OPTICAL BRAIN MONITORING IN RESUSCITATION AND EMERGENCY CARE

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Prov. App. No. 63/570,997, filed on March 28, 2024, entitled, "OPTICAL BRAIN MONITORING IN RESUSCITATION AND EMERGENCY CARE."

BACKGROUND

[0002] Available metrics, such as to assess patient response and brain oxygenation during resuscitation and emergency care treatment, and to optimize such treatment, have remained limited and problematic.

[0003] Various metrics have been used in attempting to assess such treatment and resulting patient oxygenation, but each has limitations. For example, end-tidal carbon dioxide (ETCO2) has been used in attempting to assess the effectiveness of CPR chest compression treatment, including in low blood flow patient states, as may be present in emergency care situations. However, use of ETCO2 in this regard may rely on problematic assumptions, including that changes in measured ETCO2 are exclusively due to improved patient cardiac output and blood flow. Often, however, this is not the case. While the reasons for this are difficult to identify with certainty, it is possible that chest compressions alter aspects of gas exchange in the lungs, thereby affecting ETCO2 in ways that are not directly related to increased cardiac output. As such, use of ETCO2 has limitations. Blood pressure based metrics, such as coronary perfusion pressure (CPP), or invasive diastolic arterial pressure, have also been used. However, invasive blood pressure measurement is often impractical, particularly in pre-hospital treatment, such as in cardiac arrest cases. Furthermore, available metrics may assess oxygenation by measurement taken distant from the brain.

SUMMARY

[0004] One example provides a system for providing feedback to a care provider relating to resuscitation treatment being provided to a patient, the system comprising: at least one device configured to provide a display; a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of oxygen delivery to the brain; and at least one controller, comprising at least one processor and at least one memory, coupled with the NIRS system, the at least one controller being configured to: receive the signals, based at least in part on the signals, estimate physiological parameters

comprising:

an oxygen saturation relating to the brain of the patient, and a hemoglobin concentration relating to the brain of the patient, based at least in part on at least one relationship between the oxygen saturation and the hemoglobin concentration, determine feedback relating to the resuscitation treatment being provided to the patient, and display the feedback for the care provider at least during the resuscitation treatment on the at least one device.

[0005] In some, more general, examples, the system may be configured for providing feedback to a care provider relating to an ongoing treatment not necessarily comprising resuscitation, such that adaptations to the ongoing treatment can be made by the caregiver and/or provided by automated control of one or more medical devices. The treatment may comprise ventilation treatment, manual ventilation treatment, and/or resuscitation treatment. In some examples, the at least one controller is configured to compute the at least one relationship. In some examples, the at least one relationship comprises a relationship in a computed at least two dimensional space comprising at least two axes, wherein each axis of the at least two axes is associated with at least one of: the oxygen saturation and the hemoglobin concentration. In some examples, the signals are associated with a volume of the brain of the patient. In some examples, the at least one device is incorporated into at least one of: the NIRS system, a device communicatively coupled with the NIRS system, a portable computing device, a medical device, a mechanical chest compression system, a defibrillator, and a ventilator. In some examples, the resuscitation treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter. In some examples, chest compression feedback relates to at least one of: chest compression location, chest compression depth, chest compression force, chest compression rate, and chest compression angle. In some examples, the signals relate to each of a plurality of wavelengths of electromagnetic radiation, wherein each of the plurality of wavelengths is within a range of between 640 and 900 nanometers, and wherein the plurality of wavelengths comprises a wavelength of between 750-770 nanometers, a wavelength of between 840-860 nanometers, and a wavelength of between 800-820 nanometers.

[0006] In some examples, the hemoglobin concentration is a total hemoglobin concentration. In some examples, the at least one optical sensor is configured to be coupled to the patient's head. In some examples, the at least one controller comprises at least one of: a controller of the NIRS system, a controller of a device communicatively coupled with the NIRS system, a controller of a portable computing device, a controller of a medical device, a

controller of a mechanical chest compression system, a controller of a defibrillator, and a controller of a ventilator. In some examples, the system comprises a flexible structure comprising a plurality of capacitive cells, the flexible structure configured to be positioned on at least a portion of a torso of the patient during the treatment being provided to the patient, and wherein the at least one controller is configured to: receive second signals associated with a plurality of capacitance values associated to at least a portion of the plurality of capacitive cells, based at least in part on the received second signals, estimate a change in a three dimensional shape of the flexible structure over a period of time during the providing of the treatment to the patient, and based at least in part on the estimated change in the three dimensional shape of the flexible structure, determine the feedback.

[0007] In some examples, the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second axis is associated with the hemoglobin concentration, and wherein the first axis is orthogonal to the second axis. In some examples, the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter. In some examples, the at least one controller is configured to: determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxygen saturation and the hemoglobin concentration over a period of time during the CPR chest compressions; and based at least in part on at least one parameter of the path, determine the chest compression feedback.

[0008] In some examples, based at least in part on the at least one parameter of the path, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient. In some examples, the determined path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles. In some examples, the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest

compression cycles of the multiple CPR chest compression cycles. In some examples, the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement.

[0009] In some examples, the at least one calculated shape comprises at least one convex hull. In some examples, the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull. In some examples, the one or more physiological parameters comprise at least one of: coronary perfusion pressure and pulse pressure. In some examples, the chest compression feedback comprises a display of an animated shape representative of the at least one convex hull, wherein the animated shape varies over the period of time. In some examples, the one or more convex hull parameters comprise at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude.

[0010] In some examples, based at least in part on the one or more convex hull parameters, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient. In some examples, at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

[0011] One example provides a system for managing mechanical chest compressions being provided to a patient, the system comprising: a mechanical chest compression system; a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of the patient's brain oxygenation; and at least one controller, comprising at least one processor and at least one memory, coupled with the NIRS system and the mechanical chest compression system, the at least one controller being configured to: receive the optical signals, based at least in part on the optical signals, estimate physiological parameters comprising: an oxygen saturation relating to the brain of the patient, and a hemoglobin concentration relating to the brain of the patient, based at least in part on at least one relationship between the oxygen saturation and the hemoglobin concentration, determine at least one adjustment to at least one mechanical chest compression parameter of the mechanical chest compressions being provided to the patient, and implement the at least one

adjustment to the at least one mechanical chest compression parameter of the mechanical chest compressions being provided to the patient.

[0012] In some examples, the at least one adjustment comprises at least one automatic adjustment. In some examples, the at least one adjustment is implemented following at least one confirmation by a care provider. In some examples, the at least one automatic adjustment comprises a plurality of periodic automatic adjustments. In some examples, the at least one controller is configured to: monitor the at least one mechanical chest compression parameter of the mechanical chest compressions being provided to the patient, and determine the plurality of automatic adjustments such that the at least one mechanical chest compression parameter is maintained within a specified range. In some examples, the at least one adjustment is for at least one of: improving patient oxygenation resulting from the mechanical chest compressions, and improving a probability of survival of the patient following the mechanical chest compressions. In some examples, the at least one mechanical chest compression parameter comprises at least one of: chest compression location, chest compression depth, chest compression force, chest compression rate, and chest compression angle.

[0013] In some examples, the at least one controller comprises at least one of: a controller of the NIRS system, a controller of a device communicatively coupled with the NIRS system, a controller of a portable computing device, a controller of a medical device, a controller of a mechanical chest compression system, a controller of a defibrillator, and a controller of a ventilator. In some examples, the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second axis is associated with the hemoglobin concentration, wherein the first axis is orthogonal to the second axis. In some examples, the at least one controller is configured to: determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxygen saturation and the hemoglobin concentration over a period of time during the CPR chest compressions; and based at least in part on at least one parameter of the determined path, determine the at least one adjustment.

[0014] In some examples, based at least in part on the at least one parameter of the determined path, the at least one adjustment is determined to comprise at least one of: depth of compressions, angle of compressions, and position of application of compressions on the patient. In some examples, the determined path relates to multiple CPR chest compression cycles, wherein the at least one parameter of the determined path comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space,

wherein the high frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles. In some examples, the at least one parameter of comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycles of the multiple CPR chest compression cycles. In some examples, the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement. In some examples, the at least one calculated shape comprises at least one convex hull. In some examples, the at least one adjustment is determined based at least in part on one or more parameters of the convex hull comprising at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude.

[0015] One example provides a method for providing output relating to treatment being provided to a patient, the method comprising: sensing optical signals indicative of the patient's brain oxygenation with a near infrared spectroscopy (NIRS) system comprising at least one optical sensor; receiving the signals by at least one controller; and based at least in part on the signals, estimating, by the at least one controller, physiological parameters comprising: an oxygen saturation relating to the brain of the patient, and a hemoglobin concentration relating to the brain of the patient; and based at least in part on at least one relationship between the oxygen saturation and the hemoglobin concentration, providing, by the at least one controller, output relating to the treatment.

[0016] In some examples, providing the output comprises: determining at least one adjustment to the treatment being provided to the patient, and implementing the at least one adjustment. In some examples, the treatment comprises mechanical chest compressions, and wherein the adjustment is to at least one mechanical chest compression parameter of the mechanical chest compressions. In some examples, providing the output comprises: based at least in part on the at least one relationship, determining feedback relating to the treatment being provided to the patient, and presenting the feedback for the care provider on at least one presentation device. In some examples, the treatment comprises chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter.

[0017] In some examples, the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second

axis is associated with the hemoglobin concentration, and wherein the first axis is orthogonal to the second axis. In some examples, the treatment comprises chest compressions, wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter, and wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second axis is associated with the hemoglobin concentration, and wherein the first axis is orthogonal to the second axis. In some examples, The method comprises determining a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxygen saturation and the hemoglobin concentration over a period of time during the CPR chest compressions; and based at least in part on at least one parameter of the path, presenting the chest compression feedback.

[0018] In some examples, the path relates to multiple CPR chest compression cycles, wherein the at least one parameter of the path comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles. In some examples, the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycle of the multiple CPR chest compression cycles. In some examples, the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement. In some examples, the at least one calculated shape comprises at least one convex hull. In some examples, the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull. In some examples, at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

[0019] One example provides a system for providing feedback to a care provider relating to treatment being provided to a patient, the system comprising: at least one presentation device; a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of the patient's brain oxygenation; and at least one controller, comprising at least one processor and at least one memory, coupled with the NIRS system, the at least one controller being configured to: receive the signals, based at least in part on the signals, estimate physiological parameters comprising: an

oxyhemoglobin concentration relating to the brain of the patient, and a deoxyhemoglobin concentration relating to the brain of the patient; and based at least in part on at least one relationship between the oxyhemoglobin concentration and the deoxyhemoglobin concentration, determine feedback relating to the treatment being provided to the patient, and present the feedback for the care provider at least during the treatment on the at least one presentation device. In some embodiments, the feedback is indicative of a recommended change to the treatment.

[0020] In some examples, the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter of the CPR chest compressions. In some examples, the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the deoxyhemoglobin saturation, and wherein the first axis is orthogonal to the second axis. In some examples, the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the deoxyhemoglobin concentration, and wherein the first axis is orthogonal to the second axis.

[0021] In some examples, the at least one controller is configured to: determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxyhemoglobin concentration and the deoxyhemoglobin concentration over a period of time during the CPR chest compressions; and based at least in part on at least one parameter of the path, determine the chest compression feedback. In some examples, the path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles. In some examples, the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycles of the multiple CPR chest compression cycles.

[0022] In some examples, the at least one micro path related parameter relates to at least one calculated shape associated with the high frequency movement. In some examples,

the at least one calculated shape comprises at least one convex hull. In some examples, the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull. In some examples, the one or more convex hull parameters comprise at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude. In some examples, based at least in part on the one or more convex hull parameters, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient. In some examples, at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

[0023] One example provides a method for providing output relating to treatment being provided to a patient, the method comprising: sensing optical signals indicative of the patient's brain oxygenation with a near infrared spectroscopy (NIRS) system comprising at least one optical sensor; receiving the signals by at least one controller; and based at least in part on the received signals, estimating, by the at least one controller, physiological parameters comprising: an oxyhemoglobin concentration relating to the brain of the patient, and a deoxyhemoglobin saturation relating to the brain of the patient; and based at least in part on at least one relationship between the oxyhemoglobin concentration and the deoxyhemoglobin concentration, providing, by the at least one controller, output relating to the treatment.

[0024] In some examples, providing the output comprises: determining at least one adjustment to the treatment being provided to the patient, and implementing the at least one adjustment. In some examples, the treatment comprises mechanical chest compressions, and wherein the adjustment is to at least one mechanical chest compression parameter of the mechanical chest compressions. In some examples, providing the output comprises: based at least in part on the at least one relationship, determining feedback relating to the treatment being provided to the patient, and presenting the feedback for the care provider on at least one presentation device. In some examples, the treatment comprises chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter of the chest compressions. In some examples, the at least one

relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the deoxyhemoglobin concentration, and wherein the first axis is orthogonal to the second axis.

[0025] In some examples, the treatment comprises chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the deoxyhemoglobin concentration, and wherein the first axis is orthogonal to the second axis. In some examples, the method comprises determining a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxyhemoglobin concentration and the deoxyhemoglobin saturation over a period of time during the CPR chest compressions; and based at least in part on at least one parameter of the path, presenting the chest compression feedback. In some examples, the path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles.

[0026] In some examples, the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycle of the multiple CPR chest compression cycles. In some examples, the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement. In some examples, the at least one calculated shape comprises at least one convex hull. In some examples, the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull. In some examples, at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

[0027] One example provides a system for providing feedback to a care provider relating to treatment being provided to a patient, the system comprising: at least one presentation device; a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of the patient's brain oxygenation; and at least one controller, comprising at least one processor and at least one memory,

coupled with the NIRS system, the at least one controller being configured to: receive the signals, based at least in part on the received signals, estimate at least two physiological parameters associated with the brain of the patient, based at least in part on at least one relationship between the at least two physiological parameters, determine feedback relating to the treatment being provided to the patient, wherein the at least one relationship is associated with a multidimensional space comprising at least two axes, wherein each of the at least two axes is associated with a physiological parameter of the at least two physiological parameters, and present the feedback for the care provider on the at least one presentation device.

[0028] In some examples, the at least one controller is configured to compute the at least one relationship. In some examples, each of the at least two axes is orthogonal to each of the other of the at least two axes. In some examples, the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter of the CPR chest compressions. In some examples, the at least two physiological parameters comprise a first physiological parameter and a second physiological parameter, and wherein the at least two axes comprises a first axis associated with the first physiological parameter and a second axis associated with the second physiological parameter, and wherein the at least one relationship is associated with a two dimensional space represented by the first axis and the second axis.

[0029] In some examples, the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relates to at least one CPR chest compression parameter of the CPR chest compressions. In some examples, the at least one controller is configured to: determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the first physiological parameter and the second physiological parameter over a period of time during the CPR chest compressions; and based at least in part on at least one parameter of the path, determine the chest compression feedback.

[0030] In some examples, the path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the multidimensional space, wherein the high frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles. In some examples, the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the multidimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycles of the

multiple CPR chest compression cycles. In some examples, the at least one micro path related parameter relates to at least one calculated shape associated with the high frequency movement. In some examples, the at least one calculated shape comprises at least one convex hull.

[0031] In some examples, the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull. In some examples, the one or more convex hull parameters comprise at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude. In some examples, based at least in part on the one or more convex hull parameters, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient. In some examples, at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the multidimensional space over the period of time.

[0032] In any of the provided examples described above, the feedback may be provided at least during the ongoing treatment to enable and/or direct a caregiver to modify the ongoing provision of the treatment. The feedback may be configured to provide for more effective treatment and/or treatment provided consistent with a predetermined protocol.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] Various aspects of embodiments of the present disclosure are discussed below with reference to the accompanying figures, which are not intended to be drawn to scale. The figures are included for illustrative purposes and a further understanding of the various aspects and examples. The figures are incorporated in and constitute a part of this specification, but are not intended to limit the scope of the disclosure. In the figures, identical or nearly identical components that are illustrated in various figures may be represented by like numerals. For purposes of clarity, not every component may be labeled in every figure.

[0034] FIG. 1 is a block diagram illustrating an example emergency care environment, including a software-based optical data analysis manager for providing treatment feedback or adjustments.

