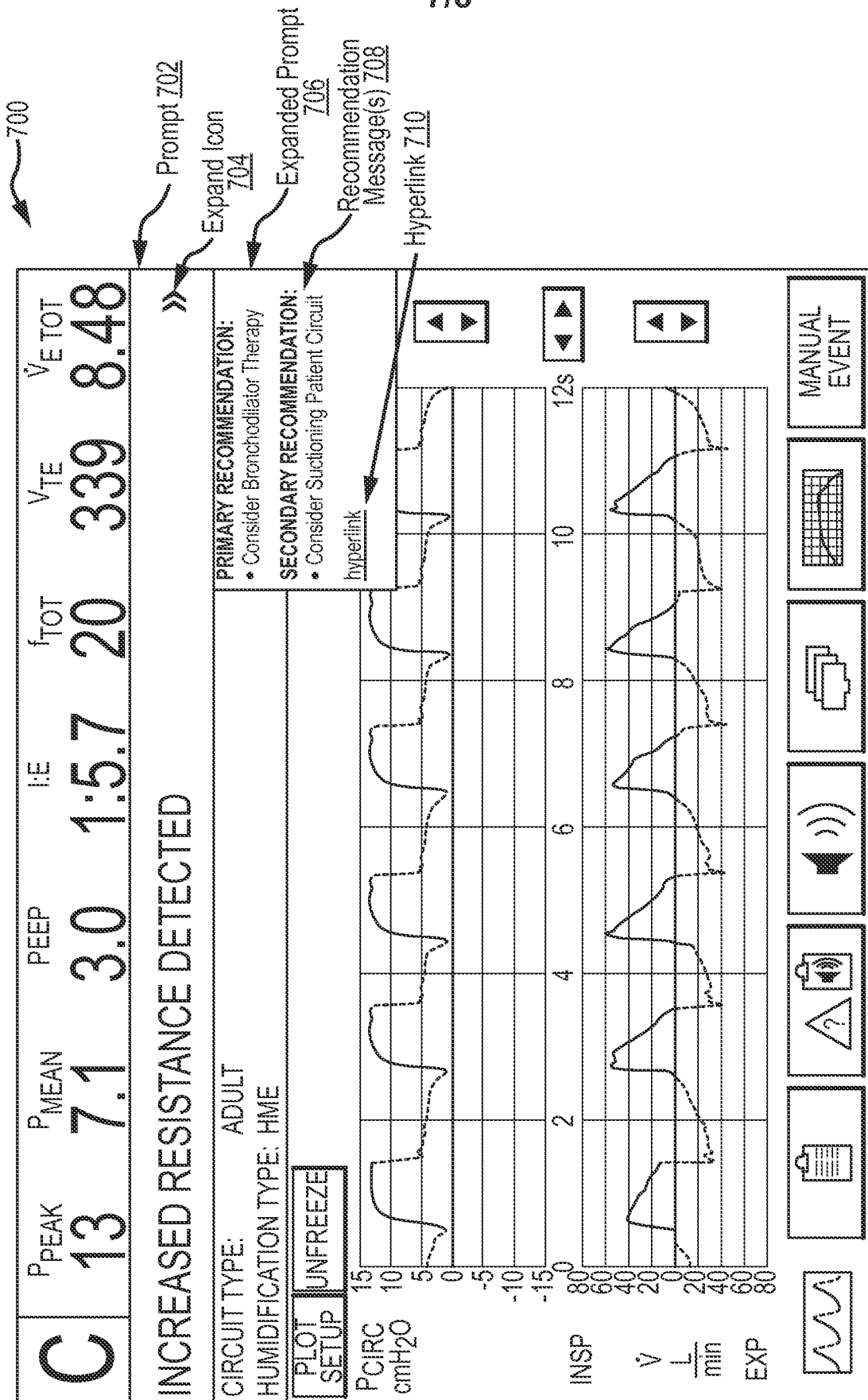


FIG.7

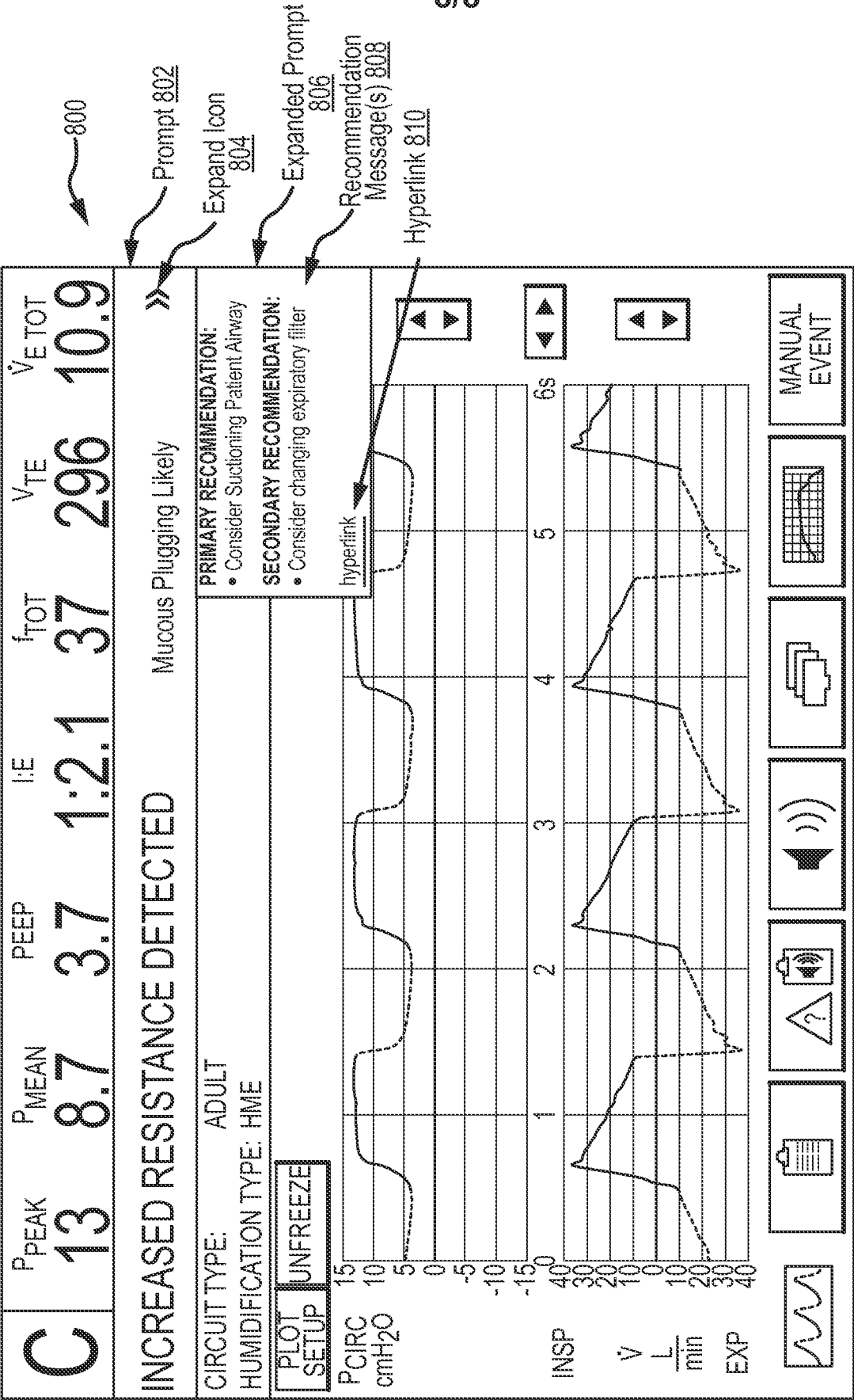


FIG.8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/062301

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61M16/00 G06F19/00
ADD.

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)
A61M G06F

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 practical, search terms used)

EPO-Internal

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X	WO 2009/149351 A1 (NELLCOR PURITAN BENNETT LLC [US]; MASIC MILENKO [US]) 10 December 2009 (2009-12-10) the whole document	1-20
A	US 2008/236582 A1 (TEHRANI FLEUR T [US]) 2 October 2008 (2008-10-02) paragraph [0068] paragraph [0030]	14
A,P	WO 2011/139586 A1 (NELLCOR PURITAN BENNETT LLC [US]; MILNE GARY [US]; HENSLEY KIRK [US];) 10 November 2011 (2011-11-10) the whole document	1-20
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	-/--	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search

15 February 2012

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Valfort, Cyril

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/062301

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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