SUMMARY

[0005] In one example, a method includes detecting, via a sensor, vibrations originating from a vein of a subject and obtaining an intensity spectrum of the detected vibrations over a range of frequencies. The method further includes using the obtained intensity spectrum to determine a metric selected from a group that includes: a pulmonary capillary wedge pressure (PCWP), a mean pulmonary arterial pressure, a pulmonary artery diastolic pressure, a left ventricular end diastolic pressure, a left ventricular end diastolic volume, a cardiac output, total blood volume, and a volume responsiveness of the subject.

[0005a] In one aspect, the present disclosure refers to a method comprising:

(a) detecting, via a sensor, vibrations originating from a vein of a subject;

(b) obtaining an intensity spectrum of the detected vibrations over a range of frequencies, wherein obtaining the intensity spectrum comprises performing a fast Fourier transform (FFT) upon a signal representing the detected vibrations to yield one or more intensities corresponding respectively to one or more frequencies of the detected vibrations; and

(c) using the obtained intensity spectrum to determine: a pulmonary capillary wedge pressure (PCWP) of the subject, wherein using the obtained intensity spectrum comprises calculating a weighted sum of the one or more intensities yielded by the FFT, wherein calculating the weighted sum comprises calculating a weighted sum of respective intensities of the subject's respiration rate, pulse rate, and one or more harmonics of the pulse rate, and wherein using the obtained intensity spectrum further comprises dividing the weighted sum by a sum of the respective intensities of the respiration rate, the pulse rate, and the one or more harmonics of the pulse rate.

[0006] In another example, a computing device includes one or more processors, a sensor, and a computer readable medium storing instructions that, when executed by the one or more processors, cause the computing device to perform functions. The functions include detecting, via the sensor, vibrations originating from a vein of a subject and obtaining an intensity spectrum of the detected vibrations over a range of frequencies. The functions further include using the obtained intensity spectrum to determine a metric selected from a group that includes: a pulmonary capillary wedge pressure (PCWP), a mean pulmonary arterial pressure, a pulmonary artery diastolic pressure, a left ventricular end diastolic pressure, a left ventricular end diastolic volume, a cardiac output, total blood volume, and a volume responsiveness of the subject.

[0006a] In another aspect, the present disclosure refers to a computing device comprising:

one or more processors; a sensor; and a computer readable medium storing instructions that, when executed by the one or more processors, cause the computing device to perform any of the methods as disclosed herein.

[0007] In yet another example, a non-transitory computer readable medium stores instructions that, when executed by a computing device that includes a sensor, cause the computing device to perform functions. The functions include detecting, via the sensor, vibrations originating from a vein of a subject and obtaining an intensity spectrum of the detected vibrations over a range of frequencies. The functions further include using the obtained intensity spectrum to determine a metric selected from a group that includes: a pulmonary capillary wedge pressure (PCWP), a mean pulmonary arterial pressure, a

CLAIMS

What is claimed is:

1. A method comprising:

(a) detecting, via a sensor, vibrations originating from a vein of a subject;

(b) obtaining an intensity spectrum of the detected vibrations over a range of frequencies, wherein obtaining the intensity spectrum comprises performing a fast Fourier transform (FFT) upon a signal representing the detected vibrations to yield one or more intensities corresponding respectively to one or more frequencies of the detected vibrations; and

(c) using the obtained intensity spectrum to determine: a pulmonary capillary wedge pressure (PCWP) of the subject, wherein using the obtained intensity spectrum comprises calculating a weighted sum of the one or more intensities yielded by the FFT, wherein calculating the weighted sum comprises calculating a weighted sum of respective intensities of the subject's respiration rate, pulse rate, and one or more harmonics of the pulse rate, and wherein using the obtained intensity spectrum further comprises dividing the weighted sum by a sum of the respective intensities of the respiration rate, the pulse rate, and the one or more harmonics of the pulse rate.

2. The method of claim 1, wherein the sensor comprises a piezoelectric sensor, a pressure sensor, a force sensor, a tonometer, an ultrasound probe, or a pressure transducer.

3. The method of any of claims 1 or 2, wherein the vibrations comprise vibrations of a wall of the vein produced by fluid flowing through the vein.

4. The method of any of claims 1-3, wherein the sensor is positioned proximately to a peripheral vein of the subject, and wherein the vibrations originate from the peripheral vein of the subject.

5. The method of any of claims 1-4, wherein the subject is a human subject or an animal subject.

6. The method of any of claims 1-5, wherein the subject is breathing spontaneously while the vibrations are detected.

7. The method of any of claims 1-6, wherein the range of frequencies is 0.05 Hz to 25 Hz.

8. The method of any of claims 1-7, wherein performing the FFT comprises performing the FFT after performing an autocorrelation of the signal.

