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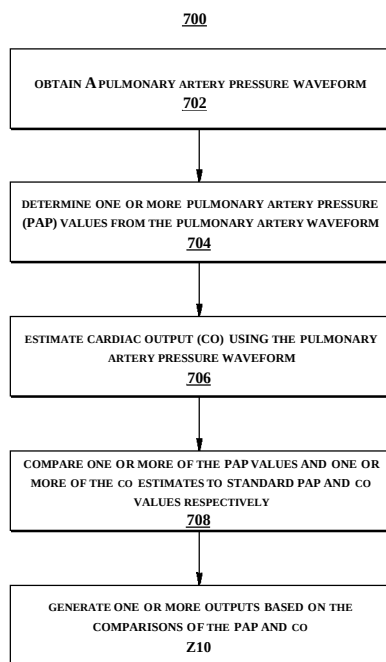
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(54) Title: DEVICES, SYSTEMS, AND METHODS FOR PULMONARY ARTERIAL HYPERTENSION (PAH) ASSESSMENT AND TREATMENT



(57) Abstract: Provided herein are devices, systems, and methods for assessing, treating, and for developing new treatments for pulmonary arterial hypertension (PAH) using pulmonary artery pressure (PAP) values and/or cardiac output (CO) estimates. The system for evaluating progress of pulmonary arterial hypertension (PAH) includes a device configured to obtain a pulmonary artery pressure waveform, a processor, and a memory coupled to the processor. The memory causes the processor to receive the pulmonary artery pressure waveform, determine one or more pulmonary artery pressure (PAP) values, and estimate cardiac output (CO).

Devices, Systems, and Methods for Pulmonary Arterial Hypertension (PAH) Assessment and Treatment

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Application No. 61/728,913, filed
November 21, 2012, and U.S. Provisional Application No. 61/799,536, filed March 15, 2013,
each of which is hereby incorporated herein by reference in its entirety.

TECHNICAL FIELD

This application generally relates to devices, systems, and methods for the assessment
and treatment of pulmonary arterial hypertension (PAH).

BACKGROUND

Pulmonary arterial hypertension (PAH) is a progressive disease that results in elevation
of the pulmonary artery pressure and ultimately development of right ventricular failure.
Baseline and periodic invasive hemodynamics via right heart catheterization are generally
obtained in order to characterize and follow the extent of hemodynamic derangement, response
to therapy, and as an end point in clinical trials of novel therapy.

SUMMARY

Provided herein are methods for assessing, treating, and for developing new treatments
for PAH.

For example, provided are methods for evaluating progress of pulmonary arterial
hypertension (PAH) in a subject, or an outcome in a subject having PAH. Example methods
include obtaining a pulmonary artery pressure waveform from the subject. One or more
pulmonary artery pressure (PAP) values are determined from the pulmonary artery waveform.
Cardiac output (CO) is estimated using the pulmonary artery pressure waveform. One or more of
the PAP values and one or more of the CO estimates are compared to standard PAP and CO
values respectively. The comparisons of PAP and CO are used to monitor the PAH progression
or outcome in the subject.

An agent can be administered to the subject, and determined PAP values and estimated
CO values, in combination, can be used for evaluating treatment of a subject having PAH. In
this regard, an example method includes administering an agent to the subject and obtaining a
pulmonary artery pressure waveform from the subject. One or more pulmonary artery pressure

(PAP) values are determined from the pulmonary artery waveform. Cardiac output (CO) is estimated using the pulmonary artery pressure waveform. One or more of the PAP values and one or more of the CO estimates are compared to standard PAP and CO values respectively, for example, to determine trends in PAP values and CO estimates in the subject. The comparisons of PAP and CO, for example trends, are used to monitor the effect of the administered agent on the PAH condition in the subject.

Additional methods for evaluating treatment of a subject having PAH include administering an agent to the subject and obtaining a pulmonary artery pressure waveform from the subject. One or more pulmonary artery pressure (PAP) values are determined from the pulmonary artery waveform and are compared to a standard PAP value. The comparison of PAP is used to monitor the effect of the administered agent on the PAH condition in the subject. A decrease in the one or more determined PAP values compared to the PAP standard, for example a decreasing trend in the subject's PAP values, indicates a beneficial effect of the administered agent on the PAH condition in the subject. An increase in the one or more determined PAP values compared to the PAP standard, for example an increasing trend in the subject's PAP values, indicates no beneficial effect of the administered agent on the PAH condition in the subject.

Additional methods for evaluating treatment of a subject having PAH include administering an agent to the subject and obtaining a pulmonary artery pressure waveform from the subject. Cardiac output (CO) is estimated using the pulmonary artery pressure waveform and compared to a standard CO value. The comparison of CO is used to monitor the effect of the administered agent on the PAH condition in the subject. In this method, an increase in the one or more estimated CO values compared to the CO standard, for example an increasing trend in the subject's CO estimates, indicates a beneficial effect of the administered agent on the PAH condition in the subject. A decrease in the one or more estimated CO values compared to the CO standard, for example a decreasing trend in the subject's CO estimated values, indicates no beneficial effect of the administered agent on the PAH condition in the subject.

Optionally, the standard PAP value in the methods described herein is one or more previously determined PAP values from the subject. For example, the standard is optionally a PAP value determined by obtaining a pulmonary artery pressure waveform from the subject and using that waveform to determine the PAP value. In this way, trends in PAP values in the subject can be monitored. These trends are optionally used to monitor PAH progression or outcome in the subject.

For example, a lowering trend in PAP values over time in, optionally, a subject having PAH, indicates improvement in the PAH condition. This can also optionally indicate improved outcome in the subject, such as, for example, reduced hospitalizations, lower mortality, or lower morbidity.

5 The trends of PAP are optionally combined with the determination and monitoring of trends in CO in the subject to evaluate the progress of PAH in the subject. For example, the standard CO value, which can be used to determine such trends, is optionally based on one or more previously estimated CO values from the subject, or established normal ranges. A rising trend in CO estimates over time in, optionally, a subject having PAH, indicates improvement in
10 the PAH condition. This can also optionally indicate or predict improved outcome in the subject, such as, for example, reduced hospitalizations, lower mortality, lower morbidity, or improved exercise tolerance. The standard PAP or CO value can also optionally be established normal hemodynamic values, such as PAP and/or CO values. Normal hemodynamic values include normal values for a given subject or population.

15 Also provided are methods of processing a pulmonary artery pressure waveform, for example, a pulmonary artery pressure waveform obtained from a subject having PAH. Examples methods of processing a pulmonary artery pressure waveform can include obtaining a pulmonary artery pressure waveform from a device configured to obtain a pulmonary artery pressure waveform from a subject; determining one or more pulmonary artery pressure (PAP)
20 values from the pulmonary artery waveform; estimating cardiac output (CO) using the pulmonary artery pressure waveform; comparing one or more of the PAP values and one or more of the CO estimates to standard PAP and CO values respectively; and generating one or more outputs based on the comparisons of PAP and CO. Example outputs include indicators or predictors of improvement or worsening of the PAH in the subject (e.g., probabilities, scores,
25 subject status indicators, trend values for PAP and/CO, graphs plotting values for PAP and/CO, etc.), instructions for treatment (e.g., instructions for administration of a pharmaceutical agent), or combinations thereof.

Also provided are systems for practicing the methods described herein, including systems for evaluating progress of pulmonary arterial hypertension (PAH) in a subject, or an outcome in
30 a subject having PAH. Example systems can comprise a device (e.g., an implantable device, such as a pressure sensor implanted in the pulmonary artery of a subject) configured to obtain a pulmonary artery pressure waveform; a processor; and a memory operably coupled to the processor. The memory can include computer-executable instructions stored thereon that, when executed by the processor, cause the processor to receive the pulmonary artery pressure

waveform; determine one or more pulmonary artery pressure (PAP) values from the pulmonary artery waveform; estimate cardiac output (CO) using the pulmonary artery pressure waveform; compare one or more of the PAP values and one or more of the CO estimates to standard PAP and CO values respectively; and provide one or more outputs based on the comparisons of PAP and CO. Example outputs include indicators or predictors of improvement or worsening of the PAH in the subject (e.g., probabilities, scores, subject status indicators, trend values for PAP and/CO, graphs plotting values for PAP and/CO, etc.), instructions for treatment (e.g., instructions for administration of a pharmaceutical agent), or combinations thereof.

The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph showing monitoring of PAP in a subject with PAH prior to and subsequent to administration of therapy to the subject.

FIGs. 2A and 2B are graphs showing consistent and accurate CO measurements using an implantable sensor as described herein.

FIG. 3 is a graph showing CO agreement with pressure changes.

FIG. 4 is a graph showing trends in CO, mPAP and TPR in a PAH subject before and after administration of treatment agents.

FIG. 5 is a graph showing estimated Cardiac Output.

FIGs. 6A and 6B are graphs illustrating CO measurement Bland-Altman Agreement with an implantable CardioMEMS® (Atlanta, GA) sensor versus a CO reference standard.

FIG. 7 is a flow diagram illustrating example operations for processing a pulmonary artery pressure waveform.

FIG. 8 is an example computing device.

DETAILED DESCRIPTION

Progressive right ventricular failure is a common consequence of PAH and is the leading cause of premature death. In the original NIH pulmonary hypertension registry, a prognostic equation was developed that included right atrial pressure, pulmonary artery pressure, and cardiac index. Right atrial pressure, cardiac index, and PAP were significant factors with respect to outcome, listed in order of statistical importance. While RA pressure has a high correlation with outcomes, this is because it is a direct symptom of RV failure, which occurs in the latter stage of the disease progression when treatment options are limited, and RV failure has a high

correlation with outcomes. However, the diagnostic usefulness of this parameter in the earlier stages of the disease progression is limited.

CO and PAP provide an indication of the ventricular stroke work, which when elevated over extended timeframes, overloads the RV and accelerate RV failure. Calculated parameters such as Stroke Work (mPAP x Stroke Volume) and Total Pulmonary Resistance (TPR) (mPAP/CO) use PAP and CO together to provide an assessment of the RV workload. Pulmonary artery pressure and pulmonary arterial pressure are used synonymously throughout.

Example inventions described herein are based on the use of PAP, CO, and other relevant metrics calculated from these parameters such as Stroke Work and TPR, alone or in combination, can be used to assess, treat, and develop new treatments for PAH and heart failure resulting from PAH. The provided methods are optionally used for evaluating progress of pulmonary arterial hypertension (PAH) in a subject, or an outcome in a subject having PAH.

The methods described herein are optionally used to develop a therapeutic agent. The term "developing" or "development" as used herein in reference to therapeutics are broad terms that include, by way of example and not limitation, prospective design, or selection, of one or more potential therapeutic methods or compounds or retrospective study of one or more therapeutic methods or compounds or design of studies of such therapeutic methods or compounds. In this regard, to develop or development of a therapeutic can include, for example, changes to an active ingredient or formulation and also includes, for example, study design for a therapeutic. Optionally, study design is for a clinical trial and development of a study design can include establishing trial metrics or trial durations.

The methods described herein can also be used to identify a candidate therapeutic agent for administration to a patient. All or a subset of the hemodynamic data, such as, for example, CO estimates and/or PAP values, can be correlated with the candidate therapeutic agent to indicate a predicted change in one or more hemodynamic values in the patient that would result from administration of the candidate agent. The predicted change can be used to indicate the predicted effect of the candidate agent on the hemodynamic parameter of the subject.

A change in one or more of the measured hemodynamic values, such as, for example, CO estimates and/or PAP values resulting from the administration of the therapeutic agent can be identified, the change indicating an effect of the therapeutic agent on the hemodynamic parameter of the subject. Optionally, the hemodynamic data comprises at least one hemodynamic value measured in a subject prior to administration of the therapeutic agent. Optionally, the hemodynamic data comprises at least one hemodynamic value measured in a subject concurrent with administration of the therapeutic agent. Optionally, the hemodynamic

data comprises at least one hemodynamic value measured in a subject subsequent to administration of the therapeutic agent. Optionally, the hemodynamic data comprises at least one hemodynamic value measured in a subject prior to administration of the therapeutic agent and at least one hemodynamic value measured in a subject subsequent to administration of the therapeutic agent. In some aspects, one or more additional therapeutic agents are administered to the subject prior to, concurrently with, or subsequent to the therapeutic agent.

Optionally, the therapeutic agent can be modified to increase the indicated effect. For example, if the indicated effect is desired, the structure of the therapeutic agent can be modified to increase the indicated effect. The therapeutic agent can also be modified to decrease the indicated effect. For example, if the indicated effect is not desirable, then the structure of the therapeutic agent can be modified to decrease the indicated effect. Moreover, an administration characteristic of the therapeutic agent can be modified to increase or decrease the indicated effect.

The administration characteristic can be selected from the group consisting of dosage amount, number of doses, timing of doses, route of administration, and total dosage. When the indicated effect is to be increased or decreased, one or more portions of the therapeutic agent responsible for the indicated effect can be determined. Optionally, a second therapeutic agent including the one or more portions of the therapeutic agent responsible for the indicated effect can be designed.