[0035] FIG. 2 is a mixed diagram illustrating example use of a software-based optical data analysis manager in determining treatment feedback or adjustments.

[0036] FIG. 3 is an example emergency care environment in which an optical data analysis manager is used in providing feedback on manual CPR chest compression treatment being provided to a patient.

[0037] FIG. 4 is an example emergency care environment in which an optical data analysis manager is used in providing adjustments to mechanical CPR chest compression treatment being provided to a patient.

[0038] FIG. 5 illustrates example use of tracked low frequency movement and tracked high frequency movement in providing CPR chest compression feedback or adjustments.

[0039] FIG. 6 illustrates example algorithmic convex hull generation.

[0040] FIG. 7 illustrates example convex hull parameters and associated physiological parameters.

[0041] FIGs. 8A-D include tables of physiology and treatment conditions that may be associated with convex hull related parameters.

[0042] FIG. 9 illustrates a display including convex hull tracking in a two dimensional (2D) space, which can be used in optimization of parameters of CPR chest compression treatment.

[0043] FIG. 10A is an example GUI including displayed convex hull parameters, associate physiological parameters, and associated CPR chest compression treatment feedback.

[0044] FIG. 10B an example GUI including a convex hull length tracker bar graph and CPR chest compression feedback.

[0045] FIG. 11 is a three-dimensional (3D) scatterplot illustrating low frequency movement in a three dimensional physiological parameter space during a set of epochs of CPR chest compressions performed on a single animal of an animal study.

[0046] FIG. 12 is a 2D scatterplot illustrating low frequency movement and high frequency movement in a two dimensional physiological parameter space during the CPR chest compressions performed on the single animal of the animal study of FIG. 11.

[0047] FIG. 13A is a 2D overlay plot illustrating low frequency movement in a two dimensional O2 sat. and total Hb conc. physiological parameter space during sets of CPR chest compressions performed on multiple animals of the animal study of FIG. 11.

[0048] FIG. 13B is a 2D overlay plot illustrating low frequency movement in a two dimensional oxyHb conc. and deoxyHb conc. physiological parameter space during sets of

CPR chest compressions performed on multiple animals of the animal study of FIG. 11.

[0049] FIG. 14 illustrates loops representing loop high frequency movement in a 2D parameter space, associated individual chest compression cycles.

[0050] FIG. 15 is a polar plot illustrating coronary perfusion pressure (CPP) relative to convex hull length and angle, in a 2D physiological parameter space, for data from the animal study of FIG. 11.

[0051] FIG. 16 includes plots illustrating tracking of convex hull centroid movement during CPR chest compressions performed on each of multiple animals of the animal study.

[0052] FIG. 17 is a block diagram illustrating example components of various devices described with reference to preceding figures.

DETAILED DESCRIPTION

[0053] Some embodiments described herein use near infrared spectroscopy (NIRS), or other near infrared or light-based monitoring, for example, such as in brain monitoring. Unlike various other non-invasive monitoring techniques, such as pulse oximetry, NIRS allows direct non-invasive monitoring of brain oxygenation and oxygen delivery, such as during resuscitation and pre-hospital treatment, where optimizing brain oxygenation and oxygen delivery to the patient's brain may be critical to the success of the treatment and to preserving the patient's neurological function following the treatment. Although many examples herein relate to use in connection with cardiac arrest and CPR chest compressions, it is to be understood that, in different embodiments and examples, techniques described herein may be used in a variety of situations and contexts, including with various types of acute care treatments and interventions.

[0054] Some embodiments described herein use NIRS monitoring. NIRS offers the potential of non-invasive direct brain oxygen delivery and brain oxygenation assessment, such as in rescue, acute care and emergency care situations. In spite of the appeal of NIRS in this regard, available techniques including use of NIRS have had limitations. For example, some techniques use NIRS in monitoring brain oxygen saturation, and use that in assessing, e.g., patient condition and response. Oxygen saturation may provide a measure of the proportion of oxyhemoglobin (hemoglobin bound to oxygen) relative to deoxyhemoglobin (hemoglobin not bound to oxygen). Arterial blood generally contains a higher proportion of oxyhemoglobin than venous blood. While an increasing brain oxygen saturation is often desirable during treatment, use of oxygen saturation alone has limitations, particularly in connection with low blood flow states as may be present in emergency care situations

(although also in situations without low blood flow states). For example, oxygen saturation alone may increase as a result of an increase oxyhemoglobin (e.g., from an influx in arterial blood) or a decrease in deoxyhemoglobin (e.g., from an outflux in venous blood), thus presenting interpretation difficulty or ambiguity. Also, interpretation of oxygen saturation may rely on the assumption that changes are a result of oscillations in arterial blood volume. However, venous blood volume changes may also be occurring, for example, during CPR chest compressions, when venous blood volume oscillations occur with each compression. For these reasons, among others, use of oxygen saturation alone has limitations.

[0055] Some embodiments provide systems, methods, apparatus and computer readable media that include use of near infrared spectroscopy (NIRS) brain monitoring, or other near infrared or light based monitoring, in providing feedback and adjustments relating to treatment being provided to a patient. In some embodiments, an (e.g. software-based) optical data analysis manager stored on at least one controller receives, from a NIRS system, signals associated with, e.g., the physiology or physiological status of the brain of a patient receiving CPR chest compression treatment (e.g., manual or automated). It is to be noted that various embodiments herein may use non-spectroscopy based techniques or methods, alternatively or in addition to spectroscopy based techniques or methods, including, e.g., techniques or methods in which optical densities are utilized in measuring physiological parameters without using spectroscopy based techniques or approaches. The optical data analysis manager, based at least in part on the received signals, estimates at least two physiological parameters associated with the brain of the patient, such as oxygen saturation (O2 sat.) and total hemoglobin concentration (total Hb conc.), and/or oxyhemoglobin concentration (oxyHb conc.) and deoxyhemoglobin concentration (deoxyHb conc.).

[0056] In the exemplary context of CPR chest compression treatment, the optical data analysis manager, based at least in part on at least one relationship between the at least two physiological parameters, which the optical data analysis manager may compute, provides feedback or adjustments relating to the CPR chest compressions or other ongoing treatment being provided to the patient. The at least one relationship, for example, may be associated with tracked movement, over a time period during treatment, in a computed multidimensional space including at least two axes associated with the at least two physiological parameters.

[0057] In some embodiments, based at least in part on the at least one relationship between at least two physiological parameters associated with the patient's brain, which parameters may be estimated using NIRS, better metrics (e.g., for use in providing feedback or adjustments) may be obtained than with known techniques. For example, in some

embodiments, at least one relationship between O2 sat. and Hb conc. may be used (or, e.g., between oxyHb conc. and deoxyHb conc., or other parameters). For example, for a particular volume of the brain (e.g., a specified, approximated or estimated three-dimensional region including brain tissue and associated with interrogation using NIRS brain monitoring of the patient), O2 sat. may provide a measure of the ratio of oxyHb to deoxyHb (typically, arterial blood is higher in oxyHb conc. and venous blood is higher in deoxyHb conc.), while total Hb conc. provides a measure of the total amount of hemoglobin (including oxyHb conc. and deoxyHb conc.) in the same volume of the brain.

[0058] In some embodiments, measurements of parameters such as total Hb conc., O2 sat., oxyHb conc. and deoxyHb conc. and may represent or reflect, e.g., changes in such parameters, such as relative to a baseline, rather than absolute measures. Furthermore, some embodiments include a recognition that, for example, O2 sat. alone may not reflect or allow differentiation in determinations between various different physiological conditions, and therefore may not allow optimal insight into or reflecting these conditions, as well as effects of treatment. In some embodiments, a relationship between O2 sat. and total Hb conc. is used, such as to allow for greater insight in these regards. For example, some clinical situations may include high total Hb conc. (which may include, e.g., shifts/changes to increased total Hb conc.), which might, in some examples, typically be considered positive/desirable (e.g., as relates to desirable physiological conditions or effects of treatment), but might be considered negative/undesirable when considered in combination with, e.g., very low O2 sat. (so that, while there is a large amount of hemoglobin present, it is almost all not oxygenated, which may lead to poor overall oxygen delivery, for example). Alternatively, some clinical situations may include very small total Hb conc., which might, in some examples, typically be considered negative/undesirable, but might be considered positive/desirable if a high O2 sat. is present (so that, while a large proportion of the hemoglobin that is present is oxygenated, there is only a very small amount of hemoglobin present, which may also lead to poor overall oxygen delivery, for example). However, as described further herein, it is to be understood that desirable conditions as relate to NIRS based parameters or parameter spaces (e.g., a total Hg conc. and O2 sat. space or an oxyHb space and deoxyHb space) may depend on, e.g., the specific desired physiological conditions or response, or specific desired effect of treatment, at that time or during that time period (e.g., at a specific time during a chest compression cycle).

[0059] In some embodiments, for example, determining, utilizing and interpreting at least one relationship between the two parameters can provide (or allow for obtaining) better

and more specific assessment of brain oxygenation physiology and conditions, and can allow for better optimization of treatment, such as to optimally increase brain oxygenation. In particular, while NIRS has been used attempting to assess brain oxygenation, existing uses have had many limitations in allowing determination of metrics to accurately assess and track brain oxygenation, including in acute care circumstances, such as during cardiac arrest, which may include situations with patients with relatively low brain oxygenation. In some embodiments described herein, it is recognized that by using a relationship between two (or more) NIRS based parameters, better and more accurate metrics may be determined. Such metrics may, in turn, be extremely useful in acute care situations, allowing better assessment and tracking of oxygen delivery to the patient and patient brain oxygenation, which can be used in better assessment and tracking of the patient's condition (or a specific physiological response at a specific time) and response to treatment, and can further be used in adjusting treatment to better optimize the effect of treatment on the patient (or the specific desired physiological effect of treatment on the patient at a specific time), and to track that effect.

[0060] In various embodiments, at least one relationship between brain associated physiological parameters may be used synergistically. For example, use of the at least one relationship may allow better assessment and interpretation of brain hemodynamics, brain arterial and venous blood flow, and overall brain oxygenation resulting from treatment and specific treatment parameters. In CPR chest compression treatment, use of the at least one relationship may also allow providing feedback, such as for optimized or improved manual chest compression treatment, or adjustments, such as for optimized automated chest compression treatment, which may result in, e.g., better oxygenation of the patient's brain. This, in turn, may lead to optimized or improved treatment and better outcomes, saving patient lives and increasing the probability of patient survival without neurological impairment. Some embodiments provide technical solutions to technical problems associated with the foregoing, including, e.g., providing better metrics for assessing patient physiological response to treatment, such as CPR chest compression treatment or other repetitive or ongoing treatment, and providing feedback or adjustments for optimizing or improving such treatment. In one or more examples that reference CPR compression treatment, it will be appreciated that the principles and/or configurations described may be applied to other treatments, as applicable.

[0061] In some embodiments, the at least one relationship between the physiological parameters may include tracking of the parameters in association with a computational multidimensional space associated with the parameters. For example, each of the

physiological parameters may be represented as, or associated with, an axis in the space. For example, in a 2D space, the horizontal axis may represent O2 sat. and the vertical axis may represent Hb conc (or, in other embodiments, oxyHb conc. and deoxyHb conc., respectively), or the horizontal axis may represent total Hb conc. and the vertical axis may represent O2 sat (or, in other embodiments, oxyHb conc. and deoxyHb conc., respectively), for example. As further described herein, in various embodiments, parameters such as O2 sat., total Hb conc., oxyHb conc., deoxyHb conc. and others may include either absolute or relative values, which may include values that express measurements (which may include estimations) relative to a baseline (e.g., in arbitrary units and relative to the baseline), which may be indicative of changes or shifts relative to the baseline, for example.

[0062] In various embodiments described herein, in variations thereof, the parameter or parameters associated with each axis may differ. For example, other embodiments may use: different associations between each axis and each physiological parameter (e.g., O2 sat. and total Hb conc., or oxyHb conc. and deoxyHb conc., or reflecting changes/shifts in these parameters); other physiological parameters, some or all of which may be determined in whole or in part by NIRS or otherwise; other 2D spaces, 3D or more than 3D spaces; spaces with non-orthogonal axes or other variations (e.g., including use of non-linear or curvilinear axes), and/or entirely different definitions that may or may not be based on one or more axes; spaces in which one or more axes do not linearly or directly relate to one or more individual physiological parameters (e.g., in which one or more axes may relate to one or more physiological parameters based on one or more mathematical expressions, functions, algorithms or models); spaces in which one or more axes relate to combinations or mathematical combinations of physiological parameters; or modified spaces, such as translated or rotated spaces, for example. In some embodiments, the magnitude of a value associated with an axis may vary linearly with the associated physiological parameter (e.g., the magnitude of a value on the X axis may vary linearly with an estimated O2 sat.). However, in some embodiments, the magnitude of a value associated with an axis may vary non-linearly with the associated physiological parameter (e.g., the magnitude of a value on the X axis may vary with the square of oxygen saturation, or in some other way), or may vary according to one or more mathematical expressions, functions, algorithms or models.

[0063] While embodiments are not limited to use with CPR chest compressions, in some embodiments, the treatment may be or include CPR chest compressions (e.g., manual or automated). During CPR chest compression treatment, using NIRS monitoring, O2 sat. and total Hb conc. of the brain (e.g., associated with a volume of the brain), or, e.g., in other

embodiments, other physiological parameters, such as oxyHb conc. and deoxyHb conc., are monitored and tracked, such as, e.g., in real time, over time, and/or over a period of time, such as continuously, in an ongoing fashion or intermittently during treatment, in a 2D space (or, e.g., a more than 2D space), such as a parameter based space, as shown and described with reference to later figures. For example, O2 sat. and total Hb conc. may be used in assessing overall brain oxygenation and changes in brain oxygenation. In some embodiments, concentrations, such as total Hb conc., oxyHb conc. and deoxyHb conc., may be molar concentrations (e.g., moles per unit of volume). In some embodiments, in plots, such as 2D plots expressing relationships between two parameters, each of the two parameters may be with regard to the same volume of the brain that is interrogated using NIRS.

[0064] In some examples, it may be difficult or impractical to determine parameters such as O2 sat., total Hb conc, oxyHb conc., deoxyHb conc., or others with precision. As such, in some embodiments, concentrations may be referred to by reference to the associated amount, e.g., of moles, or, in the case of O2 sat., e.g., a molar concentration, even though the concentrations are in fact in association with a volume. Furthermore, in some embodiments, concentrations may be expressed in arbitrary units (A.U.s), which, e.g., may allow indication of relative magnitude while avoiding specifically referring to the associated volume. For instance, in some examples, A.U.s may be based on magnitude of change relative to initial or baseline value(s) or condition(s) (e.g., an initial value may be assigned a unitless magnitude of 0-100, e.g., 50) and subsequent changes in magnitude may be relative to the initial or baseline unitless magnitude, such as lower than or higher than the initial or baseline magnitude (e.g., 25 or 75). This may reflect the fact that, in some embodiments, measurements (such as estimations) relative to an initial baseline may be more important, and may be used rather than, absolute measurements in specific units (although, in some embodiments, absolute measurements may be used). As such, in some embodiments, measurements (e.g., concentrations or proportions) may be expressed, e.g., relative to a baseline concentration, and both the baseline and the measurements relative to the baseline may be expressed without absolute units, such as by use of A.U.s. Measurements relative to the baseline may indicate whether the measured parameter is higher or lower than the baseline, and provide a relative indication of by how much. For example, a determined baseline may be expressed as 50 A.U.s. A first measurement of 60 A.U.s would be higher than the baseline (by 10 A.U.s), but a second measurement of 70 A.U.s would be higher than the baseline and higher than the first measurement (higher than the baseline by 20 A.U.s and higher than the first measurement by 10 A.U.s), and the amounts by which measurements are

higher or lower, in A.U.s, may convey a proportion or amount by which they are higher or lower. In some embodiments, A.U.s or other relative measurements may be used to express parameters such as, e.g., O2 sat., total Hb conc., oxyHb conc., and deoxyHb conc., for example.

[0065] In some embodiments, during treatment, based on the tracked O2 sat. and total Hb conc. (or, in some embodiments, other parameters) associated with the volume of the brain, brain related physiological parameters may be tracked or continuously tracked, and feedback or adjustments may be provided or continuously provided, such as to improve or optimize the effectiveness of the treatment, such as in maximizing brain oxygenation resulting from the treatment. Herein, continuous may include, e.g., repeated, frequent or ongoing, and continuously may include repeatedly, frequently or ongoingly. In various embodiments, sampling rates may be used of, e.g., 125 Hz, 250 Hz, or between, e.g., 5 Hz-2 kHz or 10-250Hz.