9. The method of any of claims 1-8, wherein performing the FFT comprises performing the FFT after performing a Hilbert-Huang Transform (HHT) or an empirical mode decomposition (EMD) upon the signal.

10. The method of any of claims 1-9, wherein performing the FFT comprises performing a nonlinear FFT.

11. The method of any of claims 1-10, wherein using the obtained intensity spectrum comprises calculating a second sum of respective intensities of two or more harmonics of a pulse rate of the subject.

12. The method of claim 11, wherein using the obtained intensity spectrum further comprises dividing the second sum by a sum of respective intensities of the subject's pulse rate and one or more harmonics of the pulse rate.

13. The method of any of claims 1-12, wherein using the obtained intensity spectrum comprises calculating a quotient of an intensity of the respiration rate divided by an intensity of the pulse rate.

14. The method of any of claims 1-13, wherein A_0 is an intensity of the subject's respiration rate, A_1 is an intensity of the subject's pulse rate (f_1), A_2, A_3, A_4, A_5, A_6, A_7, and A_8 are respective intensities of $2f_1$, $3f_1$, $4f_1$, $5f_1$, $6f_1$, $7f_1$, and $8f_1$, and wherein using the obtained intensity spectrum comprises calculating a score equal to: $6.5+4.8(0.92A_0+2A_1+0.4A_2+0.2A_3)/(A_0+A_1+A_2+A_3)+44*(A_4+A_5+A_6+A_7+A_8)/(A_1+A_2+A_3+A_4+A_5+A_6+A_7+A_8)+0.0296(A_0/A_1)$.

15. The method of any of claims 1-14, wherein using the obtained intensity spectrum comprises using an algorithm to generate a numerical score.

16. The method of claim 15, further comprising iterative derivation using leverage plots of the contribution of one or more of f_0 (respiration rate), f_1 (pulse rate), $2f_1$, $3f_1$, $4f_1$, $5f_1$, $6f_1$, $7f_1$, and/or $8f_1$ to the data collected for pulmonary capillary wedge pressure (PCWP), a mean pulmonary arterial pressure, a pulmonary artery diastolic pressure, a left ventricular end diastolic pressure, a left ventricular end diastolic volume, a cardiac output, total blood volume, or volume responsiveness, wherein log worth of the values are used to determine optimal weighting factors and constants to define a non-invasive venous waveform analysis (NIVA) volume index or score, wherein the algorithm comprises calculating a ratio of a sum of the higher harmonics of pulse rate to a sum of the amplitude of lower harmonics of pulse rate modified by a constant that normalizes the data to a known clinical output such as a pulmonary capillary wedge pressure (PCWP), a mean pulmonary arterial pressure, a pulmonary artery diastolic pressure, a left ventricular end diastolic pressure, a left ventricular end diastolic volume, a cardiac output, total blood volume, or a volume responsiveness of the subject according to $a(f_0) + b(f_1) + c(f_2) + d(f_3) + e(f_4) + g(f_5) + h(f_6) + i(f_7) + j(f_8) + (\kappa)$ divided by $l(f_0) + m(f_1) + n(f_2) + o(f_3) + p(f_4) + q(f_5) + r(f_6) + s(f_7) + t(f_8) + (\gamma)$, wherein f_0 and f_1 are frequencies derived from a fast Fourier transformation of the venous waveform and κ, γ, a, b, c, d, e, g, h, i, j, l, m, n, o, p, q, r, s, t are numerical constants that weight and normalize the algorithm.

17. The method of any of claims 1-16, wherein the method comprises carrying out steps (a)-(c) a first time prior to treatment of the subject and a second time after carrying out the treatment.

18. The method of any of claims 1-17, wherein the subject is suffering from increased or decreased cardiac output compared to control or increased or decreased intravascular volume status compared to control.

19. The method of any of claims 1-18, wherein the subject is to undergo cardiac catheterization, or has undergone cardiac catheterization or a minimally or non-invasive method to determine cardiac output or volume status.

20. The method of any of claims 1-19, further comprising determining an effect administering a fluid to the subject would have on a cardiac output of the subject.

21. The method of any of claims 1-20, further comprising: performing steps (a)-(c) to diagnose respiratory distress or hypoventilation due to one or more of the following conditions: pneumonia, cardiac disorders, sepsis, asthma, obstructive sleep apnea, hypopnea, anesthesia, pain, or narcotic use.

22. The method of any of claims 1-21, wherein using the obtained intensity spectrum comprises using the obtained intensity spectrum to determine a PCWP of the subject.

23. A computing device comprising:

one or more processors;

a sensor; and

a computer readable medium storing instructions that, when executed by the one or more processors, cause the computing device to perform any of the methods of claims 1-22.

24. A non-transitory computer readable medium storing instructions that, when executed by the computing device of claim 23, cause the computing device to perform any of the methods of claims 1-22.