The indicated effect can be used to assess safety of the therapeutic agent for administration to a mammal or population thereof. In some examples, the indicated effect is used to assess the toxicity of the therapeutic agent for administration to a mammal or population thereof. Optionally, the toxicity is cardiac toxicity. The indicated effect can also be used to assess the efficacy of the therapeutic agent for administration to a mammal or population thereof. And, the indicated effect can also be used to predict the effect or effects of the therapeutic agent or agents having the same or similar pharmacological characteristics on the hemodynamic parameter. Optionally, the indicated effect is used to predict the effect or effects of the therapeutic agent or agents having the same or similar pharmacological characteristics on a hemodynamic parameter of a mammal. In some aspects, the indicated effect is used to determine an end point for a clinical trial.

The described methods can further comprise determining one or more characteristics of the subject. The determined characteristic can be a physical, physiologic, metabolic, chronological, disease state, drug administration history, medical history, or genetic characteristic.

The characteristic can be correlated with the indicated effect in the subject. The correlation of the characteristic and the indicated effect in the subject can be used to select one or more additional subjects for administration of the therapeutic agent or for a therapeutic agent having the same or similar indicated effect. The correlation of the characteristic and the indicated effect can also be used to select one or more additional subjects to participate in a clinical trial for the therapeutic agent or for a therapeutic agent having the same or similar indicated effect.

These determinations can be used to facilitate development of a therapeutic by efficiently identifying preferred dosages that are correlated to improved physiological data for clinical trials. The determinations can also be used for determining proper dosages of commercial products for general and specific populations of subjects. For example, the described methods can be used to arrive at dosing levels based on patient/subject profiles including, but not limited to, pulmonary artery pressure response and/or cardiac output response to a study or commercial drug or with other hemodynamic metrics alone or in combination with characteristics such as age, weight and concurrent drug administration or drug-drug interaction. Example methods for facilitating development of therapeutics include methods for evaluating progress or outcome in PAH subjects, and for evaluating treatment in PAH subjects. These methods can also be used in clinical treatment and management of subjects.

Example methods include obtaining a pulmonary artery pressure waveform from the subject. One or more pulmonary artery pressure (PAP) values are determined from the pulmonary artery waveform. Cardiac output (CO) is estimated using the pulmonary artery pressure waveform. One or more of the PAP values and one or more of the CO estimates are compared to standard PAP and CO values respectively. The comparisons of PAP and CO are used to monitor the PAH progression or outcome in the subject.

Optionally, the standard PAP value is one or more previously determined PAP values from the subject. For example, the standard is optionally a PAP value determined by obtaining a pulmonary artery pressure waveform from the subject and using that wave form to determine the PAP value. In this way, trends in PAP values in the subject can be monitored. These trends are optionally used to monitor PAH progression or outcome in the subject.

For example, a lowering trend in PAP values over time in, optionally, a subject having PAH indicates improvement in the PAH condition. This can also optionally indicate improved outcome in the subject, such as, for example, reduced hospitalizations, lower mortality, or lower morbidity.

The trends of PAP are optionally combined with the determination and monitoring of trends in CO in the subject to evaluate the progress of PAH in the subject. For example, the standard CO value, which can be used to determine such trends, is optionally based on one or more previously estimated CO values from the subject.

5 The standard PAP value can also optionally be a clinically relevant target PAP value for the subject and the standard CO value can optionally be a clinically relevant CO target value for the subject. For example, an optional clinical target standard is a PAP of about 25mmHg. Optionally, the determined PAP value is less than 25mmHg. The clinically relevant target for either CO or PAP can be, for example, determined by a health care professional treating or
10 managing the PAH subject. A clinically relevant target value can be a value that is a normal value for the subject, or a population of which the subject is a member, or an improved value for the subject, goal value for the subject, or any other value determined by a health care professional managing the subject.

Optionally, one or more PAP values of the subject determined prior to determining the
15 PAP value from the obtained pulmonary artery pressure waveform are greater than 25mmHg. The clinically relevant target for either CO or PAP can be, for example, determined by a health care professional treating or managing the PAH subject.

Thus, trends in PAP and CO can be monitored relative to previous values from the subject or to clinical target values that may optionally be determined by a health care
20 professional treating or managing the subject.

The trends can be used to determine if the subject is improving. For example, a decrease in the one or more PAP values compared to the standard PAP value, combined with one or more increased or stable CO estimates compared to the standard CO value can indicate or predict improvement in the subject. In another example, one or more stable PAP values compared to the
25 standard PAP value, combined with one or more increased CO estimates compared to the CO standard value indicates or predicts improvement of the PAH in the subject.

Alternatively, a decrease in one or more CO estimates compared to the standard CO value, combined with one or more increased or stable PAP values compared to the standard PAP value can indicate or predict worsening of the PAH in the subject. In another example, an
30 increase in one or more PAP values compared to the standard PAP values, combined with a stable or decreased CO value compared to the standard CO value indicates or predicts worsening of the PAH in the subject. Optionally, as described above, trends in PAP values and trends in CO value are used together to monitor progress or to predict outcome in subjects having PAH.

In other examples, however, PAP value trends or CO value trends are used independently to monitor progress or to predict outcomes in subjects having PAH.

For example, a method for evaluating treatment of a subject having PAH includes administering an agent to the subject and obtaining a pulmonary artery pressure waveform from the subject. One or more pulmonary artery pressure (PAP) values are determined from the pulmonary artery waveform and are compared to a standard PAP value. The comparison of PAP is used to monitor the effect of the administered agent on the PAH condition in the subject. In this way, trends in PAP values independent of CO values are used to evaluate treatment of the subject for the PAH condition. A decrease in the one or more determined PAP values compared to the PAP standard, for example a decreasing trend in the subject's PAP values, indicates a beneficial effect of the administered agent on the PAH condition in the subject. An increase in the one or more determined PAP values compared to the PAP standard, for example an increasing trend in the subject's PAP values, indicates no beneficial effect of the administered agent on the PAH condition in the subject.

In regard to CO, independent of PAP, an example method for evaluating treatment of a subject having PAH includes administering an agent to the subject and obtaining a pulmonary artery pressure waveform from the subject. Cardiac output (CO) is estimated using the pulmonary artery pressure waveform and compared to a standard CO value. The comparison of CO is used to monitor the effect of the administered agent on the PAH condition in the subject. In this way, trends in estimated CO values, independent of PAP values, are used to evaluate treatment of the subject for the PAH condition. In this method, an increase in the one or more estimated CO values compared to the CO standard, for example an increasing trend in the subject's CO estimates, indicates a beneficial effect of the administered agent on the PAH condition in the subject. A decrease in the one or more estimated CO values compared to the CO standard, for example a decreasing trend in the subject's CO estimated values, indicates no beneficial effect of the administered agent on the PAH condition in the subject.

In regard to use of determined PAP values and estimated CO values, in combination, for evaluating treatment of a subject having PAH, an example method includes administering an agent to the subject and obtaining a pulmonary artery pressure waveform from the subject. One or more pulmonary artery pressure (PAP) values are determined from the pulmonary artery waveform. Cardiac output (CO) is estimated using the pulmonary artery pressure waveform. One or more of the PAP values and one or more of the CO estimates are compared to standard PAP and CO values respectively, for example to determine trends in PAP values and CO

estimates in the subject. The comparisons of PAP and CO, for example trends, are used to monitor the effect of the administered agent on the PAH condition in the subject.

The trends can be used to determine the effect of the administered agent on the PAH condition in the subject. For example, a decrease in the one or more PAP values compared to the standard PAP value, combined with one or more increased or stable CO estimates compared to the standard CO value can indicate a beneficial effect of the administered agent on the PAH condition in the subject. In another example, one or more stable PAP values compared to the standard PAP value, combined with one or more increased CO estimates compared to the CO standard value indicates a beneficial effect of the administered agent on the PAH condition in the subject.

Alternatively, a decrease in one or more CO estimates compared to the standard CO value, combined with one or more increased or stable PAP values compared to the standard PAP value can indicate no effect or a detrimental effect of the administered agent on the PAH condition in the subject. In another example, an increase in one or more PAP values compared to the standard PAP values, combined with a stable or decreased CO value compared to the standard CO value indicate no effect or a detrimental effect of the administered agent on the PAH condition in the subject.

The PAP values and or CO estimates can also be used to derive a third value indicative of progression or treatment of PAH. In this regard, as used herein, use of PAP and or CO values and estimates includes use of other values derived from PAP and CO. Derived metrics include Stroke Work and TPR, alone or in combination, which are within the definition of the use of CO and or PAP.

The administration of the pharmaceutical agent, for example, the agent administered, dosage, timing, protocol, or the like, can be modified or maintained after determining the effect of the agent on the PAH condition in the subject. For example, administration of the pharmaceutical agent is optionally maintained at its current dosage and or dosing regimen when improvement is indicated. In another example, the pharmaceutical agent is changed, or the dosage or dosing regimen modified when improvement is not indicated. In another example, the information obtained on PAP, CO, or both are used to determine an effective dosage or administration protocol for the agent or to evaluate the same, for example, in a clinical trial setting.

Therapeutic goals optionally include lowering or maintaining PAP and/or increase or maintain CO. Additional therapeutic goals include reducing or maintaining PVR. Optionally CO is increased while PAP is reduced in the subject. Optionally, CO or PAP is increased while

PAP or CO is maintained respectfully. TPR is used as a surrogate for PVR in the context of PAH. If the etiology of disease is understood by RHC to be PAH with minimal component of left heart disease, change TPR can then be used to infer changes in PVR.

Also provided are methods of processing a pulmonary artery pressure waveform, for example, a pulmonary artery pressure waveform obtained from a subject having PAH. Referring now to Figure 7, a flow diagram illustrating example operations 700 for processing a pulmonary artery pressure waveform is provided. The example operations 700 can optionally be performed using a general computing device such as the computing device described in Figure 8 below. At 702, a pulmonary artery pressure waveform is obtain or received, for example, from a device configured to obtain a pulmonary artery pressure waveform from a subject. Optionally, the pulmonary artery pressure waveform can be received directly from the device that obtains the pulmonary artery pressure waveform from the subject or can be received from a device such as a storage device, for example, that stores the pulmonary artery pressure waveform. At 704, one or more pulmonary artery pressure (PAP) values are determined from the pulmonary artery waveform. At 706, cardiac output (CO) is estimated using the pulmonary artery pressure waveform. Then, at 708, one or more of the PAP values and one or more of the CO estimates are compared to standard PAP and CO values respectively. At 710, one or more outputs are generated based on the comparisons of PAP and CO. Example outputs include indicators or predictors of improvement or worsening of the PAH in the subject (e.g., probabilities, scores, subject status indicators, trend values for PAP and/CO, graphs plotting values for PAP and/CO, etc.), instructions for treatment (e.g., instructions for administration of a pharmaceutical agent), or combinations thereof.

In the described methods, the obtained pulmonary artery pressure waveform is optionally obtained with a wireless sensor implanted in the subject. In addition, one or more of the standard pulmonary artery pressure values are optionally determined from a pulmonary artery pressure waveform obtained with a wireless sensor implanted in the subject. Therefore, the pulmonary artery pressure waveform is optionally obtained wirelessly and the standard values can be determined from a pulmonary artery waveform obtained wirelessly. In either case, the pulmonary artery pressure waveform is optionally obtained using an implanted sensor. Optionally, the implanted sensor is a pressure sensor, which is optionally implanted in the pulmonary artery of the subject. Optionally, the sensor lacks percutaneous connections. Optionally, the sensor is energized from an external source. Optionally, the sensor is a passive sensor energized to return pressure readings by an electromagnetic field.

Because of the nature of the sensors described above, the pulmonary artery pressure waveform is optionally obtained outside of a typical clinical evaluation environment. For example, the pulmonary artery waveform is optionally obtained while the subject is exercising. Exercising includes any activity of the subject. For example, exercise or exercising includes activities of daily living, prescribed exercise, walking, biking, running or the like. Optionally, the pulmonary artery pressure waveform is obtained while the subject is asleep.

An effective system and sensor for measurement of cardiovascular physiology information, such as obtaining the pulmonary artery pressure waveform is the CARDIOMEMS (Atlanta, GA) heart sensor. As described by U.S. Patents Nos. 7,699,059 entitled "Implantable Wireless Sensor" and 7,679,355 entitled "Communicating with an Implanted Wireless Sensor," these sensors are MEMS-based sensors that are implanted in the pulmonary artery, more particularly in the distal pulmonary artery branch and are configured to be energized with RF energy to return high-frequency, high-fidelity dynamic pressure information from a precisely-selected location within a patient's body.

The sensors are optionally used to generate a real-time or substantially real-time pressure waveform. Via signal acquisition and processing techniques, a pressure waveform is optionally generated via a processor coupled with memory that contains the appropriate algorithm to relate the electrical characteristics of the circuit to the pressure of the PA.

In parallel or via discrete processors and memory elements, subsequent processing of the pressure waveform is performed. Summary values for each reading optionally include systolic PAP, diastolic PAP, mean PAP, heart rate, and estimated cardiac output.

PAP values are optionally determined by analysis of the pressure waveform to determine the average maximum waveform values for systolic PAP, average minimum waveform values for diastolic PAP, and average of all waveform values for mean PAP.