[0066] For example, in some embodiments, during treatment, specific tracked movement (e.g., change of position in a parameter based space, such as over time, such as for example, as shown and described with reference to later figures) or movement meeting one or more specific conditions, may be associated with specific brain-associated physiological parameters (as may relate to, e.g., brain hemodynamics, brain oxygenation, arterial and venous blood volume shifts, or other parameters).

[0067] While various embodiments apply to various types of treatment, many non-limiting examples herein are described with reference to CPR chest compression treatment, whether manual or mechanical. In some embodiments, specific brain-associated physiological parameters may be analyzed to provide an indication of the degree of effectiveness of the ongoing treatment. Additionally, tracked movement in the 2D space (or one or more types, patterns or parameters of such movement) may be identified and used in determining or providing specific treatment feedback or adjustments, e.g., in the example of CPR chest compressions, relating to specific CPR chest compression parameters. These parameters may include, in the example of CPR chest compressions, e.g., rate, depth, force, angle, location on the patient's chest, or degree of compression release. Furthermore, this may be performed continuously (which may include, e.g., ongoingly and repeatedly) during treatment (e.g., during a period of treatment). However, in some embodiments, the feedback may be simple or less specific, such as a recommendation to simply change (or an automatic change of) one or more parameters of treatment, or to change treatment, because the patient's oxygenation status is declining, and/or to maintain a current treatment, and/or current

parameters of treatment, because the patient's oxygenation status is improving. Additionally, in some embodiments, signals may be provided for use in adjusting parameters of mechanical chest compressions, such as in closed loop control (e.g., ongoingly and without requiring user action) of such parameters.

[0068] In some embodiments, determined treatment feedback (e.g., in the CPR chest compression context, regarding parameters of manual CPR chest compressions) may include visual and continuously updated feedback displayed for one or more care providers on one or more displays, such as, e.g., on the displays of one or more smartphones, tablets, patient monitors, defibrillators, ventilators, other medical devices or systems, or other computing devices or systems. Furthermore, in some embodiments, other types of feedback, such as audio or tactile feedback, may be provided. In some embodiments, determined or updated adjustments, e.g., to parameters of automated (e.g., automated mechanical) CPR chest compression treatment, may be automatically (e.g., without requiring user input or confirmation of adjustments) and continuously implemented on, e.g., a mechanical chest compression system (which may include, e.g., one or more devices).

[0069] In some embodiments, different types of movement in a 2D space may be tracked and used. For example, low frequency movement may include movement in a 2D space (or more than 2D space), such as, e.g., larger time scale movement that may be independent of, e.g., a recurring, smaller time scale type of variation (such as, e.g., high frequency movement, as referred to below). For example, in some embodiments, low frequency movement may include overall or average movement in a space, e.g., over time, such as irrespective of smaller time scale movement such as may be due to small time scale physiological cycles, such as movements during individual heartbeats or chest compression cycles (and, e.g., phases or portions thereof). While examples of low and high frequency movement are described herein with reference to CPR chest compressions, it is to be understood that, in other types of treatment (e.g., with different types of physiological or treatment cycles), other examples of low and high frequency movement may apply).

[0070] For example, in the exemplary context of CPR chest compressions, in a 2D space where O2 sat. is represented by the X axis and total Hb conc. is represented by the Y axis, during an epoch (e.g., set of multiple) chest compressions, over a period of many chest compressions, low frequency movement may occur that includes rightward and upward movement, indicating increasing O2 sat. and total Hb conc. (e.g., as described with reference to FIGs. 5 and 12). In some examples, though not necessarily always or for all time periods, such rightward and upward movement may be indicative of increased brain oxygenation and

oxygen delivery to the brain, and effective chest compressions. However, in some examples, desirable movement in the parameter space may depend, or depend in part, in starting positions or parameter values, such as starting Hg conc. or O2 sat., for example, since each parameter may have a limit beyond which further increase is not possible. Furthermore, in various examples, and in various circumstances, desirable movement may depend, or depend in part, on current and desired specific physiological conditions, and current and desired specific effects of treatment.

[0071] For example, in CPR chest compressions, at some times or time periods, and in some instances, movement of blood – even relatively deoxygenated blood – may be relatively prioritized over delivery of blood with an increased oxygenation level. In such instances, in the Hg conc. and O2 sat. parameter space over time, (a) large upward movement (large increasing Hb conc., which may correspond with large increasing delivery of blood) and slight leftward movement (slightly decreasing O2 sat., which may correspond with slightly decreasing oxygenation of the delivered blood) may be preferable to (b) slight upward movement (slightly increasing Hb conc., which may correspond with slightly increasing delivery of blood) and slight rightward movement (slightly increasing O2 sat., which may correspond with slightly increasing oxygenation of delivered blood), since (a) may correspond with higher overall movement of blood, for example, even if slightly decreasing O2 sat. is not, itself, typically desirable. It is noted, however, that, in specific instances, times or time periods, other combinations of movement aspects, such as may include leftward and/or downward movement, may be preferred, depending on potentially temporary and situation-specific physiological and treatment goals, for example.

[0072] Additionally, in some embodiments, another type of tracked movement may include high frequency movement. For example, high frequency movement may include movement in a 2D space (or more than 2D space) that represents, e.g., smaller time scale movement (e.g., relative to a larger time scale low frequency movement) of a specific type, such as, e.g., a recurring type of variation within an overall, larger time scale low frequency movement (e.g., in various embodiments, using scales of absolute or arbitrary units, as described herein). For example, in the exemplary context of CPR chest compressions, in the O2 sat. and total Hb conc. space, tracked movement within each chest compression cycle may represent high frequency movement, while overall movement over many chest compression cycles, independent of variation during each chest compression cycle, may represent low frequency movement (examples of which are described, e.g., with reference to FIG. 5). Each chest compression cycle may include a compression phase and a release phase,

generally with a brief pause or hold period between the two. In some embodiments, high frequency movement may include, e.g., more granular or smaller time scale movement (e.g., within individual physiological or treatment cycles) than low frequency movement, and low frequency movement may include, e.g., overall, less granular or larger time scale movement than high frequency movement. Furthermore, in some embodiments, high frequency movement may include movement that includes smaller variation(s) in movement (e.g., within individual physiological or treatment cycles) that may not be explicitly or individually represented in associated low frequency movement (e.g., low frequency movement may be averaged movement over periods of time or cycles, or have high frequency movement filtered out, for example). Furthermore, in some embodiments, high frequency movement may serve as, or may be viewed as, an impulse or input to low frequency movement, for example.

[0073] In some embodiments, during CPR chest compression treatment, high frequency movement associated with each chest compression cycle, which may take the form of a loop (e.g., a generally looping pattern, whether regular or irregular, and whether closed or open) in the 2D space, may be tracked and subject to application of one or more algorithms, such as may be part of an optical data analysis manager, which may be used in determining specific parameters associated with each loop. For example, in some embodiments, an algorithm, such as a gift wrapping algorithm (e.g., examples of which are described, e.g., with reference to FIG. 6), may calculate a (e.g., theoretical, mathematical) convex hull associated with each high frequency movement loop. Specific parameters of each convex hull (e.g., centroid, length, width, angle with the X axis, and other parameters as described below) may be calculated and associated with specific physiological parameters (e.g., brain oxygenation or hemodynamics parameters) and may be used in providing feedback or adjustments relating to the CPR chest compression treatment or other ongoing treatment.

[0074] Additionally, in some embodiments, over multiple compression cycles, changes to convex hull parameters over multiple convex hulls may be tracked or continuously tracked. The tracked changes may be associated with physiological conditions or changes, and may be used in providing feedback or adjustments to CPR chest compression treatment.

[0075] Furthermore, in some embodiments, points representing the centroids of each of multiple convex hulls (associated with each of multiple chest compression cycles) may be tracked and/or plotted, or continuously tracked/plotted, such as in the 2D space referenced above. Associated centroid movement (e.g., positional change between multiple centroids) be

tracked and/or plotted. In some embodiments, centroid movement may represent movement, between multiple centroids over multiple chest compression cycles, which is independent of positional variation within each individual chest compression cycle. As such, in some examples, centroid movement may represent, or be used to identify or characterize, low frequency movement over multiple compression cycles (which, e.g., in other circumstances, may be associated with beat-to-beat measurements, where the beat might be, e.g., cardiac rhythm or CPR compression). In some embodiments, for example, high frequency movement may include a reflection of the hemodynamic shifts arising from a cardiac impulse, while low frequency movement may track the resulting hemodynamic status as effected by the high frequency movement.

[0076] In some embodiments, parameters associated with tracked low frequency movement and/or high frequency movement may be used in assessing associated physiological conditions or changes (e.g., which may relate to brain hemodynamics and/or oxygenation), and/or in determining treatment feedback or adjustments, such as, in the exemplary context of CPR chest compressions, feedback or adjustments relating to parameters of the chest compressions, to optimize or improve the treatment. For example, convex hull parameters, or changes thereto, may be used in determining and providing adjustments to, and/or closed loop control of, parameters of automated CPR chest compressions (e.g., rate, depth, force, angle, or location on the patient's chest) or in determining and providing feedback, such as visual feedback, to a care provider relating to parameters of manual chest compressions. Such feedback may, for example, be based on tracked or analyzed low frequency movement and/or high frequency movement, feedback based on convex hull parameters or changes in convex hull parameters, feedback on conditions or status of patient physiological parameters based on the foregoing, and/or feedback relating to specific parameters of CPR chest compressions (e.g., rate, depth, angle, location on the patient's chest). Such feedback relating to specific parameters of CPR chest compressions may include, for example, a suggested or recommended change in a parameter (e.g., an increase or decrease in rate, depth, force, angle, or a change in location), or whether a specific parameter is within, above or below, an optimal range (e.g., whether compression depth is within an optimal range, or too shallow or deep). Furthermore, feedback may relate to whether a currently administered treatment or therapy is considered effective or ineffective, and whether another form of treatment or therapy should be used or switched to, such as, e.g., active compression decompression (ACD) compressions, use of an impedance threshold device (ITD), adding or switching to different type of treatment (e.g., ventilation or

drug therapies). Furthermore, in some embodiments, feedback may not focus on measured parameters themselves, but on associated temporal or physical differences between them (e.g., the difference between a parameter associated with the left versus the right side of the brain, and/or differences between the current time versus a parameter associated with a five minute period of time).

[0077] In some embodiments, in the exemplary context of CPR chest compressions, based at least in part on tracked low and/or high frequency movement, notifications/messages may be provided to a care provider providing CPR chest compressions (see, e.g., FIG. 3), or signals may be provided to a mechanical chest compression system (see, e.g., FIG. 4), such as for use in closed loop control of parameters of provided mechanical chest compressions. For example, based on whether specific parameters, or combinations of parameters, of tracked movement are considered better or worse (e.g., based on desired or goal patient physiological conditions or effects of treatment at a specific time), specific parameters of chest compressions may be adjusted or not adjusted, or a recommendation may be provided to change or adjust one or more parameters, even without a specific change being indicated. For example, recommendations may include that specific parameters of treatment be changed (or changed more) if, based on tracked movement, the patient's condition is indicated as getting worse, which may, in some examples, suggest that current specific parameters of treatment are not effective or not optimally effective. Furthermore, specific parameters of treatment may not be recommended to be changed (or may be recommended to be changed less) if, based on tracked movement, the patient's condition appears to be getting better, which may, in some examples, suggest that current parameters of treatment are not effective or not optimally effective.

[0078] Various parameters of tracked low and/or high frequency movement may be used in these regards, some of which, in the exemplary context of CPR chest compressions treatment, in some examples, are described with reference to FIGs. 7 and 8A-8D. For example, as described with reference to FIG. 7, tracked movement of the centroid of a convex hull (an example of tracked low frequency movement) up and/or to the right may, in some examples (e.g., specific situations, times or time periods), be associated with improving patient oxygenation and patient condition and, potentially, effective or increasingly effective treatment, and may lead to no or less adjustment to chest compression parameters or treatment being recommended (or automatically implemented, such as in closed loop control of mechanical chest compressions). However, movement down and/or to the left may, in some examples, be associated with declining patient oxygenation and patient condition and,

potentially, less effective or decreasingly effective treatment, and may lead to adjustment of chest compression parameters, or a change in treatment(s), being recommended (e.g., a recommendation to change the location of compressions on the patient's chest, or to change another chest compression parameter, or to begin use of an ACD device and/or ITD device for active compression-decompression chest compressions). It will be appreciated that reference to movement being up, down, left or right, or any direction in the relevant space, may be dependent on the configuration of the parameter axes and therefore reference may be made, more generally, to movement in a direction for improved patient condition.

[0079] Furthermore, parameters of tracked high frequency movement (e.g., in the context of CPR chest compressions, in some examples, as described with reference to FIG. 7, increasing convex hull length) may be associated with improving patient oxygenation and patient condition, and, potentially, effective or increasingly effective treatment, and may lead to no or less adjustment to chest compression parameters being recommended. However, other parameters of tracked high frequency movement (e.g., in some examples, decreasing convex hull length) may be associated with less effective or decreasingly effective treatment, and may be associated with adjustment to chest compression parameters being recommended (e.g., a recommendation to change the location of compressions on the patient's chest, or to change another chest compression parameter, or to begin use of an ACD device and/or ITD device for active compression-decompression chest compressions).

[0080] Additionally, in some embodiments, in CPR chest compressions as well as other types of treatment, even if the parameter settings associated with, or measurement of, certain treatment parameters (e.g., depth of chest compressions) is not ideally accurate or precise, tracked high and low frequency movement (e.g., in a total Hb conc. and O2 sat., or oxyHb conc. and deoxyHb conc. parameter space, for example) may still be used in adjusting and improving treatment parameters (e.g., an increase or decrease in depth of chest compressions), since the effect of the treatment on the patient, and adjustments in parameters of treatment, may still, in some examples and to some degree, be assessed and tracked using, e.g., low and/or high frequency movement, independently or with limited dependency on the other measured treatment parameters. For example, if, based on tracked low and high frequency movement, the patient's oxygenation status is assessed to be declining, it may be, e.g., determined to recommend changing chest compression location. After that increase is implemented for a period of time, based on tracked low and high frequency movement, it may be determined that the patient's oxygenation status is improving and that no further change in location is currently needed. In some embodiments, these determinations may be

made even if the parameter setting or measurement of actual chest compression depth is not ideally accurate or precise, for example.

[0081] Furthermore, in some embodiments, changes to parameters of treatment may be suggested (e.g., whether a general suggestion to change or vary one or more parameters, or one or more specific adjustments to one or more parameters), or automatically changed. The suggested or automatic changes may be to achieve a specific desired physiological response (e.g., that may indicate or be necessary for improving patient condition) or based on a specific currently prioritized physiological response, such as, for example, in the context of cardiac arrest treatment, increasing cardiac filling or improving brain perfusion. The suggested or automatic changes may be based on physiological assessments made using, e.g., low frequency and/or high frequency movement (examples of which are provided, e.g., with reference to FIGs. 8A-D).

[0082] For example, in the exemplary context of CPR chest compressions, based on the tracked movement, notifications or messages may be provided to a care provider, or, in closed loop control of mechanical chest compressions, to adjust one or more parameters of the chest compressions. Such adjustments may be to, for example, increase or decrease the rate of chest compressions (e.g., increase or decrease the rate of compressions per minute by a certain number of compressions), increase or decrease the depth of chest compressions (e.g., by a fraction of, one, or several inches or centimeters), adjust the angle of chest compressions (e.g., such as by adjusting angle in a certain number of degrees in one or more dimensions or axes), change the location of chest compressions on the patient's chest (e.g., by moving a certain distance to the left or right and/or a certain distance in the superior or inferior direction, or, if potential locations are divided into four quadrant areas, by changing the quadrant in which chest compressions are applied), use or stop using ACD compressions, and/or use or stop using an ITD. For example, in some embodiments, messages may be displayed on a device to a care provider relating to a recommended adjustment, such as, e.g., "increase rate by x compressions per minute," "decrease angle of compressions x degrees in the superior direction relative to the patient," "move the location of compressions from quadrant A to quadrant D," "begin use of ACD device," or "begin use of ACD device and ITD device," to provide some examples.