Heart Rate is optionally determined in the following manner: The timing of repetitive relevant hemodynamic events within the cardiac cycle, such as optionally the average time interval between consecutive systolic or diastolic pressure values, is used to determine the average time interval between beats. The average time interval between beats is optionally used to determine the average heart rate as $60 \text{ (s/min.)} / \text{average time interval between beats (s/beat)}$ to determine the average heart rate in beats per minute.

Cardiac Output (CO) is estimated based on the pulmonary arterial pressure waveform using the following approach. For each cardiac cycle, the pulmonary arterial pressure waveform $P(t)$, comprised of an array of consecutive discrete paired pressure (p) and time (t) values, $P(t) =$

{(p_i,t_i), (p₂,t₂). ...}, is optionally analyzed to identify the following relevant reference pressure and time points for each beat:

- P₁,T₁ pressure and time at start of systole and end of diastole.
- P₂,T₂ pressure and time at end of the RV incident wave / beginning of reflected wave indicated as first upslope pressure incisura after the systolic upslope dP/dT max or alternatively at the maximum of the pressure beat.
- P₃,T₃ pressure and time at end of systole/end of outflow demarcated by the dicrotic notch / pulmonic valve closure.

Optionally the pressure waveform features associated with the RV incident pressure wave, and time parameters during systole are used to determine a proportional estimation of stroke volume.

The proportional estimate of stroke volume for each beat, can be determined in a variety of ways, including but not limited to the following:

- a. P₂ - P₁
- b. VP₂
- c. $\sqrt{P_2 - P_1}$
- d. $\sqrt{\text{average}(P_2, P_3)}$
- e. VP₂ x (T₃-T₁)
- f. $\sqrt{P_2 - P_1}$ x (T₃-T₁)
- g. $\sqrt{\text{average}(P_2, P_3)}$ x (T₃-T₁)
- h. VP₂ x (T₃-T₂)
- i. $\sqrt{P_2 - P_1}$ x (T₃-T₂)
- j. $\sqrt{\text{average}(P_2, P_3)}$ x (T₃-T₂)
- k. dP/dT max value between T₁ and T₂
- l. Integration of P(t) - P₁, from T₁ to T₂.
- m. Integration of the first derivative of the pressure waveform, dP(t)/dT, from T₁ to T₂.
- n. Integration of $\sqrt{P(t) - P_1}$, from T₁ to T₂.
- o. Integration of $\sqrt{dP(t)/dT}$, from T₁ to T₂.

Alternatively, for estimates which integrate pressure changes over time and which have a downstream reference pressure (P₁) (i and n) may be replaced in the equation with a value that gradually increases as the pulmonary vasculature volume increases during filling along the line that is defined by endpoints P₁,T₁ and P₃,T₃, according to the equation;

$$P(t)[P_i, T_i \text{ to } P_3, T_3] = P_1 + [(P_3 - P_1)/(T_3 - T_1)] \times (t - T_1)$$

Accordingly, the proportional estimate of stroke volume can also be performed as follows:

p. Integration of $P(t) - P(t)_{pi, Ti_{0, P3, T3}}$ from T1 to T2.

q. Integration of $V(P(t) - P(t)_{[pi, xi_{10, P3, T3}]})$ from T1 to T2.

Alternatively, for estimates that integrate pressure changes or the square root of pressure changes over time (1, n, p, and q), integration over the timeframe from T2 to T3 may also be included, with exclusion of the portion of the waveform which is attributed to the reflected wave. The reflected portion of the waveform is delineated by the line defined by endpoints P2, T2 and P3, T3, defined by the equation;

$$P(t)_{[P_2, T2 \text{ to } P3, T3]} = P_2 + [(P_3 - P_2)/(T_3 - T_2)] \times (t - T_2)$$

Accordingly, the proportional estimate of stroke volume can also be performed as follows:

r. Integration of $P(t) - P_1$ from T1 to T2 plus integration of $P(t)_{[P_2, T2 \text{ to } P3, T3]} - P_1$ from T2 to T3.

s. Integration of $V(P(t) - P_1)$ from T1 to T2 plus integration of $V(P(t)_{[P_2, T2 \text{ to } P3, T3]} - P_1)$ from T2 to T3.

t. Integration of $P(t) - P(t)_{[P_1, T1 \text{ to } P3, T3]}$ from T1 to T2 plus integration of $P(t)_{[P_2, T2 \text{ to } P3, T3]} - P(t)_{[P_1, T1 \text{ to } P3, T3]}$ from T2 to T3.

u. Integration of $V(P(t) - P(t)_{[P_1, T1 \text{ to } P3, T3]})$ from T1 to T2 plus integration of $V(P(t)_{[P_2, T2 \text{ to } P3, T3]} - P(t)_{[P_1, T1 \text{ to } P3, T3]})$ from T2 to T3.

A proportional estimate of stroke volume ($SV_{p, T0, p, est}$) is determined as the average of the compiled proportional estimates from at least one cardiac cycle. The duration or number of cardiac cycles for the averaging window can be configured as appropriate to the application. The minimum average length preferably exceeds the length of at least one respiratory cycle in order to average variation attributable to the respiratory cycle.

A proportional estimate of cardiac output is determined by multiplying the average proportional estimate of stroke volume by the measured average heart rate.

An initial reference cardiac output measurement is performed for method calibration, typically during the sensor implantation procedure using a clinically accepted measurement method such as thermodilution, modified Fick, or Fick. During the same measurement session, one or more wireless pulmonary arterial pressure waveform readings are collected. An initial patient specific constant term (A_0) is calculated as the ratio of the reference cardiac output measurement and the proportional estimate of cardiac output determined during the same measurement session. This initial patient specific constant term indirectly determines the effects of other relevant parameters such as the RV outflow tract cross sectional area (CSA) and the initial characteristic impedance during the calibration measurements ($Z_{0,i}$); $A_0 = CSA \times Z_{0,i}$.

This initial patient specific constant term is used as a calibration factor that is multiplied by the proportional estimate of cardiac output to produce the initial estimated cardiac output value;

$$CO_{est} = A_0 \times SV_{prop.est} \times HR.$$

As a corollary to Ohm's law for electrical circuits, the relationship between pressure changes (ΔP) and flow (Q) is governed by flow impedance (Z); $\Delta P(t) = Z(t) \times Q(t)$. Thus, the pressure based proportional estimate of stroke volume and cardiac output is valid only without relevant changes in impedance. This assumption is valid during short term assessments, as would be the case during an initial calibration reading of, for example, 18s length. However, flow impedance may change over longer timeframes between readings. For this reason, also accounting for changes in impedance between readings is expected to yield improved model performance.

Flow impedance has frequency and non-frequency dependent components.

The frequency dependent components of impedance are primarily associated with reflected, propagated pressure waves which dynamically influence the relationship between pressure and flow. These frequency dependent effects are incorporated into the model through the previously presented use of the first upslope incisura as the T2 timepoint in the initial stroke volume estimate. For example, more prominent reflected pressure waves or faster pressure wave propagation associated with increased pulmonary vascular impedance results in an earlier first upslope incisura, which reduces the proportional estimate of stroke volume. Conversely, less prominent reflected pressure waves or slower pressure wave propagation associated with reduced pulmonary vascular impedance results in a later first upslope incisura, which results in an increased proportional estimate of stroke volume.

In one example, changes in the non-frequency dependent, characteristic impedance after initial calibration are incorporated into the model in order to achieve improved accuracy in the stroke volume and cardiac output estimates without need for recalibration over extended timeframes.

The physiological basis for the non-frequency dependent impedance change estimate, hereafter described as characteristic impedance change, $\Delta Z(i)$, is presented as follows. The input stroke volume is a bolus injection that is introduced into the pulmonary vasculature during a minor portion of the total cardiac cycle, indicated by the timeframe from start of systole to the first upslope incisura (T2-T1). Conversely, the outgoing stroke volume leaves the pulmonary vascular through the pulmonary capillaries throughout the entire cardiac cycle. During the relatively short input stroke volume timeframe, a minor portion of the pulmonary vascular blood volume leaves the pulmonary arterial vasculature through the pulmonary capillary beds,

approximately (T2-T1)/(Time interval between beats), approximately <10% of the total outgoing stroke volume. Accordingly, changes in resistance have only a minor impact on the characteristic impedance during the short T2-T1 timeframe, and the pulmonary vasculature during the T2-T1 timeframe can be fairly approximated as a closed system, with the major component of characteristic impedance determined by the pulmonary vascular compliance, $\Delta V/\Delta P$.

With increased mean, systolic, or diastolic average pulmonary arterial pressures, the pulmonary arterial wall strain modulus increases, and compliance decreases in a predictable manner, due to the mechanical properties of the pulmonary vessels. (Pasiński TJ, CHEST 1993). Based on this relationship, changes in mean, systolic, or diastolic average pulmonary pressures from baseline to a follow-up measurement can be used to infer proportional changes in characteristic impedance from baseline values.

The relationship between average pulmonary arterial pressure changes and proportional impedance changes was determined heuristically using data obtained from 54 NYHA Class III Heart Failure patients with 116 follow-up sets of reference cardiac output measurements and wireless pulmonary arterial pressure measurements performed a mean $\pm$ st. dev. (min., max) of 463 ± 422 (48, 1281) days post implant. The estimated Cardiac Output for follow-up measurements was determined using the initially determined constant term from baseline (A_i), which does not account for changing impedance: $CO_{est_zo,i} = A_0 \times SV_{prop_est} \times HR$. The effect of changing impedance was inferred using a scatter plot of the proportional residual error at follow-up, defined as $(CO_{est_zo,i} - CO_{ref}) / CO_{est_zo,i}$, vs. changes in average pulmonary arterial pressure from baseline. There was an observed trend of residual error with respect to mean pressure changes for mean pressure changes in the provided example. The pattern of residual error as a function of mean pulmonary arterial pressure change over the threshold value from baseline to follow-up, $\Delta mPAP$, was characterized using an exponential regression, with constant term coefficient, $B = -0.025$, by the following equation (Fig. 5):

Curve fit for proportional residual error at follow-up =

$$(CO_{est_zo} - CO_{ref}) / CO_{est_zo} = 1 - e^{(B * \Delta mPAP)} = 1 - e^{(-0.025 * \Delta mPAP)}$$

Predicted residual error =

$$CO_{est_zo} - CO_{ref} \approx CO_{est_zo} \times (1 - e^{(-0.025 * \Delta mPAP)})$$

In order to incorporate the impedance change effect, the predicted residual error is subtracted from CO_{est_zo} to produce a CO estimate with impedance change effects incorporated, CO_{est_zt} .

$$CO_{est_zt} = CO_{est_zo,i} - CO_{est_zo,i} \times (1 - e^{(-0.025 * \Delta mPAP)}) = CO_{est_zo,i} \times e^{(-0.025 * \Delta mPAP)}$$

Finally, it should be noted that model coefficients, such as but not limited to the mean pressure threshold value and exponential curve fit coefficient (B), can be used to optimize results based on best fit for a given population or individual patient, using sets of pressure waveform data and CO reference values measured at more than one time with relevant CO change between measurements.

FIG. 6 shows Bland-Altman charts of CO estimate agreement with reference CO measurements performance using pressure data obtained from a CardioMEMS® (Atlanta, GA) wireless implantable sensor. The left hand chart shows consistent accuracy agreement across the measurement range. The right hand chart shows consistent accuracy agreement over extended timeframes.

It should be appreciated that the methods and associated signal processing and logical operations described herein can be implemented (1) as a sequence of computer implemented acts or program modules (i.e., software) running on a computing device, (2) as interconnected machine logic circuits or circuit modules (i.e., hardware) within the computing device and/or (3) a combination of software and hardware of the computing device. Thus, the methods and associated signal processing and logical operations discussed herein are not limited to any specific combination of hardware and software. The implementation is a matter of choice dependent on the performance and other requirements of the computing device. Accordingly, the methods and associated signal processing and logical operations described herein are referred to variously as operations, structural devices, acts, or modules. These operations, structural devices, acts and modules may be implemented in software, in firmware, in special purpose digital logic, and any combination thereof. It should also be appreciated that more or fewer operations may be performed than shown in the figures and described herein. These operations may also be performed in a different order than those described herein.

When the methods and associated signal processing and logical operations described herein are implemented in software, the process may execute on any type of computing architecture or platform. For example, referring to Figure 8, an example computing device upon which embodiments of the invention may be implemented is illustrated. The computing device 800 may include a bus or other communication mechanism for communicating information among various components of the computing device 800. In its most basic configuration, computing device 800 typically includes at least one processing unit 806 and system memory 804. Depending on the exact configuration and type of computing device, system memory 804 may be volatile (such as random access memory (RAM)), non-volatile (such as read-only memory (ROM), flash memory, etc.), or some combination of the two. This most basic

configuration is illustrated in FIG. 8 by dashed line 802. The processing unit 806 may be a standard programmable processor that performs arithmetic and logic operations necessary for operation of the computing device 800.

Computing device 800 may have additional features/functionality. For example,
5 computing device 800 may include additional storage such as removable storage 808 and non-removable storage 810 including, but not limited to, magnetic or optical disks or tapes. Computing device 800 may also contain network connection(s) 816 that allow the device to communicate with other devices. Computing device 800 may also have input device(s) 814 such as a keyboard, mouse, touch screen, antenna or other systems configured to communicate with a
10 device configured to obtain a pulmonary artery pressure waveform from a subject, etc. Output device(s) 812 such as a display, speakers, printer, etc. may also be included. The additional devices may be connected to the bus in order to facilitate communication of data among the components of the computing device 800. All these devices are well known in the art and need not be discussed at length here.

15 The processing unit 806 may be configured to execute program code encoded in tangible, computer-readable media. Computer-readable media refers to any media that is capable of providing data that causes the computing device 800 (i.e., a machine) to operate in a particular fashion. Various computer-readable media may be utilized to provide instructions to the processing unit 806 for execution. Common forms of computer-readable media include, for
20 example, magnetic media, optical media, physical media, memory chips or cartridges, a carrier wave, or any other medium from which a computer can read. Example computer-readable media may include, but is not limited to, volatile media, non-volatile media and transmission media. Volatile and non-volatile media may be implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other
25 data and common forms are discussed in detail below. Transmission media may include coaxial cables, copper wires and/or fiber optic cables, as well as acoustic or light waves, such as those generated during radio-wave and infra-red data communication. Example tangible, computer-readable recording media include, but are not limited to, an integrated circuit (e.g., field-programmable gate array or application-specific IC), a hard disk, an optical disk, a magneto-optical disk, a floppy disk, a magnetic tape, a holographic storage medium, a solid-state device,
30 RAM, ROM, electrically erasable program read-only memory (EEPROM), flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices.

In an example implementation, the processing unit 806 may execute program code stored in the system memory 804. For example, the bus may carry data to the system memory 804, from which the processing unit 806 receives and executes instructions. The data received by the system memory 804 may optionally be stored on the removable storage 808 or the non-removable storage 810 before or after execution by the processing unit 806.

Computing device 800 typically includes a variety of computer-readable media. Computer-readable media can be any available media that can be accessed by device 800 and includes both volatile and non-volatile media, removable and non-removable media. Computer storage media include volatile and non-volatile, and removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. System memory 804, removable storage 808, and non-removable storage 810 are all examples of computer storage media. Computer storage media include, but are not limited to, RAM, ROM, electrically erasable program read-only memory (EEPROM), flash memory or other memory technology, CD-ROM, digital versatile disks (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 store the desired information and which can be accessed by computing device 800. Any such computer storage media may be part of computing device 800.

It should be understood that the various techniques described herein may be implemented in connection with hardware or software or, where appropriate, with a combination thereof. Thus, the methods, systems, and associated signal processing of the presently disclosed subject matter, or certain aspects or portions thereof, may take the form of program code (i.e., instructions) embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine, such as a computing device, the machine becomes an apparatus for practicing the presently disclosed subject matter. In the case of program code execution on programmable computers, the computing device generally includes a processor, a storage medium readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and at least one output device. One or more programs may implement or utilize the processes described in connection with the presently disclosed subject matter, e.g., through the use of an application programming interface (API), reusable controls, or the like. Such programs may be implemented in a high level procedural or object-oriented programming language to communicate with a computer system. However, the program(s) can

be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language and it may be combined with hardware implementations.

Also provided are systems for practicing the methods described herein, including systems for evaluating progress of pulmonary arterial hypertension (PAH) in a subject, or an outcome in a subject having PAH. Example systems can comprise a device configured to obtain a pulmonary artery pressure waveform; a processor; and a memory operably coupled to the processor. The memory can include computer-executable instructions stored thereon that, when executed by the processor, cause the processor to receive the pulmonary artery pressure waveform; determine one or more pulmonary artery pressure (PAP) values from the pulmonary artery waveform; estimate cardiac output (CO) using the pulmonary artery pressure waveform; compare one or more of the PAP values and one or more of the CO estimates to standard PAP and CO values respectively; and provide one or more outputs based on the comparisons of PAP and CO.

In some examples, the device can be an implantable device, such as a pressure sensor implanted in the pulmonary artery of a subject. Optionally, the device is a pressure sensor, which is optionally implanted in the pulmonary artery of the subject. Optionally, the device lacks percutaneous connections. Optionally, the device is energized from an external source. Optionally, the device is a passive sensor energized to return pressure readings by an electromagnetic field.

In some embodiments, the standard PAP value is one or more previously determined PAP values from the subject, the standard CO value is based on one or more previously estimated CO values from the subject, or combinations thereof. In certain embodiments, one or more of the standard pulmonary artery pressure values are optionally determined from a pulmonary artery pressure waveform obtained with a wireless sensor implanted in the subject. Therefore, in particular embodiments, the pulmonary artery pressure waveform is optionally obtained wirelessly and the standard values can be determined from a pulmonary artery waveform obtained wirelessly. In other embodiments, the standard PAP value is a clinically relevant target PAP value for the subject, the standard CO value is a clinically relevant CO target value for the subject, or combinations thereof, as described in more detail above.

Example outputs include indicators or predictors of improvement or worsening of the PAH in the subject (e.g., probabilities, scores, subject status indicators, trend values for PAP and/CO, graphs plotting values for PAP and/CO, etc.), physiological parameters (PAP, CO, etc.), deviation from target values for a subject, instructions for treatment (e.g., instructions for administration of a pharmaceutical agent), or combinations thereof. In one example, the one or

more PAP values are less than the standard PAP value and the one or more CO estimates are greater than or approximately equal to the standard CO value, or the one or more PAP values are approximately equal to the standard PAP value and the one or more CO estimates are greater than the standard CO value; and the one or more outputs comprise an indicator or predictor of improvement of the PAH in the subject. In another example, the one or more PAP values are greater than or approximately equal to the standard PAP value and the one or more CO estimates are less than the standard CO value, or (ii.) the one or more PAP values are greater than the standard PAP value and the one or more CO estimates are less than or approximately the standard CO value; and the one or more outputs comprise an indicator or predictor worsening of the PAH in the subject.

In certain embodiments, the cardiac output estimate includes a proportional estimate of flow impedance, based on measured changes in the average pulmonary artery systolic, diastolic, or mean pressures from initial method calibration to subsequent readings. In some of these embodiments, the proportional estimate of flow impedance can be provided as an output.

In certain embodiments, the pulmonary artery pressure waveform is optionally obtained outside of a typical clinical evaluation environment. For example, the pulmonary artery waveform is optionally obtained while the subject is exercising. Exercising includes any activity of the subject. For example, exercise or exercising includes activities of daily living, prescribed exercise, walking, biking, running or the like. Optionally, the pulmonary artery pressure waveform is obtained while the subject is asleep.

As described above, provided herein are methods of predicting an outcome, evaluating progress or improvement, or treating PAH in a subject. Such methods include administering an effective amount of a pharmaceutical agent to the subject. Optionally, the pharmaceutical agents are contained within a pharmaceutical composition.

Provided herein are compositions containing the provided pharmaceutical agents and a pharmaceutically acceptable carrier described herein. The herein provided compositions are suitable of administration in vitro or in vivo. By pharmaceutically acceptable carrier is meant a material that is not biologically or otherwise undesirable, i.e., the material is administered to a subject without causing undesirable biological effects or interacting in a deleterious manner with the other components of the pharmaceutical composition in which it is contained. The carrier is selected to minimize degradation of the active ingredient and to minimize adverse side effects in the subject.

Suitable carriers and their formulations are described in Remington: The Science and Practice of Pharmacy, 21st Edition, David B. Troy, ed., Lippicott Williams & Wilkins (2005).

Typically, an appropriate amount of a pharmaceutically-acceptable salt is used in the formulation to render the formulation isotonic. Examples of the pharmaceutically-acceptable carriers include, but are not limited to, sterile water, saline, buffered solutions like Ringer's solution, and dextrose solution. The pH of the solution is generally about 5 to about 8 or from about 7 to 7.5.

5 Other carriers include sustained release preparations such as semipermeable matrices of solid hydrophobic polymers containing the immunogenic polypeptides. Matrices are in the form of shaped articles, e.g., films, liposomes, or microparticles. Certain carriers may be more preferable depending upon, for instance, the route of administration and concentration of composition being administered. Carriers are those suitable for administration of the agent to
10 humans or other subjects.

The compositions are administered in a number of ways depending on whether local or systemic treatment is desired, and on the area to be treated. The compositions are administered via any of several routes of administration, including topically, orally, parenterally, intravenously, intra-articularly, intraperitoneally, intramuscularly, subcutaneously, intracavity,
15 transdermally, intrahepatically, intracranially, nebulization/inhalation, or by installation via bronchoscopy. Optionally, the composition is administered by oral inhalation, nasal inhalation, or intranasal mucosal administration. Administration of the compositions by inhalant can be through the nose or mouth via delivery by spraying or droplet mechanism, for example, in the form of an aerosol.

20 Preparations for parenteral administration include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils such as olive oil, and injectable organic esters such as ethyl oleate. Aqueous carriers include water, alcoholic/aqueous solutions, emulsions or suspensions, including saline and buffered media. Parenteral vehicles include sodium chloride solution,
25 Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's, or fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like. Preservatives and other additives are optionally present such as, for example, antimicrobials, anti-oxidants, chelating agents, and inert gases and the like.

Formulations for topical administration include ointments, lotions, creams, gels, drops,
30 suppositories, sprays, liquids, and powders. Conventional pharmaceutical carriers, aqueous, powder, or oily bases, thickeners and the like are optionally necessary or desirable.

Compositions for oral administration include powders or granules, suspension or solutions in water or non-aqueous media, capsules, sachets, or tablets. Thickeners, flavorings, diluents, emulsifiers, dispersing aids or binders are optionally desirable.

According to the methods taught herein, the subject is administered an effective amount of the agent, or an effective amount, or dosage, or dosage regimen is determined. The terms effective amount and effective dosage are used interchangeably. The term effective amount is defined as any amount, for example, to produce a desired physiologic response.

5 Effective amounts and schedules for administering the agent may be determined using, for example, PAP and/or CO values and estimates as described herein. The dosage ranges for administration are those large enough to produce the desired effect in which one or more symptoms of the disease or disorder are affected (e.g., reduced or delayed). The dosage should not be so large as to cause substantial adverse side effects, such as unwanted cross-reactions,
10 anaphylactic reactions, and the like. The dosage may vary with the age, condition, sex, the extent of the disease or disorder, route of administration, or whether other drugs are included in the regimen, and can be determined by one of skill in the art. The dosage can be adjusted by the individual physician in the event of any contraindications. Dosages can vary, and can be administered in one or more dose administrations daily, for one or several days. Guidance can
15 be found in the literature for appropriate dosages for given classes of pharmaceutical products.

 In some examples, the effective dosage or amount, or an effective dosage or treatment regimen or protocol is that which lowers or maintains PAP and/or that raises or maintains CO at a desired level. For example, a desired PAP and/or CO level is a level that is expected to have an improved outcome compared to a previous PAP and/or CO level or levels in an individual or
20 from a control determined from a population of individuals. Either may be referred to as a standard. Therefore, for example, an effective dose or amount is optionally that which reduces or maintains PAP and/or CO at a therapeutic level that is expected to result in an improved outcome or in one or more reduced or maintained clinical conditions.

 As used herein, the terms treatment, treat, or treating refers to a method of reducing the
25 effects of a disease or condition or symptom of the disease or condition. Thus in the disclosed method, treatment can refer to a 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or 100% reduction in the severity of an established disease or condition or symptom of the disease or condition. For example, a method for treating a disease is considered to be a treatment if there is a 10% reduction in one or more symptoms of the disease in a subject as compared to a control.
30 Thus, the reduction can be a 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, or any percent reduction in between 10% and 100% as compared to native or control levels. It is understood that treatment does not necessarily refer to a cure or complete ablation of the disease, condition, or symptoms of the disease or condition.

Example 1: Evaluation of PAH treatment using an implantable pressure sensor to monitor PAP.

A 53 year old black male presented with PAH. As shown in FIG. 1, the subject initially presented with a PAP above 30 mm Hg. As further shown in FIG. 1, treatment with Lasix and then Metolaxone reduced PAP in the subject to below 25 mm Hg. The subject was maintained between about 25 mmHg and 10 mm Hg. The reduction and maintenance of PAP indicated successful treatment of PAH in the subject.

Example 2: Hemodynamic parameters for evaluation and monitoring of PAH using an implantable pressure sensor.

As shown in FIGs. 2A and B, an implantable pressure sensor, as described herein, was used to evaluate CO. FIG. 2A indicates measurement of CO is subject having mPAP > 25 and a PVR >3. As shown in FIG. 2B, CO was in agreement with PVR across a wide PVR range.

FIG. 3 shows CO agreement with small pressure changes. Small mPAP changes (<5mm Hg) were common, occurring for 55 of 96 (57%) of right heart catheterization subjects. The level of CO agreement for these patients was comparable with larger mPAP changes. A one sample equivalence test was performed to compare the results for the low and high pressure change groups. This test demonstrated equivalence to the reference measurements with an equivalence margin of 0.5L/min.