[0083] In some embodiments, notifications or adjustments may be triggered based on certain conditions and/or thresholds being met. For example, such conditions and/or thresholds may be based on parameters of low frequency or high frequency movement (which may include, e.g., a specific movement over a specific period of time, or a rate of

movement over a specified period of time), parameters of convex hulls relating to high frequency movement, or in other ways. For example, in the context of CPR chest compressions, in some instances, or at some times or time periods, in the O2 sat. (X axis) and total Hb conc. (Y axis) space, tracked convex hull centroid movement down or to the left, or, e.g., down and/or to the left at a minimum threshold specified amount or rate, may warrant changing chest compression parameters or conditions, whereas tracked convex hull centroid movement up and to the right, or, e.g., up and/or to the right at a minimum threshold specified amount or rate, may warrant not changing chest compression parameters or conditions. Additionally, in some examples, magnitude of low or high frequency change or rate of change over time may be associated with magnitude of specific recommendations. For example, in some instances, tracked convex hull movement down and/or to the left a large amount or at a higher rate (e.g., relative to a baseline), may lead to a larger recommended or automatic change (e.g., a greater increase chest compressions per minute), whereas tracked convex hull movement down and/or to the left a small amount or at a lower rate may lead to a smaller recommended or automatic change. As another example, in some instances, tracked smaller or decreasing convex hull length of a large amount (e.g., relative to a baseline), may lead to a larger recommended change (e.g., a greater increase chest compressions per minute), whereas tracked smaller or decreasing convex hull length of a small amount may lead to a smaller recommended change. Furthermore, for example, in control of parameters of mechanical chest compressions (e.g., via signals sent to an automated chest compression system), adjustments to specific parameters (e.g., rate, depth, angle, location on the patient's chest) may be based on such factors.

[0084] Feedback or adjustments may be updated and provided continuously during a period of CPR chest compressions, allowing a care provider to continue to adjust as needed to achieve, restore or maintain optimized parameters, for optimized or improved effectiveness of treatment. Furthermore, in some embodiments, feedback, or continuous feedback, may be provided that relates to physiological conditions or parameters that may be associated with or estimated based on NIRS monitoring and/or other near infrared or light based monitoring (e.g., continuously updated O2 sat., total Hb conc., oxyHb conc. and/or deoxyHb conc.), and/or low frequency movement and/or high frequency movement (e.g., continuously updated convex hull parameters, convex hull tracking, convex hull centroid movement parameters). In various embodiments, associated displays may be provided that may allow a care provider to see, perceive or appreciate effects of adjustments made to chest compression parameters, and/or may aid the care provider in determining or deciding on such adjustments

or the degree or amount of such adjustments, or to see whether previous adjustments had a positive, negative or neutral physiological effect, for example.

[0085] FIG. 1 is a block diagram illustrating an example emergency care environment 100 including a software-based optical data analysis manager 64 for providing output 74, which may include treatment feedback and/or adjustments (e.g., to initiating or ongoing manual or automated CPR chest compression treatment). Communications between devices may take place, for example, using wired connections and/or wirelessly via the Internet and/or one or more local or wide area wireless networks 80 (e.g., which may include long range and short range wireless networks, Bluetooth, and others). A patient 56 is shown, receiving treatment 52 (e.g., medical treatment, emergency treatment, resuscitation treatment, in-hospital or pre-hospital treatment, etc.). In some embodiments, the treatment 52 may include CPR chest compression treatment. In various embodiments, the treatment may be provided by one or more care providers (e.g., manual chest compressions), such as care provider 54, and/or one or more treatment devices or systems, such as treatment device/system 78, such as a mechanical chest compression device or system for providing mechanical, automated chest compressions.

[0086] During treatment, an optode based spectral monitoring/NIRS headset (e.g., one or more items worn by, placed on, or fixed on the patient's head) is coupled with (e.g., worn by, placed on, or fixed on) the patient's head, e.g., so that the electrodes, probes or optodes are placed symmetrically or asymmetrically (e.g., left to right) on/about the skull, such as symmetrically on the forehead, such as superior to the orbits, over portions of one or both hemispheres. In some embodiments, bi-hemispheric probes may be used, which may allow for comparative analysis of signals received relating to each hemisphere. Furthermore, in some embodiments, probes in addition to, or other than, optical probes may be used, such as muscle or brain probes, which may also be used in comparison of signaling from different probes and different types of probes, for example. For example, as shown, a NIRS headset 58 is worn/mounted on the patient's head, which includes two optical sensors 57 placed on each of the right and left side of the patient's forehead, for a total of four optical sensors 57. For example, a care provider may affix the NIRS headset 58 to the patient's head prior to or during treatment. In various embodiments, various types of, e.g., NIRS headsets or other systems/devices, sensors and sensor configurations may be used. In other embodiments, other systems/devices besides or in addition to a headset may be used, such as, for example, separate or connected individual electrodes, or various separate or connected components, where each may include one or several electrodes (e.g., patches, or pads) or sensors including

electrodes, potentially among other components or sensing components. For example, in some embodiments, each of the optical sensors 57 may include multiple channels (e.g., three), such as, e.g., short separation channels, each with different receiver-transmitter distances, where data from each of the three channels may be used or combined in various ways or according to various algorithms, for increased measurement accuracy, including, e.g., improved noise filtering and artifact removal. In various embodiments, since a NIRS channel may relate to a source-detector pair for a given wavelength, various numbers of source optodes may be used, which may generate a larger or multiplied number of channels. In some embodiments, more than two wavelengths of lights are utilized, such as 3, 4, 5, 10 or more, such as to increase data and model quality, reliability or accuracy.

[0087] During treatment, input 60 is sent to computational/medical device(s)/system(s) 62. The input 60 may include, e.g., signals sent from the spectral monitoring/NIRS headset 58 and may also include other signals, such as other signals relating to other aspects of the patient or treatment being provided to the patient, such as may allow for an estimation or assessment of the physiological status or condition of the patient (or specific physiological characteristics or changes), and/or an assessment of the effectiveness of the current treatment (or specific physiological effects of treatment). In some embodiments, the input may further include, e.g., data from motion sensors on the patient, such as to improve artifacts rejection, or electrodes to provide electroencephalogram (EEG) monitoring, such as for coupling with the optical data, and/or for motion artifact rejection. The device(s)/system(s) 62 may include, for example, one or more computing devices such as, e.g., computers, portable computing devices, tablets or smartphones, and/or one or more medical devices, such as defibrillators (such as automated external defibrillators (AED(s)), ventilator(s), or others. As depicted, two devices 70, 72 are shown; however, in other embodiments, a single device or more than two devices or systems may be included.

[0088] The input 60 is received by an optical data analysis manager 64 of the device(s)/system(s) 62, which may be software-based. The optical data analysis manager 64 may include software (e.g., algorithm(s)) included on one or more memories of one or both of the controllers 66, 68 (or, in some embodiments, on one or more memories of one or more computerized components other than controllers). Each of the controllers may include, e.g., one or more processors, and memory (e.g., read only memory (ROM) and random access memory (RAM)). In the example shown, software of the optical data analysis manager 64 is distributed between controllers 66, 68 of devices 70, 72 of the device(s)/system(s) 62. In some embodiments, the devices 70, 72 may communicate and coordinate with each other

(whether directed by the optical data analysis manager 64 in this regard or otherwise) such that the optical data analysis manager 64 may operate in an integrated and unified manner. In other embodiments, however, only one device and/or one controller may be included, or more than two devices and/or more than two controllers may be included.

[0089] The optical data analysis manager 64, based at least in part on at least a portion of the input 60, estimates at least two physiological parameters, which may be associated with the patient's brain. For example, based on NIRS signals relating to NIRS monitoring, the optical data analysis manager 64 may determine (e.g., estimate) at least two brain associated physiological parameters, such as, e.g., O2 sat. and total Hb conc., or oxyHb conc. and deoxyHb conc.. In some embodiments, the optical data analysis manager 64 may track 79 at least one relationship between each or some of the at least two physiological parameters. The at least one relationship, for example, may be associated with a computed multidimensional space including at least two axes associated with the at least two physiological parameters.

[0090] The optical data analysis manager 64, for example, using analysis relating to the tracked at least one relationship, and, in some embodiments, the treatment related signals, determines output 74 that may include feedback, or continuous feedback, for display on the device 76 to the care provider 54, and/or adjustments for implementation on the treatment device/system 78. For example, the treatment related signals may relate to parameters of the treatment. For example, in CPR chest compression treatment, the treatment related signals may allow determination (such as estimation) of, e.g., current chest compression rate, depth, force, angle, and/or location on the patient's chest. The feedback may relate to one or more parameters of the treatment and may allow optimization or improvement of the treatment. For example, the feedback may provide displayed guidance on whether to increase, decrease, or maintain the same chest compression rate, or to keep the same or change, in a specified way and/or by a specified amount, one or more other chest compression parameters. The feedback may also include feedback associated with physiological parameters of the patient, such as, e.g., the at least two physiological parameters, and/or feedback associated with the at least one relationship. Additionally or alternatively, the optical data analysis manager 64 may provide adjustments, or continuous adjustments. For implementation on the treatment device/system 78 (if included). For example, the treatment device/system 78 may include a mechanical chest compression system, and the adjustments may be to one or more parameters of the automated chest compression treatment (e.g., chest compression rate, depth, force, angle, and/or location on the patient's chest).

[0091] In some embodiments, a NIRS system (such as, in some embodiments, may include NIRS headset 58) may include one or more source-detector sensor probes, such as such as two probes mounted on each side of the patient's head. In some embodiments, one or more sources (e.g., laser light transmitting sources) and one or more detectors may be included with each probe, such as, e.g., two light sources per probe. Each light source may transmit one or more wavelengths of light, such as two, three, four or more wavelengths. The wavelengths may include, e.g., among potentially other wavelengths, wavelengths between, e.g., 600-2,500 nm, or, e.g., between 640 and 900 nm, such as, e.g., 760 nm (or between 750-770 nm), 803 nm (or between 800-820 nm) and 847 nm (or, e.g., between 840-860 nm), exactly or approximately, which, as described further herein, may be used in estimation of deoxyHb conc., oxyHb conc. and Hb (total Hb) conc., respectively. For example, in some embodiments, wavelengths include, in addition to at least one wavelength before and one wavelength after the isosbestic point (e.g., 808nm), zero, one or several additional wavelengths, such as at the isosbestic point and/or after it, such as at 900nm or 930nm, such as for signal strengthening, for example. In some embodiments, the light (or other electromagnetic radiation) and wavelengths may be from, e.g., visible light, non-visible light, white light, laser light, or near infrared light emitted from a near infrared light emitting diode (LED), for example. In some embodiments, a NIRS system may include, in addition to a headset (including mounted probes), one or more other coupled devices, such as one or more other computerized devices, such as one or more handheld and/or other devices.

[0092] FIG. 2 is a mixed diagram 200 illustrating example use of a software-based optical data analysis manager 210 in determining feedback or adjustments relating to treatment being provided to a patient. The optical data analysis manager 210 may include software for implementing various embodiments as described herein. In various embodiments, the optical data analysis manager may be included with any of various device(s) or system(s) (e.g., one or more computing or medical devices or systems).

[0093] At step 202, during treatment 207 being provided to a patient, an optical data analysis manager 210 (e.g., a software-based optical data analysis manager of one or more controllers of one or more computing and/or medical devices) receives signals 209 associated with a patient's brain during treatment (e.g., manual or automated CPR chest compression treatment). For example, the optical data analysis manager 210 may receive, among other things, NIRS signals 209 from continuous NIRS monitoring 208 of the patient's brain during the treatment 207.

[0094] At step 204, based at least on part on the received signals, the optical data

analysis manager 210 estimates at least two physiological parameters 212 associated with the patient's brain (e.g., O2 sat. and total Hb conc., or oxyHb conc. and deoxyHb conc.).

[0095] At step 206, based at least in part on at least one relationship between the estimated at least two physiological parameters 212 (e.g., which the optical data analysis manager 210 may determine or track, e.g., over time, a period of time, and/or in a parameter based space), which the optical data analysis manager may compute, the optical data analysis manager 210 determines or updates feedback and/or adjustment(s) associated 214 with the treatment

[0096] At step 208, the optical data analysis manager 210 presents (e.g., displays) the determined or updated feedback and/or implements the determined adjustment(s) 216. In some embodiments, following step 208, the method 200 returns to step 202, and steps 204-208 may be continuously repeated over time during the treatment or a period of the treatment (e.g., one or more epochs of chest compressions). For example, in some embodiments, with CPR chest compression treatment, updating may occur once per compression cycle, or several times per compression cycle (e.g., once per compression phase and once per release phase), or once per a specified number of compression cycles. In some embodiments, although treatment feedback and/or adjustment(s) may be provided with a specified frequency, associated monitoring (e.g., NIRS monitoring), and other steps or possible steps, such as receiving of the signals, determination of the at least two physiological parameters, and determination or tracking of the at least one relationship, may occur with a different frequency, e.g., higher frequency. For example, among other possible implementations, monitoring may be performed at 125 Hz or more, and the feedback may be provided at under 1 Hz.

[0097] FIG. 3 is an example emergency care environment 300 in which a software-based optical data analysis manager 322, which may include programming stored on one or more controllers, is used in providing feedback 324 on manual CPR chest compression treatment being provided to a patient 306 by a care provider 304. Communications between devices may take place, for example, using wired connections and/or wirelessly via the Internet and/or one or more local or wide area wireless networks 332.

[0098] In various embodiments, various methods and devices may be used in determining or estimating various chest compression parameters, such as, e.g., compression rate, depth, force, angle and location on the patient's chest. For example, in some embodiments, sensors may be used that include, e.g., one or more motion sensors (including, for example, accelerometers), force sensors (such as, e.g., to detect start and end of a chest

compression), magnetic sensors, velocity sensors, displacement sensors, impedance sensors, capacitance sensors, and/or sensors that are part of a defibrillation electrode assembly or a defibrillation pad, may be used. For example, as shown in FIG. 3, a compression puck including an accelerometer 336 is placed under the hand of a care provider 304 providing manual CPR chest compressions. Measured changes in acceleration can be used to determine or estimate movement associated with chest compressions. In embodiments in which a defibrillation pad is used, a portion of the pad may include an accelerometer. Additionally or alternatively, in some embodiments, a flexible structure 334 of capacitive cells, as described in PCT International Application No. PCT/US2023/019346, published as Publication No. WO2023205383, herein incorporated herein by reference in its entirely, may be used in determining changes and shape and deformations of the surface of the patient's chest associated with chest compressions, and in determining chest compression parameters. Details of example implementations of use of a flexible structure, such as with an accelerometer, which can used in some embodiments described herein, can be found, for example, in Publication No. WO2023205383, including with reference to FIGs. 1B (flexible structure used with accelerometer in manual CPR chest compressions without a defibrillation pad) and 1C (flexible structure used with accelerometer in manual CPR chest compressions with a defibrillation pad).

[0099] As shown in FIG. 3, various chest compression related signals (or data) 308 (e.g., obtained using one or more sensors, such as accelerometers, an applied flexible structure, or both), which may convey data relating to, e.g., chest compression rate, depth, force, angle and location on the patient's chest, may be sent (e.g., by wired or wireless coupling) to one or more devices, systems, or platforms, such as to controller 314 of tablet computing device 320, as shown. It is to be understood that sending can be indirect or indirect. For example, sending from a first device to second device may include, e.g., sending directly from the first device to the second device without any intermediary devices, or sending indirectly from the first device to the second device via one or more intermediary devices, for example. A software-based optical data analysis manager 322 may be included on the controller 314 the tablet computing device. As described with regard to FIG. 1, however, in some embodiments, an optical data analysis manager may be distributed between multiple devices, such as may include, for example, other computing or medical devices 332 (such as, e.g., a defibrillator, ventilator, or other emergency care device), or one or more devices of a remote computing platform 330. In some embodiments, signals to the optical data analysis manager may be received by multiple such devices (or transferred

therebetween), and signals may be sent by one or more of such devices.