FIG. 4 shows use of the implantable sensors described herein to determine changes in CO, TPR and PAP after medication revisions in subjects having PAH. As shown, the estimated CO was shown to rise after medication revision, while the TPR and mPAP were reduced. The data show the progression of PAH in subject following treatment. The data show trends in mPAP, CO and TPR in a subject with PAH. The data further show the combined use of mPAP, CO and TPR trends in monitoring a subject having PAH prior and subsequent to administration of a treatment to the subject.

FIG. 5 shows the estimated Cardiac Output during the follow-up measurement was determined using the initially determined constant term from baseline (A_0), which does not account for changing impedance: $CO_{es,t-z_0,i} = A_i \times SV_{p,t_0p.est} \times HR$. The effect of changing impedance was inferred by a scatter plot of the proportional residual error at follow-up, defined as $(CO_{est_z_0,i} - CO_{ref}) / CO_{es_z_0,i}$, relative to changes in average pulmonary arterial pressure from baseline. There was an observable trend of residual error with respect to mean pressure changes for mean pressure changes over a threshold value, over 25mm Hg in the provided example. The pattern of residual error as a function of mean pulmonary arterial pressure change over the

threshold value from baseline to follow-up, $\Delta\eta\tau\text{PAP}$, was characterized using an exponential regression, with constant term coefficient $B = 0.03$.

FIGs. 6A and 6B show Bland-Altman charts of CO estimate agreement with reference CO measurements performance using pressure data obtained from a CardioMEMS® (Atlanta, GA) wireless implantable sensor. FIG. 6A shows consistent accuracy agreement across the measurement range. FIG. 6B shows consistent accuracy agreement over extended timeframes.

Disclosed are materials, compositions, and components that can be used for, can be used in conjunction with, can be used in preparation for, or are products of the disclosed methods and compositions. These and other materials are disclosed herein, and it is understood that when combinations, subsets, interactions, groups, etc. of these materials are disclosed that while specific reference of each various individual and collective combinations and permutations of these compounds may not be explicitly disclosed, each is specifically contemplated and described herein. For example, if a method is disclosed and discussed and a number of modifications that can be made to a number of molecules including the method are discussed, each and every combination and permutation of the method, and the modifications that are possible are specifically contemplated unless specifically indicated to the contrary. Likewise, any subset or combination of these is also specifically contemplated and disclosed. This concept applies to all aspects of this disclosure including, but not limited to, steps in methods using the disclosed compositions. Thus, if there are a variety of additional steps that can be performed, it is understood that each of these additional steps can be performed with any specific method steps or combination of method steps of the disclosed methods, and that each such combination or subset of combinations is specifically contemplated and should be considered disclosed.

Publications cited herein and the material for which they are cited are hereby specifically incorporated by reference in their entireties.

WHAT IS CLAIMED IS:

1. A system for evaluating progress of pulmonary arterial hypertension (PAH) in a subject, or an outcome in a subject having PAH, comprising:
 - (a) a device configured to obtain a pulmonary artery pressure waveform;
 - (b) a processor; and
 - (c) a memory operably coupled to the processor, the memory having further computer-executable instructions stored thereon that, when executed by the processor, cause the processor to:
 - i. receive the pulmonary artery pressure waveform;
 - ii. determine one or more pulmonary artery pressure (PAP) values from the pulmonary artery waveform;
 - iii. estimate cardiac output (CO) using the pulmonary artery pressure waveform;
 - iv. compare one or more of the PAP values and one or more of the CO estimates to standard PAP and CO values respectively; and
 - v. provide one or more outputs based on the comparisons of PAP and CO.
2. The system of claim 1, wherein the standard PAP value is one or more previously determined PAP values from the subject.
3. The system of claim 1 or 2, wherein the standard CO value is based on one or more previously estimated CO values from the subject.
4. The system of claim 1, wherein the standard PAP value is a clinically relevant target PAP value for the subject.
5. The system of claim 1 or 4, wherein the standard CO value is a clinically relevant CO target value for the subject.
6. The system of any of claims 1-5, wherein (i.) the one or more PAP values are less than the standard PAP value and the one or more CO estimates are greater than or approximately equal to the standard CO value, or (ii.) the one or more PAP values are approximately equal to the standard PAP value and the one or more CO estimates are greater than the standard CO value; and
wherein the one or more outputs comprise an indicator or predictor of improvement of the PAH in the subject.

7. The system of any of claims 1-5, wherein (i.) the one or more PAP values are greater than or approximately equal to the standard PAP value and the one or more CO estimates are less than the standard CO value, or (ii.) the one or more PAP values are greater than the standard PAP value and the one or more CO estimates are less than or approximately the standard CO value; and

wherein the one or more outputs comprise an indicator or predictor worsening of the PAH in the subject

8. The system of any of claims 1-7, wherein the one or more outputs comprise a trend in PAP in the subject, a trend in CO in the subject, or a combination thereof.

9. The system of any of claims 1-8, wherein the one or more outputs comprise instructions for treatment.

10. The system of any of claims 1-9, wherein the one or more outputs comprise instructions for administration of a pharmaceutical agent.

11. The system of any of claims 1-10, wherein one or more of the standard pulmonary artery pressure values are determined from a pulmonary artery pressure waveform obtained with a wireless sensor implanted in the subject.

12. The system of any of claims 1-11, wherein the device comprises an implantable device.

13. The system of any of claims 1-12, wherein the device comprises a wireless sensor implanted in the subject.

14. The system of claim 13, wherein the implanted sensor is a pressure sensor.

15. The system of claim 14, wherein the pressure sensor is implanted in a pulmonary artery.

16. The system of claim 15, wherein the sensor lacks percutaneous connections.

17. The system of claim 16, wherein the sensor is energized from an external source.
18. The system of claim 17, wherein the sensor is a passive sensor energized to return pressure readings by an electromagnetic field.
19. The system of any of claims 1-18, wherein the pulmonary artery pressure waveform is wirelessly from the sensor.
20. The system of any of claims 1-19, wherein the pulmonary artery pressure waveform comprises a pulmonary artery pressure waveform obtained while the subject is exercising.
21. The system of any of claims 1-19, wherein the pulmonary artery pressure waveform comprises a pulmonary artery pressure waveform obtained while the subject is asleep.
22. The system of any of claims 1-21, wherein the cardiac output estimate includes a proportional estimate of flow impedance, based on measured changes in the average pulmonary artery systolic, diastolic, or mean pressures from initial method calibration to subsequent readings.
23. A method of processing a pulmonary artery pressure waveform, comprising:
 - (a) obtaining a pulmonary artery pressure waveform from a device configured to obtain a pulmonary artery pressure waveform from a subject;
 - (b) determining one or more pulmonary artery pressure (PAP) values from the pulmonary artery waveform;
 - (c) estimating cardiac output (CO) using the pulmonary artery pressure waveform;
 - (d) comparing one or more of the PAP values and one or more of the CO estimates to standard PAP and CO values respectively; and
 - (e) generating one or more outputs based on the comparisons of PAP and CO.
24. The method of claim 23, wherein the standard PAP value is one or more previously determined PAP values from the subject.
25. The method of claim 23 or 24, wherein the standard CO value is based on one or more previously estimated CO values from the subject.

26. The method of claim 23, wherein the standard PAP value is a clinically relevant target PAP value for the subject.

27. The method of claim 23 or 26, wherein the standard CO value is a clinically relevant CO target value for the subject.

28. The method of any of claims 23-27, wherein (i.) the one or more PAP values are less than the standard PAP value and the one or more CO estimates are greater than or approximately equal to the standard CO value, or (ii.) the one or more PAP values are approximately equal to the standard PAP value and the one or more CO estimates are greater than the standard CO value; and

wherein the one or more outputs comprise an indicator or predictor of improvement of the PAH in the subject.

29. The method of any of claims 23-27, wherein (i.) the one or more PAP values are greater than or approximately equal to the standard PAP value and the one or more CO estimates are less than the standard CO value, or (ii.) the one or more PAP values are greater than the standard PAP value and the one or more CO estimates are less than or approximately the standard CO value; and

wherein the one or more outputs comprise an indicator or predictor worsening of the PAH in the subject

30. The method of any of claims 23-29, wherein the device comprises a wireless sensor implanted in the subject.

31. The method of any of claims 23-30, wherein one or more of the standard pulmonary artery pressure values are determined from a pulmonary artery pressure waveform obtained with a wireless sensor implanted in the subject.

32. The method of any of claims 23-31, wherein the pulmonary artery pressure waveform is obtained wirelessly.

33. The method of claim 32, wherein the pulmonary artery pressure waveform is obtained using an implanted sensor.

34. The method of claim 33, wherein the implanted sensor is a pressure sensor.
35. The method of claim 34, wherein the pressure sensor is implanted in a pulmonary artery.
36. The method of claim 35, wherein the sensor lacks percutaneous connections.
37. The method of claim 36, wherein the sensor is energized from an external source.
38. The method of claim 37, wherein the sensor is a passive sensor energized to return pressure readings by an electromagnetic field.
39. The method of any of claims 23-38, wherein the pulmonary artery pressure waveform is obtained while the subject is exercising.
40. The method of any of claims 23-38, wherein the pulmonary artery pressure waveform is obtained while the subject is asleep.
41. A method of evaluating progress of pulmonary arterial hypertension (PAH) in a subject, or an outcome in a subject having PAH, comprising:
- (a) obtaining a pulmonary artery pressure waveform from the subject;
 - (b) determining one or more pulmonary artery pressure (PAP) values from the pulmonary artery waveform;
 - (c) estimating cardiac output (CO) using the pulmonary artery pressure waveform;
 - (d) comparing one or more of the PAP values and one or more of the CO estimates to standard PAP and CO values respectively; and
 - (e) using the comparisons of PAP and CO to monitor the PAH progression or outcome in the subject.
42. The method of claim 41, wherein the standard PAP value is one or more previously determined PAP values from the subject.

43. The method of claim 41 or 42, wherein the standard CO value is based on one or more previously estimated CO values from the subject.
44. The method of claim 41, wherein the standard PAP value is a clinically relevant target PAP value for the subject.
45. The method of claim 41 or 44, wherein the standard CO value is a clinically relevant CO target value for the subject.
46. The method of claims 41-45, wherein:
- a. a decrease in the one or more PAP values compared to the standard PAP value combined with one or more increased or stable CO estimates compared to the standard CO value, or
 - b. one or more stable PAP values compared to the standard PAP value combined with one or more increased CO estimates compared to the CO standard value indicates or predicts improvement of the PAH in the subject.
47. The method of claims 41-45, wherein:
- a. a decrease in one or more CO estimates compared to the standard CO value combined with one or more increased or stable PAP values compared to the standard PAP value, or
 - b. an increase in one or more PAP values compared to the standard PAP values combined with a stable or decreased CO value compared to the standard CO value indicates or predicts worsening of the PAH in the subject.
48. The method of claims 41-47, wherein the obtained pulmonary artery pressure waveform is obtained with a wireless sensor implanted in the subject.
49. The method of claims 41-48, wherein one or more of the standard pulmonary artery pressure values are determined from a pulmonary artery pressure waveform obtained with a wireless sensor implanted in the subject.
50. The method of claims 41-49, further comprising administering a pharmaceutical agent to the subject.

51. The method of claims 41-50, wherein the pulmonary artery pressure waveform is obtained wirelessly.

52. The method of claim 51, wherein the pulmonary artery pressure waveform is obtained using an implanted sensor.

53. The method of claim 52, wherein the implanted sensor is a pressure sensor.

54. The method of claim 53, wherein the pressure sensor is implanted in a pulmonary artery.

55. The method of claim 54, wherein the sensor lacks percutaneous connections.

56. The method of claim 55, wherein the sensor is energized from an external source.

57. The method of claim 56, wherein the sensor is a passive sensor energized to return pressure readings by an electromagnetic field.

58. The method of claims 41-57, wherein the pulmonary artery pressure waveform is obtained while the subject is exercising.

59. The method of claims 41-57, wherein the pulmonary artery pressure waveform is obtained while the subject is asleep.

60. The method of claim 50, further comprising modifying or maintaining the administration of the pharmaceutical agent.

61. The method of claim 60, further comprising maintaining administration of the pharmaceutical agent at its current dosage and or dosing regimen when improvement is indicated.

62. The method of claim 60, wherein the pharmaceutical agent is changed, or the dosage or dosing regimen modified when improvement is not indicated.

63. A method for evaluating treatment of a subject having PAH, comprising:

- (a) administering an agent to the subject;
- (b) obtaining a pulmonary artery pressure waveform from the subject;
- (c) determining one or more pulmonary artery pressure (PAP) values from the pulmonary artery waveform;
- (d) estimating cardiac output (CO) using the pulmonary artery pressure waveform;
- (e) comparing one or more of the PAP values and one or more of the CO estimates to standard PAP and CO values respectively; and
- (f) using the comparisons of PAP and CO to monitor the effect of the administered agent on the PAH condition in the subject.

64. The method of claim 63, wherein the standard PAP value is based on one or more previously determined PAP values from the subject.

65. The method of claims 63 or 64, wherein the standard CO value is based on one or more previously estimated CO values from the subject.

66. The method of claim 63, wherein the standard PAP value is a clinically relevant target PAP value for the subject.

67. The method of claim 63 or 66, wherein the standard CO value is a clinically relevant CO target value for the subject.

68. The method of claims 63-67, wherein:

- a. a decrease in the one or more PAP values compared to the standard PAP value combined with one or more increased or stable CO estimates compared to the standard CO value, or
- b. one or more stable PAP values compared to the standard PAP value combined with one or more increased CO estimates compared to the CO standard value indicates or predicts improvement of the PAH in the subject.

69. The method of claims 63-67, wherein:

- a. a decrease in one or more CO estimates compared to the standard CO value combined with one or more increased or stable PAP values compared to the standard PAP value, or

- b. an increase in one or more PAP values compared to the standard PAP values combined with a stable or decreased CO value compared to the standard CO value indicates or predicts worsening of the PAH in the subject.

70. The method of claim 63-69, wherein the standard is a PAP of about 25mmHg.

71. The method of claim 70, wherein the obtained reading is less than 25mmHg.

72. The method of claim 71, wherein one or more PAP values of the subject determined prior to determining the PAP value from the obtained pulmonary artery pressure waveform are greater than 25mmHg.

73. The method of claims 63-72, wherein the pulmonary artery pressure waveform is obtained is obtained wirelessly.

74. The method of claim 73, wherein the pulmonary artery pressure waveform is obtained using an implanted sensor.

75. The method of claim 74, wherein the implanted sensor is a pressure sensor.

76. The method of claim 75, wherein the pressure sensor is implanted in a pulmonary artery.

77. The method of claim 76, wherein the sensor lacks percutaneous connections.

78. The method of claim 77, wherein the sensor is energized from an external source.

79. The method of claim 78, wherein the sensor is a passive sensor energized to return pressure readings by an electromagnetic field.

80. The method of claims 63-79, wherein the pulmonary artery pressure waveform is obtained while the subject is exercising.

81. The method of claims 63-79, wherein the pulmonary artery pressure waveform is obtained while the subject is asleep.

82. The method of claims 63-81, wherein the monitored effect is used to determine an effective dosage for the agent.

83. The method of claims 63-82, further comprising modifying or maintaining the administration of the pharmaceutical agent.

84. The method of claim 83, further comprising maintaining administration of the pharmaceutical agent at its current dosage and or dosing regimen when improvement is indicated.

85. The method of claim 83, wherein the pharmaceutical agent is changed, or the dosage or dosing regimen modified when improvement is not indicated.

86. A method for evaluating treatment of a subject having PAH, comprising:

- (a) administering an agent to the subject;
- (b) obtaining a pulmonary artery pressure waveform from the subject;
- (c) determining one or more pulmonary artery pressure (PAP) values from the pulmonary artery waveform;
- (d) comparing one or more of the PAP values to a standard PAP value; and
- (e) using the comparison of PAP to monitor the effect of the administered agent on the PAH condition in the subject.

87. The method of claim 86, wherein the standard PAP value is based on one or more previously determined PAP values from the subject.

88. The method of claim 86, wherein the standard PAP value is a clinically relevant target PAP value for the subject.

89. The method of claims 86-88, wherein the obtained pulmonary artery pressure waveform is obtained with a wireless sensor implanted in the subject.

90. The method of claims 86-89, wherein one or more of the standard pulmonary artery pressure values are determined from a pulmonary artery pressure waveform obtained with a wireless sensor implanted in the subject.

91. The method of claims 86-90, wherein a decrease in the one or more determined PAP values compared to the PAP standard indicates a beneficial effect of the administered agent on the PAH condition in the subject.

92. The method of claims 86-90, wherein an increase in the one or more determined PAP values compared to the PAP standard indicates no beneficial effect of the administered agent on the PAH condition in the subject.

93. A method for evaluating treatment of a subject having PAH, comprising:

- (a) administering an agent to the subject;
- (b) obtaining a pulmonary artery pressure waveform from the subject;
- (c) estimating cardiac output (CO) using the pulmonary artery pressure waveform;
- (d) comparing one or more of the estimated CO values to a standard CO value; and
- (e) using the comparison of CO to monitor the effect of the administered agent on the PAH condition in the subject.

94. The method of claim 93, wherein the standard CO value is based on one or more previously estimated CO values from the subject.

95. The method of claim 93, wherein the standard CO value is a clinically relevant target CO value for the subject.

96. The method of claims 93-95, wherein the obtained pulmonary artery pressure waveform is obtained with a wireless sensor implanted in the subject.

97. The method of claims 93-96, wherein one or more of the standard CO value is determined from a pulmonary artery pressure waveform obtained with a wireless sensor implanted in the subject.

98. The method of claims 93-97, wherein an increase in the one or more estimated CO values compared to the CO standard indicates a beneficial effect of the administered agent on the PAH condition in the subject.

99. The method of claims 93-97, wherein a decrease in the one or more estimated CO values compared to the CO standard indicates no beneficial effect of the administered agent on the PAH condition in the subject.

100. The method of claims 23-99, wherein the cardiac output estimate includes a proportional estimate of flow impedance, based on measured changes in the average pulmonary artery systolic, diastolic, or mean pressures from initial method calibration to subsequent readings.

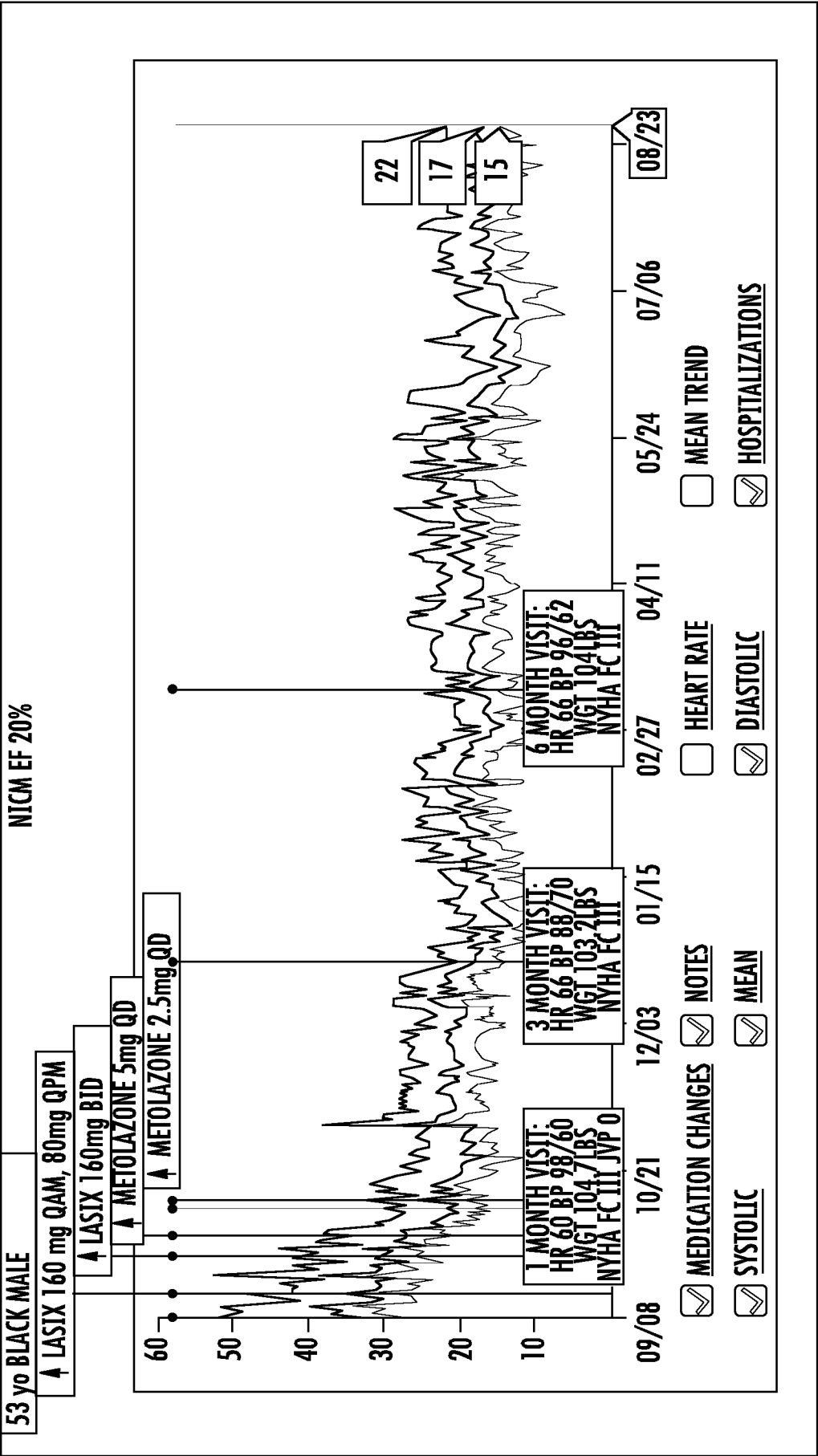
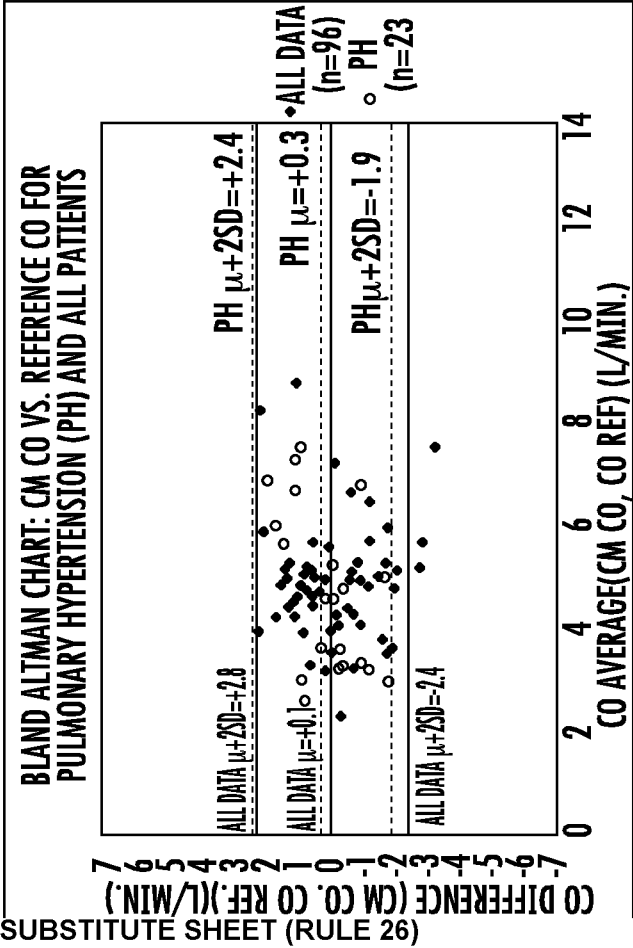


FIG. 1

CARDIAC OUTPUT: READY FOR PAH USE

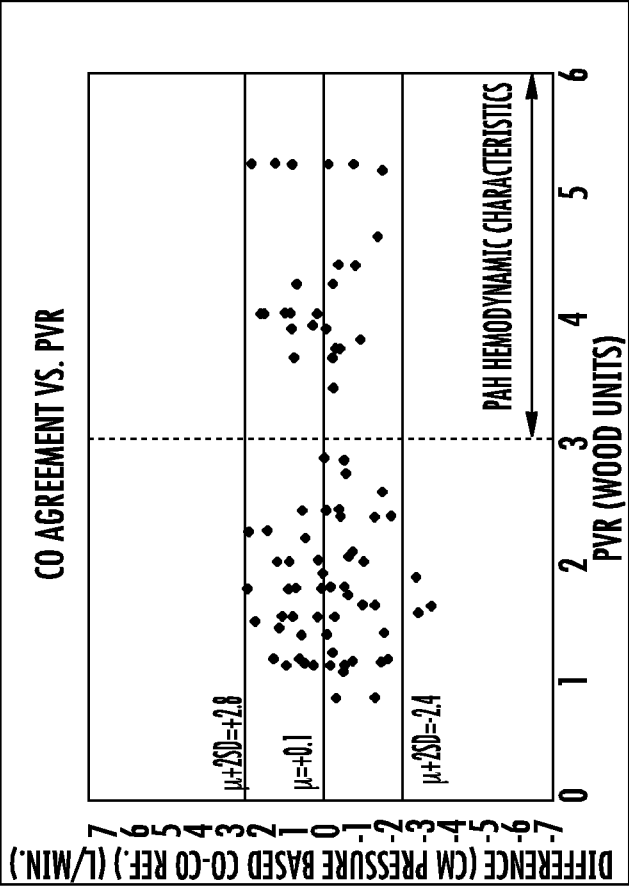
CONSISTENT AND ACCURATE CO PERFORMANCE:

IN PH COHORT
(mPAP>25 AND PVR>3)