[0100] A spectral monitoring/NIRS headset 312, an example of which is described with reference to FIG. 1, may be coupled with the patient's head, and spectral monitoring/NIRS signals (or data) 310 may be sent, for example, to the controller 314 of the tablet computing device 320 (and/or, in some embodiments, to one or more other communicatively coupled devices or systems, e.g., one or more other computing or medical devices 332, such as a defibrillator, patient monitor or ventilator, or one or more devices of a remote computing platform 330).

[0101] The optical data analysis manager 322 of the controller 314 (and/or elsewhere) performs analysis using input including the spectral monitoring/NIRS signals (or data) 310. Based at least in part on the analysis and the chest compression related signals 308, the optical data analysis manager 322 determines and outputs treatment feedback 324, such as feedback relating to the CPR chest compressions provided to the patient 306, such as to optimize the effect of the chest compressions. As described in detail herein, the analysis may include, for example, determining and tracking of at least one relationship between brain-associated physiological parameters determined based at least in part on the NIRS signals 310. In the embodiment shown, the determined treatment feedback may be displayed 316 on a display 318 of the tablet computing device 320 (and/or elsewhere). The feedback may include, for example, feedback relating to chest compression parameters (e.g., rate, depth, force, angle, or location on the patient's chest), such as, e.g., feedback to maintain, increase or decrease with regard to particular parameter, and may or may not include the amount of a suggested increase or decrease, for example. Additionally, the treatment feedback may include feedback associated with particular physiological parameters of the patient.

[0102] In some embodiments, the process and determinations described with reference to FIG. 3 are repeated continuously during treatment, and displayed feedback is continuously updated and changed accordingly during treatment. This may allow a care provider providing chest compressions to continually correct and optimize parameters of the provided chest compressions, which may increase the probability of patient survival and retention of full neurological function following treatment.

[0103] FIG. 4 is an example emergency care environment 400 in which an optical data analysis manager 402, which may include programming stored on one or more controllers, is used in providing adjustments to mechanical CPR chest compression treatment being provided to a patient 450 via a mechanical chest compression system 406 (e.g., a piston based or band based system). Communications between devices may take place, for example,

using wired connections and/or wirelessly via the Internet and/or one or more local or wide area wireless networks 440. For example, in some embodiments, the adjustments may be used in closed loop control of mechanical chest compressions (e.g., closed loop control of mechanical chest compression parameters such as compression rate, depth, force, angle and/or location on the patient's chest).

[0104] The mechanical chest compression system 406 may include, e.g., various sensors that may be used in determining various chest compression parameters, such as, e.g., compression rate, depth, force angle and location on the patient's chest. Additionally or alternatively, in some embodiments, as described with reference to FIG. 3, a flexible structure 334 of capacitive cells, as described in PCT International Application No. PCT/US2023/019346, published as Publication No. WO2023205383, may be used in determining changes and shape and deformations of the surface of the patient's chest associated with chest compressions, and in determining chest compression parameters. For example, in the exemplary context of CPR chest compressions, in some embodiments, a flexible structure may be used, as referenced previously herein, such as in correlating a specific chest compression location on the chest of a patient with patient oxygenation or oxygen delivery, or with a specific corresponding physiological effect, such as brain perfusion, which, in turn, may be used, e.g., in recommending changes in treatment, such as, in the exemplary context of CPR chest compression treatment, chest compression location (e.g., to a different quadrant, as described previously herein) to improve overall patient oxygenation, or brain perfusion specifically.

[0105] As shown in FIG. 4, various chest compression related signals (or data) 414 (e.g., regarding parameters of chest compressions as determined or estimated, for example, using one or more sensors, an applied flexible structure, or both), which may convey data relating to, e.g., chest compression rate, depth, force, angle and location on the patient's chest, may be sent (e.g., by wired or wireless coupling) to one or more devices, systems, or platforms, such as to the controller 418 of a tablet computing device 420, as shown. A software-based optical data analysis manager 402 may be included on a controller 418 of the tablet computing device 420. As described with regard to FIG. 1, however, in some embodiments, an optical data analysis manager may be distributed between multiple devices, such as may include, for example, other computing or medical devices 432 (such as, e.g., a defibrillator, ventilator, or other emergency care device), or one or more devices of a remote computing platform 430.

[0106] A spectral monitoring/NIRS headset 412 (or system), an example of which is

described with reference to FIG. 1, may be coupled with the patient's head, and spectral or optical monitoring/NIRS signals (or data) 410 may be sent, for example, to the controller 418 of the tablet computing device 420 (and/or, in some embodiments, to one or more other communicatively coupled devices or systems, e.g., one or more other computing or medical devices 432, such as a defibrillator, patient monitor or ventilator, or one or more devices of a remote computing platform 430).

[0107] The optical data analysis manager 402 of the controller 418 (and/or elsewhere) performs analysis on input including the chest compression related signals (or data) 414 and the spectral monitoring/NIRS signals (or data) 410. Based at least in part on the analysis and the chest compression related signals, the optical data analysis manager 402 determines and outputs adjustments 404 (if and as determined appropriate), such as to parameters of the automated chest compressions, such as to optimize the effect of the chest compressions. As described in detail herein, the analysis may include tracking of at least one relationship between brain-associated physiological parameters determined based at least in part on the NIRS signals 410. As described in detail herein, the analysis may include, for example, tracking of at least one relationship between brain-associated physiological parameters determined based at least in part on the NIRS signals 410.

[0108] FIG. 5 illustrates example 500 use of tracked low frequency movement (e.g., a larger time scale movement, as described previously) and high frequency movement (e.g., smaller time scale movements or variations within the larger time scale movement, as described previously) in providing CPR chest compression feedback or adjustments. Simplified plot 510 illustrates low frequency movement in a 2D space having O2 sat. as the horizontal axis and total Hb conc. as the vertical axis, and is generally similar to plots relating to the animal studies as described with reference to later figures.

[0109] Box 502 represents tracked, changing O2 sat. and total Hb conc. during, e.g., an epoch of CPR chest compressions (e.g., manual or automatic). Box 504 represents use of the tracked parameters (e.g., O2 sat. and total Hb conc.) in generating associated tracking in the 2D space (e.g., calculating plots in the 2D space).

[0110] Curve 526 represents the O2 sat. and the total Hb conc. as they change over time from point 522, during ventricular fibrillation, to point 524, which represents the end of an epoch of chest compression cycles (e.g., in some examples, a two minute epoch, but, in other embodiments, an epoch may be defined as a different period of time of chest compressions, or in other ways, such as based on duration or a number of provided chest compression cycles, for example). In the lower portion of the plot, O2 sat. moves from a

position toward the right of the plot (relatively high), when ventricular fibrillation (VF) starts, steadily to the left (decreasing) over time, representing a period of time during VF and without CPR chest compressions, with cardiac output and cerebral hemodynamics correspondingly low. The upper portion of the plot, with O2 sat. moving steadily to the right (increasing) over time, and total Hb conc. higher than during ventricular fibrillation without chest compressions, and slightly increasing over time, represents a period of time during an epoch of chest compression cycles, with cardiac output and cerebral hemodynamics increasing as a result of the chest compressions. Overall, as described further with reference to simplified plot 514, curve 526 shows a looping shape, moving generally in a clockwise direction, first to the left during ventricular fibrillation, which is generally indicative of poor cardiac output and overall oxygenation, due to the VF, and later to the right and upward during the epoch of CPR chest compressions, which is generally indicative of increasing cardiac output and overall oxygenation, due to the chest compressions. While curve 526 is illustrated as a continuous curve, in various embodiments, it could be generated based on, or could be plotted as, e.g., a sequence of points over time.

[0111] In the exemplary context of CPR chest compressions, simplified plot 512 illustrates high frequency movement within a small portion of the low frequency movement, representative of a small portion of the entire time of the low frequency movement illustrated in plot 510. Specifically, plot 512 illustrates high frequency movement within small box 527 of plot 510, with large box 528 providing a magnified view of high frequency movement within small box 527. In some embodiments, for example, high frequency movement may relate to or be driven by a physiology based cycle of perfusion, which may start with an influx of blood volume and increase in oxygen concentration (e.g., due to cardiac pumping or a chest compression) as well as a corresponding subsequent outflux of blood and decrease in oxygen concentration. As such, high frequency movement may be affected by changes occurring in different phases of the cycle. However, in some embodiments, low frequency movement may filter or average out such phase driven fluctuations, e.g., such as by being driven by or reflecting convex hull centroid movement, for example.

[0112] It is noted that the variations illustrated in plot 512 are not visible in plot 510. As described previously, in some embodiments, low frequency movement may not include variation associated with high frequency movement, and may instead only show movement independent of such variation. For example, as described further with reference to later figures, low frequency movement may be plotted based on centroid movement of a sequence of centroids associated with high frequency movement (e.g., sequential high frequency

movement loops). However, in various embodiments, low frequency movement may be defined, calculated and generated in other ways. For example, in some embodiments, low frequency movement may be tracked by a low-pass filtered signal relating to the optically-derived data (e.g., total Hb conc. and O2 sat., or oxyHb conc. and deoxyHb conc.), a moving average of the data, or based on more complex analysis of the data, such as based on tracking the start and end points of each physiological cycle (e.g., chest compression cycle) and determining the point to point variations between the start and end points for each cycle.

[0113] As can be seen, in this example, curve 530 appears as a highly varied curve including a series of irregular loops (although other examples of high frequency movement might appear differently). As described further herein, in some examples, individual loops of high frequency movement (such as may include irregular or partial/non-closed loops) may be associated with changes that occur during the compression and release phases of a single CPR chest compression cycle. For example, in some embodiments, individual loops, whether regular or irregular, may be associated with changes arising from a single chest compression, or may be associated with a single heartbeat.

[0114] In some embodiments, individual high frequency movement loops (or, as described herein, convex hulls associated with individual loops) may be defined and/or plotted so as to be independent of the generally small amount of low frequency movement that occurs during the time period of the individual loop. As such, in some embodiments, plots representing individual high frequency movement loops may filtered so as to remove the effect of the low frequency movement that occurred during the loop; that is, the loop may be plotted so as to be independent of low frequency movement, instead representing only the high frequency movement that occurred during the period of the loop. In some embodiments, plots of loops could be generated and used that show or reflect both low frequency movement and high frequency movement.

[0115] Additionally, in some embodiments, plots associated with high frequency movement may show, for example, a single loop (or single convex hull associated with a loop) that represents an average (or, e.g., other statistical combination) over a period of multiple loops. For example, as shown in FIG. 14, described in detail later herein, each plotted loop represents an average over a specified period of multiple CPR chest compressions (e.g., a break-in period, or a period of compressions at a specified location, etc.). In some embodiments, shapes or constructs other than convex hulls may be used, and various types of associated parameters may be used. For example, in some embodiments, an ellipse (or other shape) may be fit to the data for an individual loop, and parameters

associated with the ellipse may be determined and utilized, such as major and minor diameter, angles in the space, area, perimeter, origin, and/or others.

[0116] Furthermore, in some embodiments, tracking of one or more parameters based on convex hull analysis may include averaging over a series of loops (or high frequency movement in a more general sense) over a period time, may allow filtering out of intracycle variability, noise, uncoupling noise, and/or motion artifacts, which may allow may more accurate assessment of, e.g., the physiological effects on the brain of each cycle. Additionally, in some embodiments, analysis of loops and how they change in subsequent cycles (e.g., longer, rounder, etc.) may allow assessment of features of each cycle, and corresponding physiological changes, which may, in turn, inform recommendations, such as for adjustments to treatment parameters. For example, such features may allow assessment of whether blood entering the brain, or the interrogated tissue of the brain, is being oxygenated and to what degree, or potentially just oscillating back and forth without being oxygenated, or oxygenated much, and not changing the O2 sat., or not changing the O2 sat. much.

[0117] Furthermore, in various embodiments, individual points of a low frequency movement or high frequency movement plot may be determined continuously or at sequential points in time, which may be separated by small or predetermined amounts of time, which amounts of time may vary between different embodiments. Additionally, in various embodiments, low frequency movement and high frequency movement plots may be generated based on all determined points, or based on a subset of points, which subset may be defined in any of various ways (e.g., including a point only for every N sequential points, where N is some number larger than 1, or based on more complex selection criteria, or algorithm(s) may be applied to determine which points to include, for example). Additionally, in various embodiments, an approximated continuous curve for a plot of low frequency movement or high frequency movement may be generated in various ways based on plotted individual points – e.g., with lines connecting sequential points, using a best fit or smoothing algorithm(s), etc.

[0118] Simplified example plot 514 shows a set of points illustrating a loop associated with high frequency movement over a single chest compression cycle. Example individual points are shown, but are not intended to illustrate all points that might actually be included. Additionally, while plot 514 is intended to represent a single high frequency movement loop within box 528 of plot 512, the depicted plot 536 is for conceptual illustration only, and, as such, does not necessarily accurately depict a loop of high frequency movement within box 529 of plot 512. In plot 514, generally, the bottom portion includes points

corresponding with the compression phase of the associated compression cycle, while the top portion of the plot includes points corresponding to the decompression phase

[0119] Plot 540 represents an approximation of a convex hull 542 generated based on the loop of plot 514 (although a convex hull is actually a multi-sided polygon). In some embodiments, as described in detail with reference to later figures, features of an individual convex hull (e.g., length, width, angle with the X axis, and others), or analysis thereof as well as relating to movement of a sequence of convex hulls (e.g., tracking centroid movement), such as may include centroid movement vectors (associated with movement direction and magnitude between sequential or non-sequential convex hulls, for example), may be interpreted to correspond with physiological conditions or changes. Furthermore, features of convex hulls, or analysis thereof, may be used in determining feedback and/or adjustments to optimize ongoing CPR chest compressions, as represented by box 550, and in presenting feedback and/or causing implementation of the adjustments, as represented by box 552, or in other ways, such as in assessing physiological status or changes in the patient (e.g., brain perfusion status), such as relative to an initial baseline, and such as with respect to specific administered treatments or interventions. For example, in some embodiments, such features may be provided as input to an optical data analysis manager, which, based at least in part on analysis thereof, may provide feedback and/or adjustments.

[0120] FIG. 6 illustrates an example 600 of algorithmic convex hull generation. In some embodiments, each convex hull is generated based on a high frequency movement loop (which, as described above, may represent, e.g., a loop associated with a single chest compression cycle). A convex hull may be characterized as, e.g., the smallest convex polygon containing a set of points in a plane. As such, a convex hull may be a polygon that encloses all of the set of points in a loop. In some embodiments, with regard to a specific loop, a convex hull may be generated by using a gift-wrapping algorithm. The algorithm may, e.g., identify exterior points by projecting angles from each specific point to determine if a point exists that is more exterior than the associated specific point. The algorithm may report various parameters of the convex hull, including vertices, perimeter, and area, among others. The algorithm may determine the convex hull vertex that is closest to the first sample point of a chest compression and assessing whether the loop is traverses clockwise or counterclockwise. In some embodiments, for example, traversal orientation may be determined by selecting a first vertex in time, and adjacent/connecting vertices, and determining clockwise or counterclockwise traversal orientation – e.g., clockwise may be indicated if the connecting vertex to the left is an earlier data point than the connecting vertex

to the right, and counterclockwise may be indicated if the connecting vertex to the left is an later data point than the connecting vertex to the right. The algorithm may determine the length of the convex hull based on the two farthest vertices (examples of which are described, e.g., with reference to FIG. 7). The algorithm may determine the angle of the convex hull with the X axis based on the angle between a length vector and the X axis (saturation axis) and this length vector. The algorithm may calculate the width based on the largest perpendicular distance between the length and vertices on either side. For example, if the shape used in an ellipse, the width may be the minor axis, which is the largest distance perpendicular to the length (major axis) which would also coincide as traversing the origin. In the case of a convex hull, there could be a narrow one side and a wide second side, for example, where the perpendicular distance to the length that is largest on one side of the length line doesn't traverse the origin (centroid) and may or may not traverse a different point in the length distance than the largest perpendicular distance to the other side. Because of this, the width may be defined as the largest perpendicular distance to one side of the line added to the largest perpendicular distance on the other side of the line. As such, the width may be considered as the width of a hypothetical enclosing box that tightly encloses the hull oriented along the length vector, for example.