A

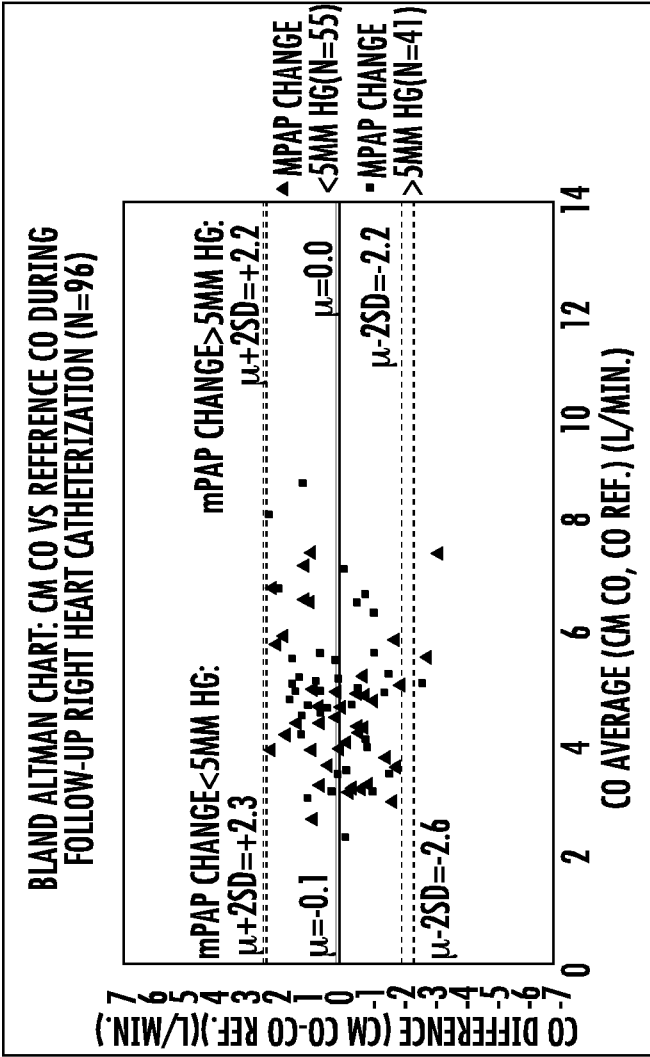
ACROSS WIDE PVR RANGE



B

FIG. 2

CARDIAC OUTPUT AGREEMENT
WITH SMALL PRESSURE CHANGES

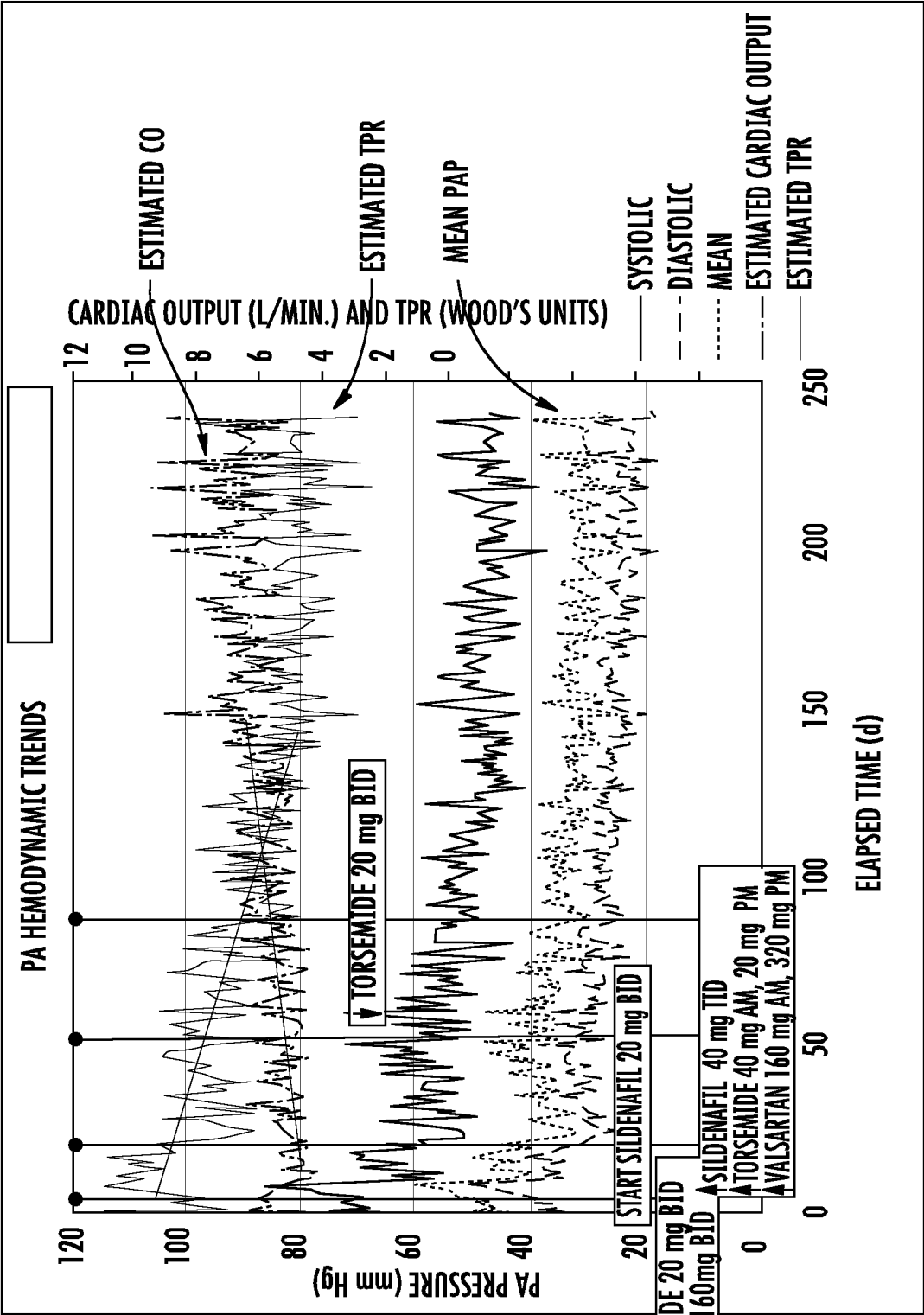


- SMALL mPAP CHANGES (<5MM HG) WERE COMMON, OCCURRING FOR 55 OF 96 (57%) OF THE FOLLOW-UP RHC'S.
- THE LEVEL OF CO AGREEMENT FOR THESE PATIENTS WAS COMPARABLE TO THOSE WITH LARGER mPAP PRESSURE CHANGES.
- A ONE-SAMPLE EQUIVALENCE TEST¹ WAS PERFORMED TO COMPARE THE RESULTS FOR THE LOW AND HIGH PRESSURE CHANGE GROUPS. THIS TEST DEMONSTRATED EQUIVALENCE TO THE REFERENCE MEASUREMENTS WITHIN AN EQUIVALENCE MARGIN OF 0.5L/MIN.:

GROUP	OBS	MEAN	STD.ERR.	[90%CONF.INTERVAL]
mPAP CHANGE>5 mm Hg	41	0.03	0.17	-0.259 0.323
mPAP CHANGE<5 mm Hg	55	-0.13	0.16	-0.401 0.146

FIG. 3

EXAMPLE PRESSURE, CARDIAC OUTPUT, AND
TPR TRENDS CHART



ELEVATED TPR,
SECONDARY
PULMONARY
HYPERTENSION

ABLE TO
DETERMINE
CHANGE IN
CO, TPR,
AND PA
PRESSURE
TRENDS AFTER
MEDICATION
REVISIONS

FIG. 4

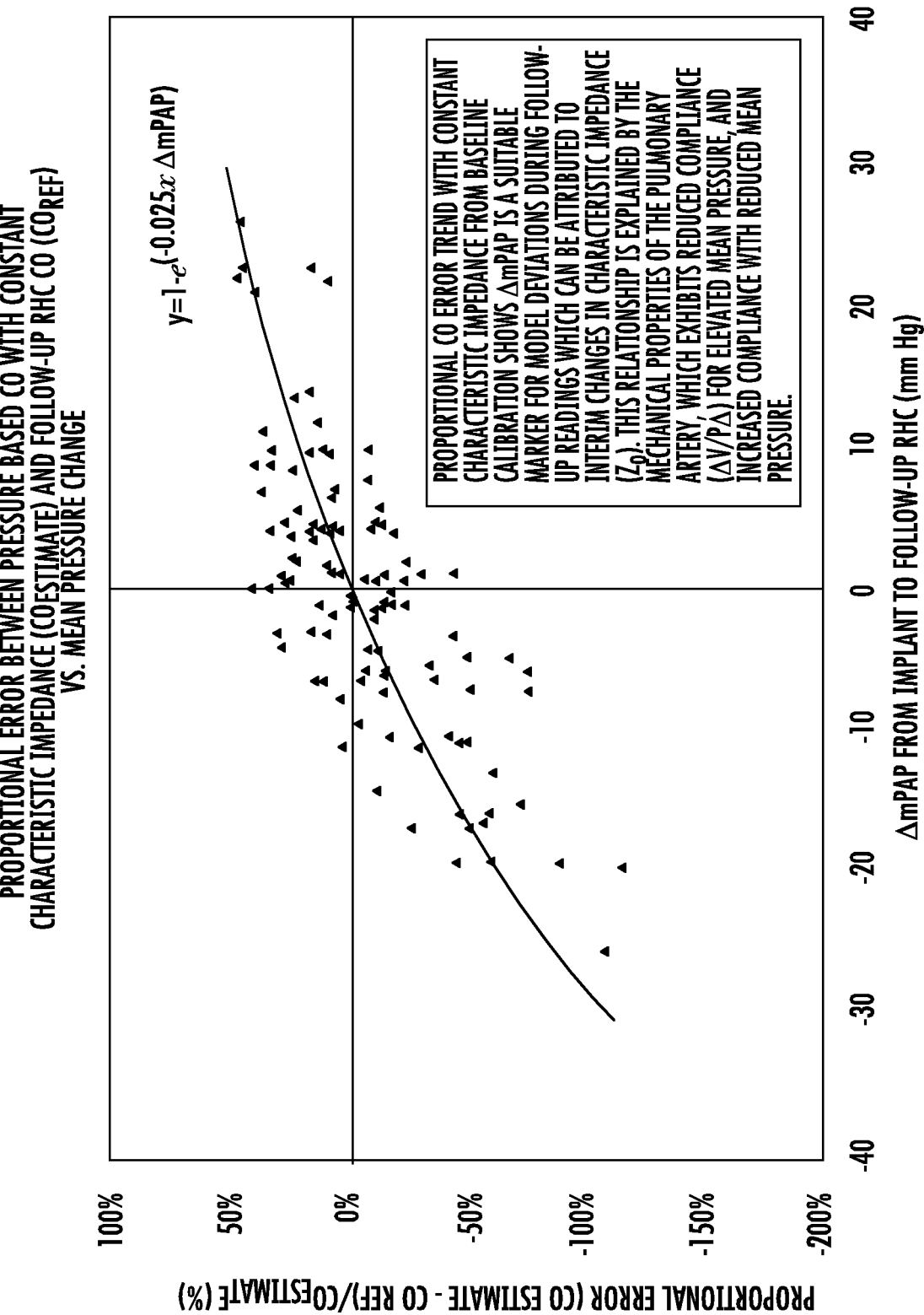


FIG. 5

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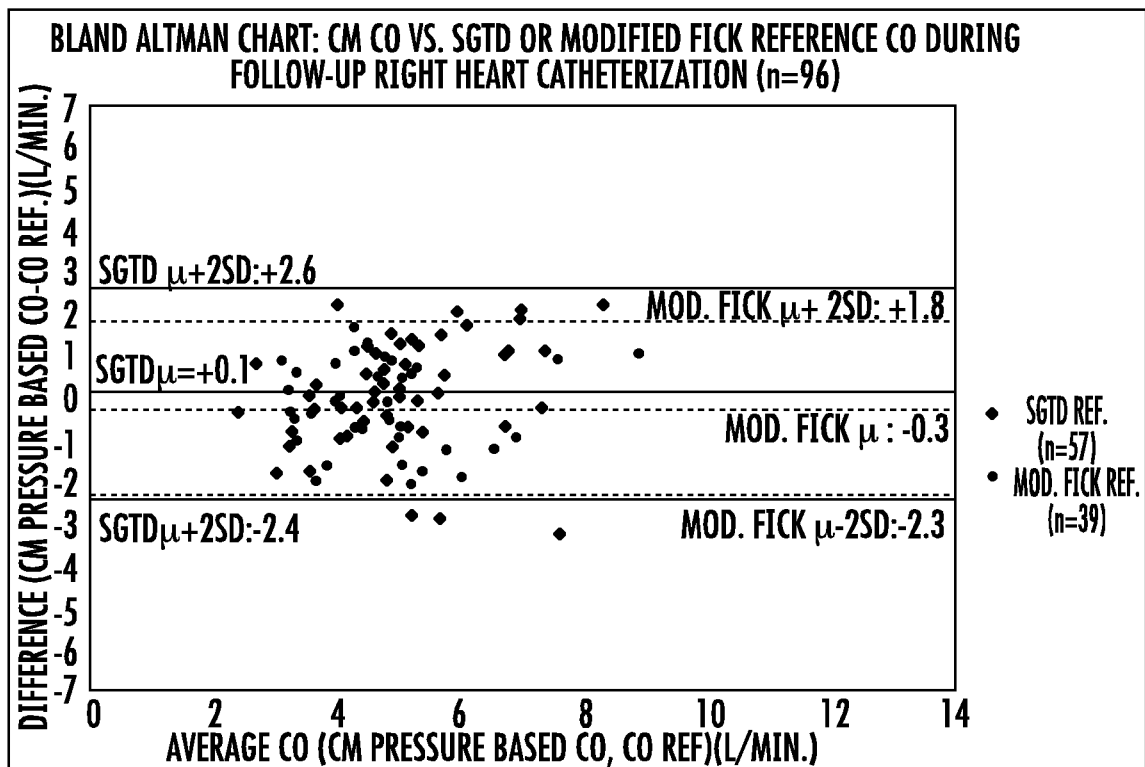