[0121] In the example shown in FIG. 6, an algorithm takes, as input, a set of points, such as points in a 2D O2 sat. and total Hb conc. space (including, e.g., point 604), which may represent a high frequency movement loop associated with an individual chest compression cycle (or, e.g., a loop representing an average or mean of many such loops, such as an average or mean of all of the compression cycle loops of an epoch of chest compressions, for example). The algorithm (such as, e.g., may include a gift wrapping algorithm) determines each side (as depicted, sides 1-6) of the convex hull, to ultimately generate the complete (in this example, six-sided) convex hull 602.

[0122] FIG. 7 illustrates example convex hull parameters and associated physiological parameters. An example approximated convex hull 704, such as may be associated with a single compression cycle (or, in other embodiments, an average or mean or other mathematical or algorithmic combination/computation of/based on many such cycles, for example) is shown. The approximated convex hull appears as a smooth curved closed shape, but the actual convex hull that it represents is a many-sided closed polygon. In various embodiments, approximated convex hulls or actual convex hulls may be used in determining (which may include estimating) various convex hull parameters. In various embodiments, approximated convex hulls may be determined in various ways, such as, e.g., by use of a best

fit or smoothing algorithm to generate a smooth curve approximation of a convex hull, for example (or, in other embodiments, other shapes, such as an ellipse).

[0123] Various parameters associated with one or more convex hulls, or an approximation thereof, may be associated with various physiological parameters, conditions or changes. In some embodiments, feedback or adjustments, such as may relate to CPR chest compressions, may be determined and provided based at least in part on such convex hull parameters, and/or the physiological parameters, conditions or changes that the convex hull parameters may represent or suggest, for example. While parameters of an individual convex hull may represent high frequency movement parameters, some parameters may be associated with convex hulls but may be associated with low frequency movement. For example, in some embodiments, for multiple, e.g., sequential, convex hulls, which may represent successive CPR chest compression cycles, movement (e.g., positional change) between the centroids of the convex hulls may be tracked, and may be represented as one or more vectors with magnitude and direction. Such vectors, for example, while derived using convex hulls (e.g., centroids of convex hulls), may be associated with low frequency movement through the space (e.g., movement that is independent of positional variation within each individual convex hull). Multiple convex hull parameters are illustrated in FIG. 7, which may be, e.g., features tracked over time to represent parameters.

[0124] In some examples, convex hull directionality 716 (e.g.,, clockwise or counter-clockwise) may reflect the order in which points of the convex hull are generated, where the directionality is from earlier to later generated points. Convex hull directionality 716 may be associated with, e.g., dominant physiological or oxygenation related factors at different times during a compression cycle. For example, in some embodiments and examples, directionality may provide an indication of the dominant factor in a given cardiac loop associated with the local brain tissue. For an example using a loop that is primarily along the diagonal, when starting clockwise, the dominant effect may be incoming blood and increased Hb conc. without much change the O2 sat., such that that the O2 sat. as the blood pulse arrives is the same as it previously was before the influx of blood. After that, as the blood enters the tissue, O2 sat. starts increasing, which is then followed by blood exiting the tissue. On the other hand, if, for the same shape and spatial orientation of loop, the directionality is counterclockwise, then the dominant effect of the incoming blood volume may be to change O2 sat., in that there is an influx of oxygenated blood without much change to the Hb conc. at first, but then gets to an O2 sat. level where more arriving blood no longer changes the O2 sat. much. The exiting of the blood is then associated with a loss in Hb conc.

[0125] In some examples, convex hull length 710 may be associated with cardiac output from the associated compression (that is, the compression phase of the associated compression cycle), where greater length may correspond with greater cardiac output, and the angle associated with that length may be indicative of whether the cardiac output that generated the blood influx into the brain was more or less oxygenated.

[0126] In some examples, convex hull width 706 may be associated with the degree of hemodynamic activity or change during the cycle. For example, a larger width may indicate that, as the cycle occurred, there were large translations back and forth in the space, where Hb conc. and O2 sat. varied throughout and traversed the space with variations indicative of shifts in venous/arterial volumes or potentially of systemic forward flow, and where, if the width is small, the incoming blood may be more likely to have entered and exited the tissue without a lot of activity, e.g., moving blood but without causing much physiological effect, such as from oscillating blood flow.

[0127] In some examples, convex hull angle 714 (in this example, with the X axis, corresponding with O2 sat.) may be associated with the cause(s) of the changes in Hb conc. and O2 sat. during the cycle, such as, for example, whether the cycle mainly includes, e.g., a change in O2 sat. without significant blood volume changes, or is, e.g., dominated by large changes in Hb conc. without significant shifts O2 sat. In some examples, a convex hull tracked low frequency movement vector 702 (as may be, for example, associated with tracked movement of the centroids of sequential convex hulls), which may represent low frequency movement over a period of CPR chest compressions, may be indicative of overall brain oxygenation, where movement to the right (indicating increasing O2 sat.) and movement up (indicating increasing total Hb conc.) may be associated with overall improving brain oxygenation.

[0128] In some examples, convex hull area 720 may be indicative of an amount of hemodynamic variation during the cycle, although more specific interpretation may require consideration of other convex hull parameters. In some examples, area may be indicative of the total amount of variation resulting from a cardiac impulse, where large areas are indicative of large hemodynamic shifts whereas small areas may be indicative of poor hemodynamic results from that cardiac impulse.

[0129] In some examples, assuming that the brain tissue is adequately perfused, primarily horizontal low frequency movement (e.g., significant changes in O2 sat. without much chance in Hb conc.) may, in some cases, result from metabolic activity or from venous blood leaving at the same rate of incoming arterial blood (so that Hb conc. remains

approximately the same, but O2 sat. increases due to the greater oxygenation of arterial blood). In some examples, in situations in which there is a low volume of blood in the brain, primarily horizontal movement may be caused by large shifts in O2 sat., but only for a small volume of blood.

[0130] It is to be understood that, in some embodiments, various parameters may need to be interpreted differently with regard to low frequency and high frequency movement. In some example, high frequency movement may be a result of a cardiac impulse, and it may not, or may not often, produce motion in one axis only, but may generate approximately horizontal or approximately vertical movement in the space. In high frequency movement, approximately vertical movement may be indicative of Hb conc. increasing without changes to O2 sat., e.g., influx of blood that has the same O2 sat. as the tissues had before the blood entered the brain. In high frequency movement, variations of O2 sat. as a result of a cardiac impulse may be uncommon, but if the effect is primarily horizontal movement, it may indicate that little blood actually arrived at the brain tissues and that the main effect seen is shifts in O2 sat.

[0131] In low frequency movement, approximately vertical movement may indicate that the region of brain measured has an increasing amount of blood at the same saturation that it had before. In low frequency movement, approximate horizontal movement may be indicative of negligible Hb conc. shifts as the O2 sat. changes. In low frequency movement, if the brain tissue was adequately perfused, primarily horizontal movement may indicate that the Hb conc. is changing without any change in the O2 sat from, for example, metabolic activity or from venous blood leaving at the same rate of incoming arterial blood. If the brain doesn't have a large volume of blood, primarily horizontal movement may more likely be caused by large shifts in O2 sat. but relatively low volume of blood.

[0132] Convex hull centroid 712 may be identified/calculated as a point having an X coordinate of the mean O2 sat., and a Y coordinate of the mean total Hb conc., for the convex hull. As described above, in some embodiments, while many convex hull related parameters are parameters of individual convex hulls may represent high frequency movement parameters, convex hull centroid movement (e.g., over a sequence of multiple convex hulls) may represent a low frequency movement parameter. In some embodiments, low frequency movement, which may relate to larger time scale movement, may provide a greater overall indication of changes in patient oxygenation and conditions over the larger time scale, relative to information provided by high frequency movement. However, as described below, various high frequency movement parameters can also be associated with significant changes

in patient physiology. As such, parameters of both low frequency movement (e.g., as may be represented by convex hull centroid movement) and high frequency movement can provide information that can be used, e.g., by some embodiments of an optical data analysis manager, such as in determining associated patient oxygenation and other conditions, and, in the exemplary context of CPR chest compressions, in providing feedback and adjustments relating to CPR chest compressions, for example, to optimize the effect of a treatment in delivering oxygen to the patient.

[0133] The length of a convex hull (in the O2 sat. and total Hb conc. space) may be defined as the longest distance between two vertices in the convex hull and may be determined by the magnitude of change in both the X axis and Y axis. In some embodiments, it is observed that length may provide an index of arterial and venous blood volume shifts in the volume and tissue being interrogated. The length of the convex hull may be affected by both the total arterial and venous blood volume shift and the relative volume shifts of arterial and venous blood. The angle of the convex hull in this space can be used to better interpret the nature of the blood volume shift, as described with reference to FIG. 8D. In some examples, it may be better/desirable for convex hull length to increase after initiating chest compressions, and to be maintained, as a decrease in length may be associated with a drop in pulse pressures generated by each compression. However, a decrease in length coupled with a decrease in angle may indicate, for example, that less blood is arriving at the brain tissue and that the primary shifts in the brain that are occurring are changes in O2 sat.

[0134] In the O2 sat. and Hb space, an approximately 90° convex hull angle of some given length may occur due to a chest compression that created an oscillation in total Hb conc. but a relatively small oscillation in O2 sat., indicating that oxyHb conc. and deoxyHb conc. may have contributed in the same ratio as was contributed prior to the associated influx of blood to the total observed total Hb conc. shift. Alternatively, it could also occur if an arterial-venous oxygen gradient is maintained, in which case a 90° convex hull angle may indicate a blood volume shift in which the ratio of oxyHb conc. and deoxyHb conc. remain constant through the compression cycle. Conversely, an approximately 0° convex hull angle may occur due to a chest compression that created an oscillation in O2 sat. but a relatively very small oscillation in total Hb conc. Angle may be determined by the arterial-venous oxygen gradient and the relative total Hb conc. shifts of arterial and venous blood. It noted that angle value, along with other convex hull parameters and metrics, may vary or depend on the relative scaling between volume and saturation in the associated space. Furthermore, in other multidimensional spaces, parameter values may be affected by scaling between axes.

[0135] FIGs. 8A-D include tables 800, 820, 840, 860 of physiology and treatment conditions that may be associated with specific convex hull related parameters, in some examples. It is to be understood that what is better/desirable may be dependent on specific circumstances and prioritized physiological and treatment objectives at a particular time or time period. For example, at certain times or time periods, increasing Hb conc. may be prioritized, where at other times increasing O2 sat. may be prioritized. Furthermore, at certain times or time periods, decreasing one or both may be better/desirable. In one or more examples, the systems described herein may be configured to receive an input indicating patient condition and the feedback may be based, at least in part, on the associated physiology & treatment conditions shown in the tables.

[0136] FIG. 8A includes a table 800 of physiology and treatment conditions that, in some examples, may be associated with convex hull centroid movement along the X axis in a 2D O2 sat. (X axis) and total Hb conc. (Y axis) space. In some examples, An increase in O2 sat. (rightward movement) may be better/desirable (e.g., to a natural maximum/resting value of, e.g., 60-70%), and decreases may be worse/to be avoided. In some embodiments, it is observed that an increase in O2 sat. may be due to arterial dilation leading to an increased proportion of arterial blood volume. In some examples, in hemorrhage, O2 sat. may decrease with increased loss of arterial blood volume. In some examples, in long duration CPR chest compressions, O2 sat. may depend on CPR depth and, if ventilation is provided, with positive end-expiratory pressure (PEEP) levels. In some examples, in long duration CPR chest compression treatment, deeper compressions and optimal PEEP levels may result in higher O2 saturations for, e.g., the first 6-8 epochs (e.g., 2 minute epochs) but O2 saturations may decline over time after that.

[0137] FIG. 8B includes a table 820 of physiology and treatment conditions that, in some examples, may be associated with convex hull centroid movement along the Y axis (Hb conc.), in the O2 sat. (X axis) and total Hb conc. (Y axis) space. In some examples, Increases in total Hb conc. (upward movement) may be better/desirable (to a natural maximum) and decreases may be worse/to be avoided. In some examples, decreases in total Hb conc. may correspond with decreases in blood delivery.

[0138] In various example, increases in Hb conc. may be due to treatments that improve cardiac output or blood delivery to the brain, for example. In some examples, an increase in total Hb conc. may be due to arterial dilation leading to an increased proportion of arterial blood volume. In some examples, in hemorrhage, total Hb conc. may decrease with increased loss of arterial blood volume, and may increase with return of blood. In some

examples, in long duration CPR chest compressions, total Hb conc. may depend on CPR depth and, if ventilation is provided, with positive end-expiratory pressure (PEEP) levels. In some examples, in long duration CPR chest compression treatment, deeper compressions and optimal PEEP levels may result in higher Hb concentrations for, e.g., the first 6-8 chest compression epochs (e.g., 2 minute epochs) but may decline over time after that.

[0139] FIG. 8C includes a table 840 of physiology and treatment conditions that may be associated with convex hull length, in some examples, in both the O2 sat. and total Hb conc. space and the deoxyHb conc. and oxyHb conc. space. It is to be noted that while, in various examples, increases or decreases in various treatment parameters may be considered better/desirable, that may only be the case within a certain range (e.g., in some examples, deeper chest compressions may be desirable, but only when in a safe or optimal range). In some examples, greater length may be desirable/better, and length may be generally proportional to the magnitude of arterial and venous volume of blood shifts. In some examples, changes in length may reflect declines or improvements in patient status during normal sinus rhythm, and changes in patient responsiveness to chest compressions, e.g., during cardiac arrest. In some examples, larger lengths may be better, and may indicate larger pulse pressures and better cardiac output. In some examples, smaller lengths may be worse, and may indicate ineffective cardiac output for either normal sinus rhythm or CPR chest compressions. In some examples, CO2 induced vasodilation may lead volume to transient declines in pulsatile shifts, and constriction following the removal of CO2 may lead to increased pulsatility, causing an increase in length. In some examples, in hemorrhage, length may increase with increased pulse pressure, but later decrease with blood volume and blood pressure decreases. In some examples, in long duration CPR chest compressions, deeper compressions (within a certain range) may lead to greater length, and length may be greatest with mid-level PEEP levels at least for the first 6-8 chest compression epochs (e.g., 2 minute epochs) but may decline over time after that. For example, the effectiveness of chest compressions may decrease over time. In some examples, greater lengths may be associated with better cardiac output while smaller lengths may be associated with poor cardiac outputs.

[0140] FIG. 8D includes a table 860 of physiology and treatment conditions that may be associated with convex hull angle (relative to the X axis), in some examples, in both the O2 sat. and total Hb conc. space and the deoxyHb conc. and oxyHb conc. space. In some examples, smaller angles may be desirable/better, and angle may depend on the relative volume shifts of arterial and venous blood. In some examples, in the O2 sat. and total Hb conc. space, smaller angles may correspond with larger changes in O2 sat. relative to blood

volume shift, which may indicate that blood volume shift is driven more by arterial blood. In some examples, in the deoxyHb conc. and oxyHb space, smaller angles may correspond with larger shifts in oxyHb conc. relative to deoxyHb conc. In some examples, in the O2 sat. and total Hb conc. space, generally, angle may increase when arterial blood volume shift declines more relative to the venous blood volume shift. However, in some examples, in hemorrhage, when blood volume loss causes CH length to become small enough, angle may become more variable. In long duration CPR, compression depths (and, if ventilation is provided, ventilation strategies) that optimize coronary perfusion pressure (CPP) may decrease angle, but the angle may increase over time.

[0141] For the exemplary context of CPR chest compressions, FIG. 9 illustrates a display 900, such as an animated display, including convex hull tracking in a two dimensional space, which can be used in optimization of parameters of CPR chest compression treatment, such as illustrated, for example, with reference to FIG. 3. In some embodiments, during the providing of manual CPR chest compressions to a patient 964 by a care provider 966, a display may be provided (and/or, in some embodiments, other presentations, such audio or tactile presentations, for example), on a display device(s) 980 (e.g., any device(s) including or configured to provide a display or displays, potentially among other features and functions), such as a computer, portable computing device or tablet, smartphone, or medical device (e.g., a defibrillator, patient monitor or ventilator). As illustrated in FIG. 3, NIRS monitoring 968 is being performed on the patient 964 during treatment, and an optical data analysis manager, of one or more devices, may be used in determining the display/presentation, as well as determining associated parameters, e.g., of the patient 964, patient physiology, and parameters derived using the NIRS monitoring, such as convex hulls and convex hull related parameters.

[0142] In some embodiments, a display 900 may be provided (which, in some embodiments, could be provided in whole or in part on a virtual reality or augmented reality headset, for example), based on which the care provider 966 may be able to quickly and efficiently adjust, when needed, parameters of treatment (e.g., chest compression rate, depth, force, angle, and location on the patient's chest). In some embodiments, however, the display 900 may be provided to another care provider, who may not be performing CPR chest compressions, or remote care provider, who may, for example, communicate with or advise the care provider 916 providing the CPR chest compressions.

[0143] In various embodiments, various types of data may be displayed, which may be determined, for example, by an optical data analysis manager using NIRS monitoring data.

This may include, for example, feedback on chest compression parameters, or other displayed images or data that the care provider 966 may use, such as in determining potential adjustments to parameters of chest compressions. This may include, for example, displayed images or data on physiological parameters of the patient or treatment, such as may include displayed images or data on convex hull related parameters, such as, for example, convex hull centroid movement or convex hull parameters such as length, width, X or Y axis components of magnitude, angle with the X axis, area, ratios of individual parameters, centroids, or other parameters, as well as tracking (image-based and/or numerical) of how such parameters are changing over time during the chest compressions.

[0144] Furthermore, in some embodiments, simple display components may be included to guide or inform the care provider 966, such as components that indicate whether a specific convex hull parameter is increasing or decreasing, or whether it is in an ideal range, above the ideal range or below the ideal range, potentially along with associated chest compression parameter feedback to achieve optimal ranges, for example (e.g., to adjust, such as increase, decrease or otherwise change, or keep the same, a specific parameter of the chest compressions, such as chest compression rate, depth, force, angle, and location on the patient's chest). Furthermore, in some embodiments, a color coding scheme may be used, such as to display parameters, or display components or backgrounds associated with parameters, within an optimal range in green or first color, within a near optimal range in yellow or second color, and outside and not near an optimal range in red or third color, for example. For example, as described previously, in some embodiments, parameters of tracked low frequency and high frequency movement may be used in determining messaging to a care provider relating to parameters of chest compressions being provided to a patient. In some embodiments, such messaging could include associated color coding. For example, green may indicate that one or more parameters of the chest compressions should not be changed, yellow may indicate that a small adjustment should be made, and associated text may specify the small adjustment (e.g., a specified increase or decrease in depth in number of centimeters depth, or a specified increase or decrease in rate in number of compressions per minute), and red may indicate that a large adjustment should be made, and associated text may specify the large adjustment.

[0145] In some embodiments, once the care provider 966 becomes experienced with, for example, convex hull parameter feedback, the care provider 966 may be aware of changes to chest compression parameters that can be made to improve the convex hull parameters (e.g., to move them into an optimal range), which may, in turn, help optimize or improve

chest compression parameters. Additionally, in some embodiments, displayed images or data, such as physiological and/or convex hull related data, may be displayed for other uses or care providers, who may be monitoring treatment or providing treatment other than CPR chest compressions (e.g., defibrillation or ventilation). Such displays may include, for example, displays in polar coordinates for visual tracking of the two parameters over time

[0146] In some embodiments, the display 900 may include the various types of feedback. For example, the display may illustrate convex hull movement and change during chest compressions, such as in a series of images (e.g., display screen images 970a-c) or an animated presentation including such images. In a series of images or animated presentation, convex hull centroid movement may illustrate low frequency movement over multiple chest compressions, such as in an example 2D space as described above (e.g. an O2 sat. and total Hb conc. space). Furthermore, each illustrated convex hull may include labelled parameters (e.g., centroid, angle, length, width, area, with or without numerical indications of value or relative value), and, in a series of images or animated presentation of multiple convex hulls, ongoing changes to convex hull shape (over multiple convex hulls) as a whole, as well as changes to convex hull parameters, may be visible. Still further, in some embodiments, a care provider 966 may adjust parameters of chest compressions based at least in part on such low frequency movement and high frequency movement associated feedback.

[0147] For example, as shown in FIG. 9, a display 900 may be provided, such as on the display device 980 (e.g., any device configured to provide a display, potentially among other features and functions) viewable by the care provider 966, such as may include, among other things, an animated or frequently updated display, including a changing display, as illustrated by simplified display screen images 970a-c, of a sequential series of convex hulls 952a-c, at a sequential series of times (times 1-3) such as in real time or near real time (e.g., on a compression cycle basis, and/or within seconds or a fraction of a second of real time). The display screen images 970a-c may also include images and/or data relating to specific convex hull related parameters (e.g., a bar graph relating to convex hull lengths, which may provide the care provider with real-time feedback, such as relating to oxygen delivery or brain perfusion being accomplished by each chest compression). Furthermore, displays may be rapidly updated so that the changing of each parameter over time (e.g., over chest compressions) can be seen and appreciated. For example, displayed arrows 972a-c may show vectors indicating as centroid movement (e.g., between sequential or sequentially spaced convex hulls, or between a period of multiple sequential convex hulls), where the direction and length of each arrow may correspond with the associated centroid movement vector

direction and magnitude (e.g., in an O2 sat. and total Hb conc. space, or a deoxyHb conc. and oxyHb conc. space, or another parameter space). Other displayed features may include convex hull length 958a-c, width 950a-c and angle 956a-c, for example. Although not shown in FIG. 9, in some embodiments, numerical data may be provided (and frequently updated and adjusted) to indicate the values of each parameter, and/or color coding, as referenced above, may also be provided. While not shown in FIG. 9, the display 900 may be accompanied by, or include, various associated continually updated patient physiological parameters and chest compression parameter feedback (for example, as shown in FIG. 10).

[0148] In some examples, convex hull movement, and/or change over time during chest compressions, may be displayed to care provider, e.g., in series of images or animated presentation on display of device. In some examples, convex hull centroid movement may illustrate low frequency movement (over multiple compressions) in Hb/O2 space over time during chest compressions. In some examples, changing convex hull parameters (e.g., area, angle, length, width) may show high frequency movement changes from compression to compression or between sets of compressions. In some examples, a care provider may adjust compression parameters, e.g., based on observations of convex hull movement and shape change, or associated provided feedback.

[0149] For the exemplary context of CPR chest compressions, FIG. 10A is an example graphical user interface (GUI) 1000 including displayed convex hull parameters, associated physiological parameters, and associated CPR chest compression treatment feedback, which may be provided, for example, in a treatment environment such as that shown in FIG. 3 (including manual CPR chest compression treatment, NIRS monitoring, and a software-based optical data analysis manager), such as on a display device (e.g., any device configured to provide a display, potentially among other features and functions) of a care provider providing the CPR chest compressions, and/or on one or more display devices of one or more other care providers or users. Display features 1002-1018 may provide, among other things, selected, integrated or curated information regarding various patient physiological parameters, information on parameters relating to one or more treatments being performed on the patient, and information and/or images providing guidance to the care provider, such as may relate to parameters of the provided chest compression treatment. Examples may include one or more of the display features 1002-1018.

[0150] In the GUI 1000, a displayed "XX" represents a value or measurement displayed for the associated parameter, with or without dimensions or units (e.g., an oxygen saturation of 55%, or a breaths per minute (BPM) of 11). In some embodiments, a GUI 1000

(or more than one) may be provided, such as on one or more computerized or medical devices (e.g., computers, portable computing devices such as tablets or smartphones, medical devices, defibrillators, ventilators, or others). The GUI 1000 may display, for example, physiological parameters, convex hull parameters, and treatment feedback, such as chest compression feedback. The displayed physiological parameters may include, for example, physiological parameters determined using NIRS data or otherwise, as well as determined using an optical data analysis manager or otherwise. Some or all of the displayed convex hull parameters may be associated with various of the displayed physiological parameters. The treatment feedback, such as CPR chest compression feedback, may be determined (such as at least in part by an optical data analysis manager) based at least in part on at least some of the determined physiological parameters and/or the determined convex hull parameters. The various displayed data may be presented continuously, and may be frequently updated to reflect changing conditions during, for example, CPR chest compression treatment (and potentially other treatment such as ventilation, electrotherapy or defibrillation).

[0151] Specifically, displayed parameters 1002 include pulse oximetry based patient oxygen saturation (SpO2), heart rate, and CPR chest compression parameters including depth, rate and angle. Displayed parameters 1002 also include a perfusion performance indicator (PPI), which may provide an indication of whether depth and rate are both within an optimal range, and, optionally, how close they are to optimal range, as well as, optionally, a release indicator, which may provide an indication of whether all compression pressure has been removed from the patient's chest (full release), or, optionally, how close present conditions are to full release. The PPT and release indicators are, for example, available in R series ® defibrillators available by ZOLL medical Corp. of Chelmsford, MA. Display feature 1004 shows a continuously updated patient electrocardiogram (ECG) waveform. Displayed parameters 1016 include BPM, tidal volume (Vt), end tidal carbon dioxide (EtCO2) and PEEP (in examples in which ventilation is provided).

[0152] Displayed parameters 1006, 1008, 1010, 1012 show parameters that, in some embodiments, may be determined or estimated at least in part by an optical data analysis manager based at least in part on NIRS monitoring of the patient's brain. Displayed parameters 1006 including O2 sat. (e.g., as a percentage), total Hb conc., oxyHb conc. and deoxyHb conc. (in various embodiments, for the concentrations, an indication relating to units may be displayed, such as, e.g., mol/L, mol/m^3 or arbitrary units (A.U.)). Displayed parameters 1008 include coronary perfusion pressure (CPP) and pulse pressure. Displayed

parameters 1010 include convex hull related parameters, including length, width and angle with the X axis (which, in this example, represents O2 sat.), and area.

[0153] Displayed image 1012 includes a continuously updated plot of a current convex hull (or a simplification, estimation or approximation thereof), in an O2 sat. and total Hb conc. space (in this example), including marked or labelled features of the convex hull, such as length, width, angle with the X axis, and an arrow representing centroid movement (as described with reference to FIG. 9) (e.g., relative to the centroid associated with the last compression cycle).

[0154] Displayed parameters 1018 include CPR chest compression feedback, such as, in the example shown, "increase depth." In some embodiments, a specific amount of suggested increase may also be shown (e.g., "by 1/4 inch"). In some embodiments, an optical data analysis manager is used in determining the feedback, such as based at least in part on one or more of NIRS brain monitoring data, physiological parameters determined or estimated based at least in part on NIRS brain monitoring related data, low frequency movement related parameters, high frequency movement related parameters, and/or convex hull related parameters (which may include low frequency movement or high frequency movement related parameters). For example, in some embodiments, a recommendation could be provided or displayed to change chest compression location from one quadrant of a grid, representing a portion of the surface of the patient's chest, to another. Convex hull parameters, such as length, could be assessed and used in determining when to recommend changing to another quadrant, or convex hull lengths could be represented in a display (e.g., a bar graph) and the care provider could use this in assessing when to change location (e.g., in some examples, if length is declining, is declining at a high enough rate, or declines beyond some threshold). In other embodiments, some of the features shown in FIG. 10A may be provided and/or other parameters, or combinations of parameters, may be utilized, however.

[0155] For the exemplary context of CPR chest compressions, FIG. 10B is an example display portion 1050, which may be a portion of a graphical user interface (GUI), including a convex hull length tracker bar graph 1052 and including CPR chest compression feedback 1054. The display portion 1050 may, for example, be part of a GUI, displayed to a care provider providing CPR chest compressions to a patient, on a device such as a patient monitor, defibrillator, computer, tablet, or other medical, computing or display device.

[0156] As described previously, in some example situations, times or time periods during the providing of chest compressions, sufficiently large convex hull length, and/or increasing convex hull length (e.g., over time during chest compressions) may be used as an

indication of effective chest compressions and effective oxygen delivery to the patient (in other examples, convex hull may be used as an indication other or more specific physiological conditions, such as amount of cardiac output or brain perfusion, for example). In the example shown, the bar graph 1052 includes a darkened portion (or indicator portion) 1058 that is proportional to the current convex hull length, where a larger darkened portion corresponds to a greater length. Furthermore, in the example shown, the bar graph 1052 includes a dotted line 1056 that may indicate a threshold that may be associated with sufficient oxygen delivery and effective chest compressions, where, when the darkened portion is below that threshold, oxygen delivery is considered to be insufficient and the chest compressions are considered to be ineffective, while, then the darkened portion is above that threshold, or within a certain range above that threshold, oxygen delivery is considered to be sufficient and the chest compressions are considered to be effective.

[0157] It is to be understood that the example shown is a relatively simple one, and, in other examples, additional or more granular information may be provided. For example, in some embodiments, the darkened portion 1058 may be colored, and the color may vary depending on the indicated effectiveness of the chest compressions in delivering oxygen to the patient. This may include, for example, being colored green if the convex hull length is at or above the threshold, indicating effective chest compressions; being colored yellow if the convex hull length is below the threshold and within a first range defined by a first upper value and a first lower value, indicating less than effective chest compressions; and being colored red if the convex hull length is below the threshold and within a second range defined by a second upper value and a second lower value, which second range is lower than the first range, indicating chest compressions that are even less effective than chest compressions achieving convex hull lengths within the yellow color range.

[0158] Furthermore, in other examples, the bar graph 1052, or other graphs or display features, may alternatively or additionally provide an indication of amount or rate of increase or decrease in convex hull length, such as over an immediately past period of time (e.g., a specific number of immediately prior chest compression cycles, for example). Additionally, in other examples, graphs of other convex hull parameters, or other high or low frequency movement parameters, may also be provided, and/or may be factors in assessing an indicated quality of chest compressions and/or oxygen delivery, for example.

[0159] In the example shown, based on the convex hull length being below some specified threshold less than the threshold indicated by dotted line 1056 (and potentially other factors), CPR feedback is provided to the care provider to switch to ACD compressions 1054,

which may increase the effectiveness of the chest compressions and increase oxygen delivery to the patient. In other examples, feedback may be provided to adjust other parameters of the chest compressions (e.g., rate, depth, force, angle or location), or to switch to another treatment strategy (e.g., ACD chest compressions and use of an ITD device, for example). In other examples, if the convex hull length is at or above the threshold (and, in some examples, if other conditions warrant), and the chest compressions are considered effective and oxygen delivery is considered adequate, no feedback may be provided, or feedback may be provided to continue with current chest compression parameters. In other examples, the care provider may become familiar and experienced with using the convex hull length tracker 1052 even without the CPR chest compression feedback, such that the care provider may themselves determine, based on the displayed convex hull length (and potentially other factors), whether the quality of the chest compressions and oxygen delivery is sufficient, and whether parameters of the chest compressions should or should not be changed, and, if they should be changed, by how much or at what rate (e.g., if convex hull length is short enough, decreasing, or decreasing at a high enough rate, the care provider may determine to increase the depth of chest compressions by a certain amount or change the quadrant location of the chest compressions, for example).

[0160] It is to be understood that, while FIG. 10B provides an example in the context of CPR chest compression parameters, in other embodiments with different treatment being provided, different types of low and/or high frequency movement may be tracked and analyzed, and graphical or other display features and feedback may be provided, as appropriate for the treatment being provided.

[0161] FIGs. 11 is a 3D scatterplot 1000 illustrating low frequency movement in a three dimensional physiological parameter space during a set of epochs of CPR chest compressions performed on a single animal of an animal study, and FIG. 12 is a 2D scatterplot 1200 illustrating low frequency movement and high frequency movement in a two dimensional physiological parameter space relating to the same set of epochs of CPR chest compressions of the animal study of FIG. 11.

[0162] In the 3D space of FIG. 11, the X axis represents optical density at wavelength 760 nm, which is associated with deoxyHb conc., the Y axis represents optical density at wavelength 847 nm, which is associated with oxyHb conc., and the Z axis represents optical density at 803 nm, which is associated with total Hb conc. (total Hb). In the 2D space of FIG. 12, the X axis represents estimated O2 sat. (in %) and the Y axis represents estimated total Hb conc. (in arbitrary units (A.U.)). However, in various embodiments, various other axis-to-

physiological parameter (or combination of parameters, etc.) correspondence may be used, and various non-linear correspondences may be used between a particular axis and a particular physiological parameter (e.g., where a combination of multiple parameters may be factors with regard to what is represented by a particular axis, and/or where a single parameter may be a factor in what is represented by each of multiple axes, for example).