FIG. 6A

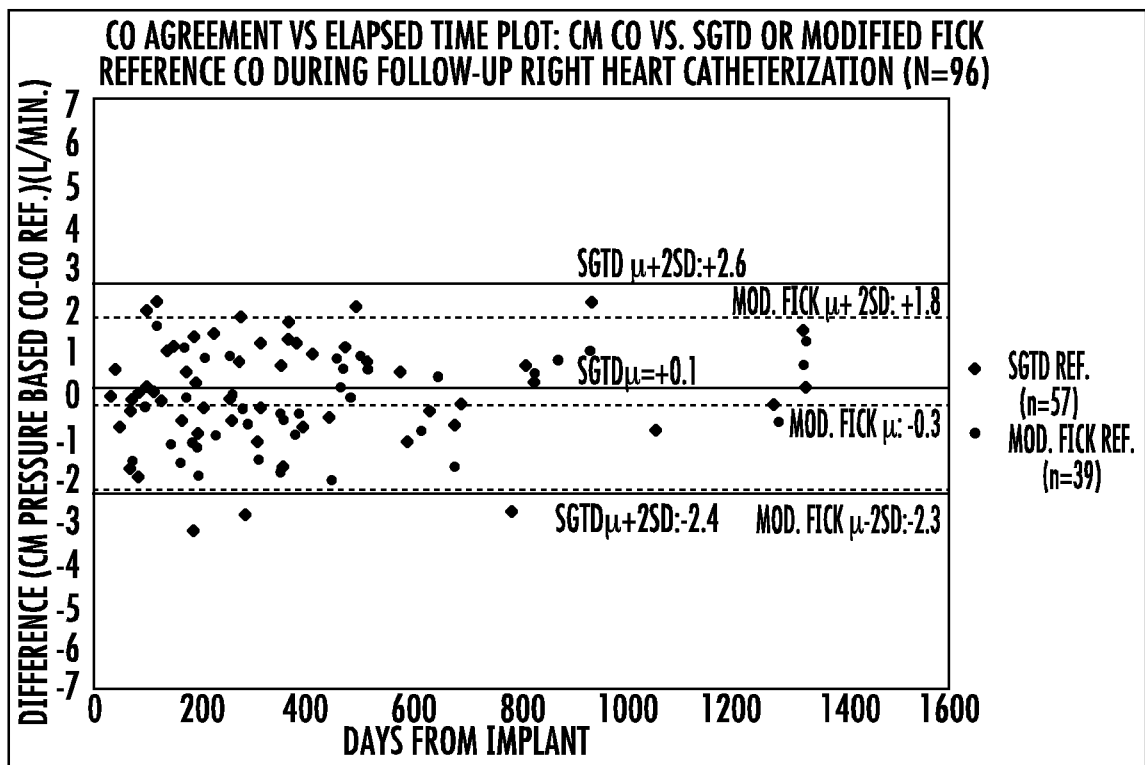
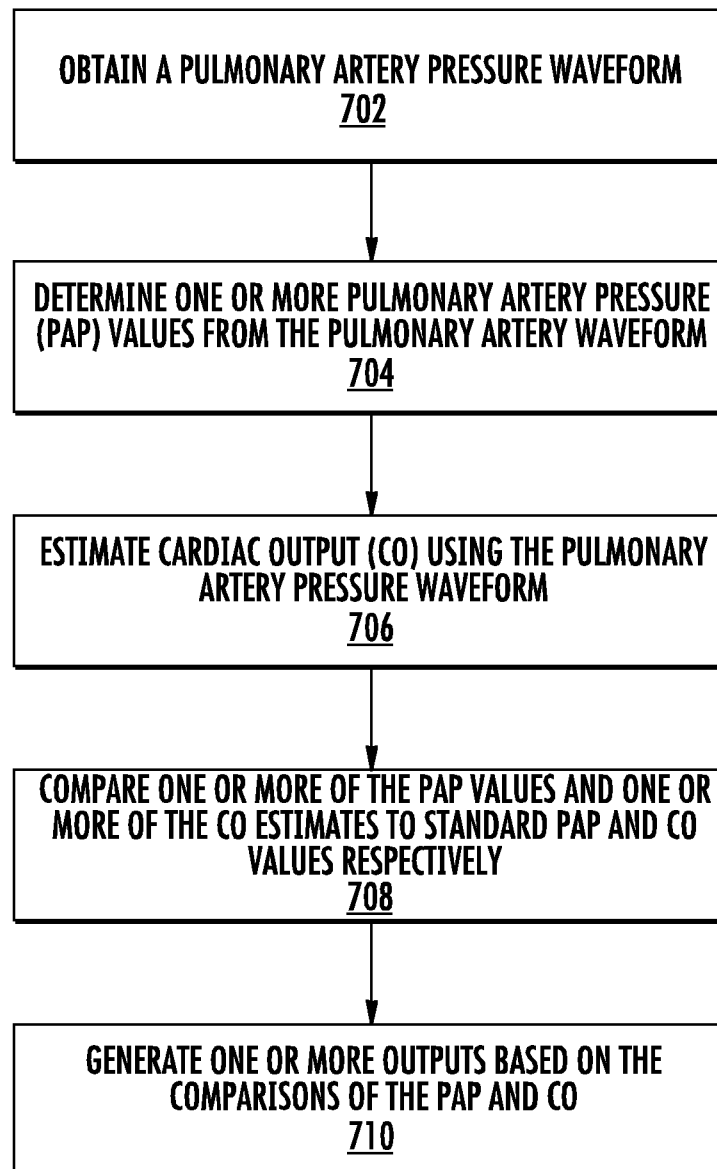


FIG. 6B

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700**FIG. 7**

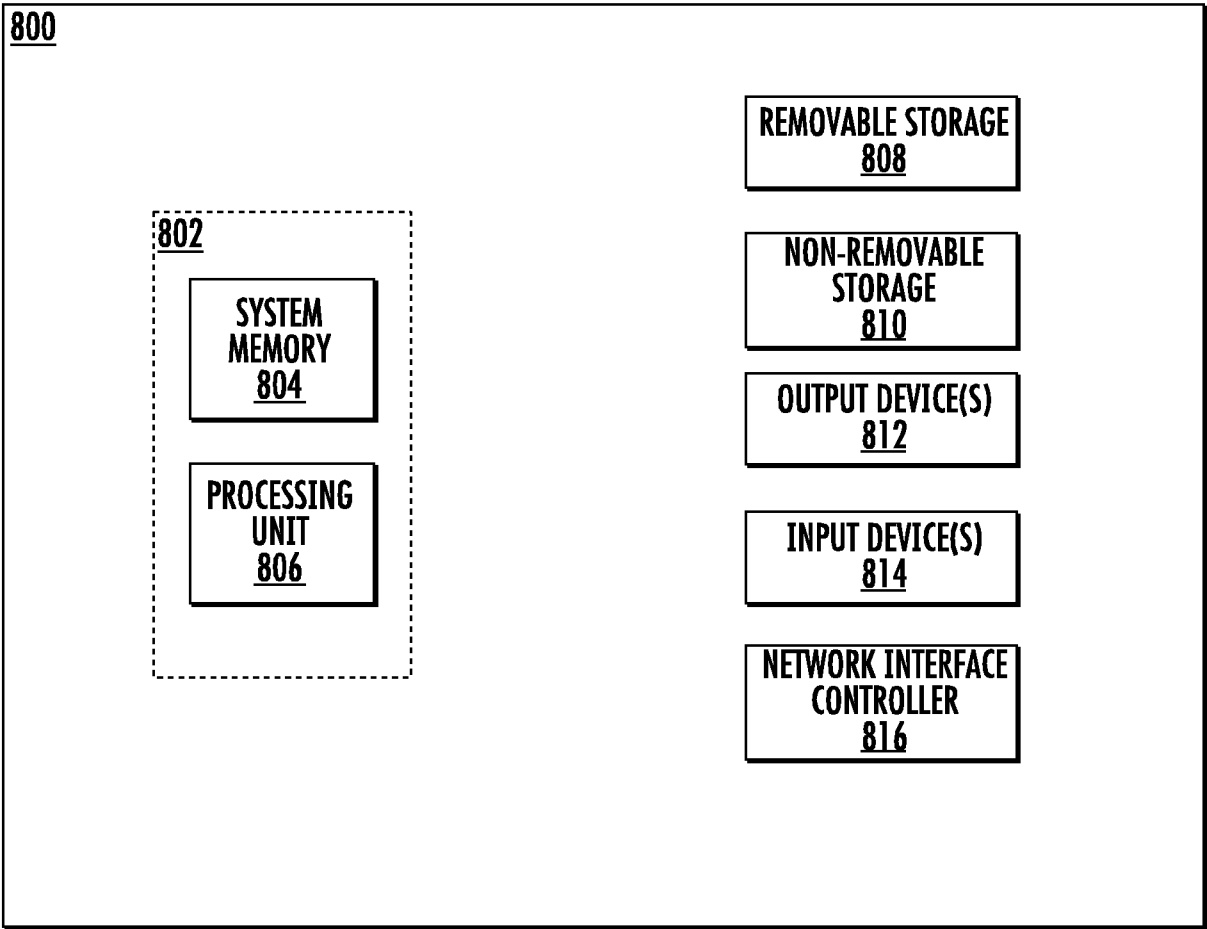


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US201 3/071 294

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61 B 5/021 , 5/029 (2014.01)

USPC - 600/485

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)

IPC(8) - A61B 5/00, 5/02, 5/021, 5/026, 5/029 (2014.01)

USPC - 600/300, 301, 481, 485, 486, 526

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

CPC - A61B 5/00, 5/02, 5/02028, 5/021, 5/026, 5/027, 5/029, 8/06, 8/065 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase, Google Patents, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7,024,244 B2 (MUHLENBERG et al) 04 April 2006 (04.04.2006) entire document	1-5, 23-27, 41-45, 63-67, 86-88, 93-95
A	US 2010/0094144 A1 (DORON) 15 April 2010 (15.04.2010) entire document	1-5, 23-27, 41-45, 63-67, 86-88, 93-95
A	US 2010/0286535 A1 (BLOMQVIST) 11 November 2010 (11.11.2010) entire document	1-5, 23-27, 41-45, 63-67, 86-88, 93-95
A	US 201 1/0098767 A1 (SUGIMACHI et al) 28 April 201 1 (28.04.201 1) entire document	1-5, 23-27, 41-45, 63-67, 86-88, 93-95

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

22 January 2014

Date of mailing of the international search report

07 FEB. 2014

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US20 13/07 1294

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

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

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

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos. : 6-22,28-40,46-62,68-85,89-92,96-100
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

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

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

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee,
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

专利名称(译)	用于肺动脉高压 (PAH) 评估和治疗的装置 , 系统和方法		
公开(公告)号	EP2922465A1	公开(公告)日	2015-09-30
申请号	EP2013856796	申请日	2013-11-21
[标]申请(专利权)人(译)	的CardioMEMS		
申请(专利权)人(译)	的CardioMEMS , INC.		
当前申请(专利权)人(译)	的CardioMEMS , INC.		
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发明人	WHITE, JASON JORDAN, RALPH MOORE, JOHN, ERIK YADAV, JAY		
IPC分类号	A61B5/021 A61B5/029 A61B5/00 A61B5/02 A61B5/0215 G06F19/00		
CPC分类号	A61B5/002 A61B5/02028 A61B5/0215 A61B5/029 A61B5/686 A61B5/7275 A61B5/7282 A61B2560 /0219 A61B2560/0228 A61B2562/0247 G06F19/3456 G16H20/10 G16H50/20 G16H50/30 A61B5/02		
优先权	61/728913 2012-11-21 US 61/799536 2013-03-15 US		
其他公开文献	EP2922465A4		
外部链接	Espacenet		

摘要(译)

本文提供了使用肺动脉压 (PAP) 值和/或心输出量 (CO) 估计来评估 , 治疗和开发肺动脉高压 (PAH) 的新治疗的装置 , 系统和方法。用于评估肺动脉高压 (PAH) 进展的系统包括配置成获得肺动脉压力波形的装置 , 处理器和耦合到处理器的存储器。存储器使处理器接收肺动脉压力波形 , 确定一个或多个肺动脉压 (PAP) 值 , 并估计心输出量 (CO) 。