[0163] Following electrically induced ventricular fibrillation (VF), in total, 8 epochs of chest compressions are represented, including 2 epochs of break-in chest compressions (the first to approx. 1" depth, the second to approx. 2" depth), 3 epochs of low position chest compressions (targeting the left ventricle (LV)) (labelled "low"), and 3 epochs of high position chest compressions (targeting the left ventricular outflow tract (LVOT)) (labelled "high"), each of the low and high position compressions to approx.. 2 inch depth. The approximate relative locations of the high position and the low position on the subject animal are shown by squares 920 and 922, respectively, in the image above the plot 1100. The epochs of chest compressions include, as labelled in FIGs. 11 and 12, 901 1 break-in, 902 2 break in, 903 3 low, 904 4 high, 905 5 low, 906 6 high, 907 7 low, 908 8 high. In FIG. 11, as indicated by key 921, earlier chest compressions are represented in lighter color in each trajectory, while later chest compressions are represented in darker color.

[0164] In some embodiments, it is observed that each epoch of chest compressions creates a visible trajectory in the 3D and 2D spaces of the plots 1100, 1200 of FIGs. 11 and 12. In some examples, (though not necessarily at all times or during all circumstances, given varying conditions including per-heartbeat arterial and venous hemodynamics), during an epoch of chest compressions, it is desirable that Hb (total Hb) increase (which may be associated with greater blood volume and improved blood flow), and that oxyHb conc. as well as O2 sat. increase (both of which indicate a greater proportion of oxygenated blood). It is further observed that, in association with the foregoing, in some examples, there may be desirable directional aspects to low frequency movement in both spaces, which may apply regardless of where in the spaces that the movement occurs (although location in the space may affect interpretation in some ways or instances). It is further observed that, in some examples, analogous desirable aspects may exist in other analogous spaces, e.g., spaces with different axes.

[0165] In some instances, it may only be possible to effectively target, make improvement with reference to, or optimize improvement with regard to, e.g., one (or some) parameter (or, e.g., one dimension, if the dimension corresponds with the parameter) at a particular time or during a particular time period. For example, with reference to FIG. 11,

during the providing of CPR chest compressions, it may be considered desirable to move the trajectory toward higher total Hg conc. and toward higher oxyHg conc., but a strategy may be employed to increase, or optimally increase, one at a time. For example, in some implementations, the trajectory may first be moved to higher total Hg conc. by targeting the high position (the LVOT position) and/or by employing active compression-decompression (ACD) chest compressions, impedance threshold device (ITD) and/or other techniques which may, for example, effect intrathoracic pressure and increase venous pressure and flows, which may result in increased total Hg conc.. At some point in time after this strategy has been initiated, however, such as, for example, when a specified total Hg conc. threshold has been reached, compression location (whether manual or, for example, mechanical and/or closed loop controlled) may be changed to be centered closer to the low position (the LV position) to increase the amount of active decompression, increase the amount of blood send through the lungs, and increase blood oxygenation, which may result in increased oxyHg conc..

[0166] In the 3D space of plot 1100 of FIG. 11, in some examples, low frequency movement in the direction of increasing Y axis values (higher oxyHb conc.) and increasing Z axis values (Hb conc.) (upward) may be desirable. Furthermore, in some examples, in the 2D space of the plot 1200 of FIG. 12, low frequency movement in the direction of increasing X axis values (higher O2 sat.) and increasing Y axis values (Hb conc.) (upward) may be desirable. In some embodiments, aspects of such trajectories (e.g., parameters of high frequency movement and high frequency movement) are used in optimization of parameters of manual and automatic chest compressions. This may include, for example, by being used in determining feedback to a care provider relating to parameters of manual chest compressions. In some embodiments, for example, aspects of low frequency movement or high frequency movement are associated with physiological conditions or changes, and feedback or adjustments may be based at least in part on aspects of the low frequency movement or the high frequency movement, aspects of the associated physiological conditions or changes, or both.

[0167] Additionally, some embodiments provide output such as automatic adjustments (e.g., not requiring user interaction), such as may include closed loop control, for automated (e.g., mechanical, belt/band-based, piston-based) chest compression systems. For example, in some embodiments, ongoing or periodic adjustments may be used in closed loop control of automated or mechanical chest compressions (e.g., of parameters such as location on the chest, rate, depth, and/or angle of compressions). In some embodiments, for example,

based at least in part on at least one relationship between at least two physiological parameters, such as O2 sat. and Hb conc., or oxyHb conc. and deoxyHb conc., output (e.g., signals or commands) may be provided for, e.g., control, or closed loop control of automated chest compressions, which signals or commands may be transmitted to an automatic chest compression system for implementation, for example.

[0168] In some embodiments, with regard to the plot 1100 of FIG. 11, it is observed that, overall, the eight epochs of chest compressions caused low frequency movement from the lower left of the plot 1100, toward the upper right, which suggests an increase in the amount of Hb present in the interrogated volume of the brain, and the associated brain tissue, which is indicative of the overall positive effect of the chest compressions on the animal's oxygenation condition. Furthermore, it is observed that chest compressions in the two different locations (low and high) appeared to cause different types of shifts in blood volume.

[0169] In this regard, observations are made regarding the sequential epochs of chest compressions: 905 5 low, 906 6 high, 907 7 low, 908 8 high. Generally, for example, in plot 1100, it can be seen that, in the pair of high location chest compressions 906 6 high, 908 8 high, movement starts toward the right and generally moves (in a looping manner) toward the left whereas, in the pair of low position compressions 905 5 low, 907 7 low, movement starts toward the left and generally moves toward the right. The different trajectories may be associated with the different chest compression locations, which suggests that the chest compressions at the different locations had different effects on blood volumes. Since the four trajectories generally form a loop, it is observed that chest compressions at these locations may have worked synergistically. Specifically, chest compressions in the low location may have moved blood to the venous side (with increasing deoxyHb conc., while chest compressions in the high location generally moved blood toward the arterial side of the cardiovascular system (with increasing oxyHb conc.). As described previously, in some embodiments and examples, various low frequency and high frequency movement and parameters may be used to guide toward different goals (e.g., at different times, and what is better/desirable with regard to such movement and parameters may depend on the specific goal).

[0170] The 2D plot 1200 of FIG. 12 also provides examples of low frequency movement and high frequency movement in the 2D space occurring during each epoch of chest compressions. As an example, for epoch 906 6 high (of high position chest compressions), for the trajectory overall, low frequency movement (which is, as described previously, independent of movement variation within each individual compression cycle)

can be observed, from the start of the epoch (at approximately the position labelled as 908a start) relative to the finish of the epoch (at approximately the position labelled as 908b finish), in the rightward direction of higher O2 sat. (X axis). Additionally, high frequency movement can be observed. For example, dotted box 924a encloses movement associated with a number of individual compression cycles, each of which tends to show generally looping high frequency movement. Dotted box 924b provides a close-up of the movement enclosed in dotted box 924a. For example, in the high frequency movement looping variations shown in dotted box 924b, points 926a and 926b (where point 926b occurs after/later than point 926a) are during a decompression phase of a single compression cycle. Notably, the overall high frequency movement between from point 926a to point 926b is actually leftward (toward decreasing O2 sat.), even though the overall movement from the start 908a of the epoch to the finish 908b of the epoch is rightward (increasing O2 sat.). Of course, in other examples of high frequency movement (within a compression cycle), movement may be observed rightward, and magnitudes of movement will vary. As described previously, in some embodiments, low frequency movement may be characterized or identified by movement represented by positional change in the centroids of a sequence of convex hulls, where each convex hull represents looping movement associated with a single compression cycle.

[0171] In the sequence illustrated in FIG. 12, the subject animal starts with a resting heartbeat and normal sinus rhythm. This is indicated by the cluster of points labelled 930a. In some embodiments, it is observed that, during period 930a, prior to VF, O2 sat. is at a normal, healthy level for the animal (e.g., generally between 60-70%).

[0172] In accordance with previous description, a specific NIRS related parameter, such as O2 sat. alone, may not allow for ideal or complete assessments. For example, difficulty of interpretation or ambiguity may be presented by the fact that O2 sat. may increase as a result of an increase in oxyHb conc. or a decrease in deoxyhb conc., and interpretation may not take into account venous blood volume changes. As such, in some embodiments, consideration of O2 sat. and total Hg conc. (or, in other embodiments, other combinations of parameters) together, including relative changes in both over time during treatment (as may be reflected in low frequency and high frequency movement), may allow for much greater insight and better assessment of patient physiology, patient response, and effectiveness of treatment, as well as potentially allow for determinations regarding changes or adjustments to treatment that may better optimize the effect of treatment.

[0173] For example, in some embodiments, shifts in total blood volume in the brain

and degree of oxygenation of blood in the brain are both accounted for to optimize such assessments, such as by use of low and/or high frequency movement. In the exemplary context of CPR chest compressions, during the compression phase or downstroke of a chest compression cycle, the same or similar pressure may be applied to both veins and arteries into and out of the brain. Generally, blood may flow into the brain when the pressure in the arteries going into the brain is greater than the pressure in the veins coming out of the brain, which may be different than with normal sinus rhythm, in which blood may be pushed into the arteries but not into the veins. As such, during the compression phase of a compression cycle, no blood flow to the brain may be induced. However, during the decompression phase or upstroke of a chest compression, arterial pressures may be sustained or somewhat sustained, e.g., due to high elastances of the arteries, which may, e.g., allow greater storage or retention of pressure in the arteries. As such, during the decompression phase, this, in turn, may lead to higher pressures in the arteries going into the brain than in the veins going out of the brain, resulting in blood flow into the brain.

[0174] In some embodiments, shifts in blood flow between arterial blood flow and venous blood flow may affect high frequency movement, such as in the total Hb conc. and O2 sat. space. For example, referring to the high frequency movement shown in FIG. 7, in some examples, the total Hb conc. component 708 may be an indicator of brain pressure in that it may be an indicator of relative volumes of brain tissue and brain vasculature. In some examples, during chest compressions, it may be better to decrease brain pressure or spikes in brain pressure. In some examples, in FIG. 7, reduction of the ratio of length 710 to width 706 may indicate that blood flows more easily or better into the brain, e.g., causing better blood flow and cerebral perfusion, and may therefore be desirable. In some examples, adjustments or use of techniques such as ACD compressions and head-up CPR (which may include controlled elevation of the head and thorax, as well as use of ACD compressions and an ITD) may provide such a reduced length to width ratio, and may result in improved blood flow and cerebral perfusion.

[0175] However, during induced VF 904, rapid, large low frequency movement occurs in the leftward direction, indicating rapidly declining O2 sat. as a result of the greatly interrupted cardiac output associated with VF. A sequence of 8 epochs of CPR chest compressions then commences, as described above, starting with the approximate start 901a of the first epoch of break-in compressions 901 and ending with the finish 908b of the final epoch 908 of high position chest compressions 908 8 high. From start 901a to finish 908b, overall low frequency movement can be seen, with large upward (higher total Hb conc.) and

rightward (higher O2 sat.) movement. This is associated with the overall improvement of the oxygenation condition of the animal. As such, it is observed from the plot 1200 that, initially, VF, starting from a normal sinus rhythm 930, leads to a large deterioration of the animal's oxygenation condition, leading to overall large leftward low frequency movement (lower O2 sat.). This is interrupted with the sequence of 8 epochs of chest compressions, from approximately point 901a to approximately point 908b, leading to an overall large improvement in the animal's oxygenation condition, as can be seen be the associated overall large rightward (higher O2 sat.) and upward (higher total Hb conc.) low frequency movement.

[0176] FIG. 13a is a two-dimensional overlay plot 1300 illustrating low frequency movement in a two dimensional O2 sat. and total Hb conc. physiological parameter space during sets of CPR chest compressions performed on multiple animals of the animal study of FIG. 11. The axes in the plot 1300 of FIG. 13 are the same as in the plot 1200 of FIG. 12. Specifically, plot 1300 shows overlays associated with each of nine animals in an animal study. Each overlay (1333 animal 1, 1334 animal 2, 1336 animal 3, 1337 animal 4, 1338 animal 5, 1339 animal 6, 1340 animal 7, 1341 animal 8, 1342 animal 9) relates to a set of 8 CPR chest compression epochs performed on the animal, following induced VF. Overlay 1342 relates to animal 9 in the study, which is the same animal as is associated with the plots 1100, 1200 of FIGs. 11 and 12 and represents overlay of all of the epochs of chest compressions, as plotted in plot 1100 of FIG. 11 and plot 1200 of FIG. 12.

[0177] FIG. 13B is a two-dimensional overlay plot 1300 illustrating low frequency movement in a two dimensional oxyHb conc. and deoxyHb conc. physiological parameter space during sets of CPR chest compressions performed on multiple animals of the animal study of FIG. 11. Specifically, plot 1350 shows overlays associated with each of the nine animals the same animal study as relates to FIG. 13a, but in a different parameter space. Each overlay (1383 animal 1, 1384 animal 2, 1386 animal 3, 1387 animal 4, 1388 animal 5, 1389 animal 6, 1390 animal 7, 1391 animal 8, 1392 animal 9) relates to a set of 8 CPR chest compression epochs performed on the animal, following induced VF. Overlay 1392 relates to animal 9 in the study, which is the same animal as is associated with the plots 1100, 1200 of FIGs. 11 and 12 and represents overlay of all of the epochs of chest compressions, as plotted in plot 1100 of FIG. 11 and plot 1200 of FIG. 12, but represented in the oxyHb conc. and deoxyHb conc. parameter space. While various embodiments are described primarily with regard to the total Hb conc. and O2 sat. parameter space, it is to be understood that, in other embodiments, other parameter spaces and parameters may be used, such as the two

dimensional oxyHb conc. and deoxyHb conc. parameter space as used in FIG. 13B, or others. For example, just as FIG. 12 shows the example of low frequency and high frequency movement in the total Hb conc. and O2 sat. parameters space, low frequency and high frequency movement also exists in other spaces, such as the oxyHb conc. and deoxyHb conc. parameter space, for example, or other two or more dimensional parameter spaces.

[0178] In accordance with the description of FIG. 11, it can be seen that, during VF 1344, and before the start 1345 of the 8 epochs of chest compressions, substantial overall leftward low frequency movement (decreasing O2 sat.) can be seen, as the animal's oxygenation status rapidly declines with poor cardiac output as a result of VF. However, from the start 1345 and the finish 1346 of the 8 epochs of chest compressions, substantial overall rightward low frequency movement (increasing O2 sat.) and upward movement (increasing total Hb conc.) can be seen, as the animal's condition overall improves with improved cardiac output as a result of the chest compressions. In general, similar aspects can be observed in the trajectories 1333-1341 associated with each of the other animals in the study.

[0179] FIG. 14 illustrates loops representing loop high frequency movement in a two dimensional parameter space, associated individual chest compression cycles, along with portions of associated convex hulls, associated with the animal study of FIG. 11. Specifically, for each period of 8 sequential two minute epochs of CPR chest compressions (1404, 1406, 1408, 1410, 1412, 1414, 1416, 1418), including, as labelled, 3 low position epochs and 3 high position epochs), a single plot is provided. A baseline loop 1440 is also shown, which corresponds with healthy heartbeats before ventricular fibrillation was induced. For each plot, the X axis represents O2 sat. (in %) and the Y axis represents Hb (total Hb) conc. (in arbitrary units (A.U.s)). Each single plot represents average high frequency movement (which can be observed to generally appear as a partial or complete loop) over each compression cycle, averaged over all of the compression cycles of that epoch. For each plot, low frequency movement is filtered out, so that each plot represents only the average high frequency movement loop and is not affected by low frequency movement occurring during the high frequency movement.

[0180] Each of the high frequency movement loops shows a generally similar pattern for each epoch of chest compressions, looping in a counterclockwise direction from start to finish. As an example, for loop 1440, corresponding with an epoch of low position compressions, starting at start point 1430, movement proceeds generally downward (decreasing total Hb conc.) and slightly leftward (decreasing O2 sat.) during the compression phase of the chest compression cycle, and generally upward (increasing total Hb conc.) and

slightly rightward (increasing O2 sat.) during the release phase of the chest compression cycle. In some embodiments, for each of the averaged loops, a convex hull may be generated. In other embodiments, a convex hull could be generated for other loops, such as loops associated with individual compression cycles, or loops associated with an average of other sets of compression cycles, with or without low frequency movement filtered out, for example.

[0181] FIG. 15 is a polar plot 1500 illustrating coronary perfusion pressure (CPP) relative to convex hull length and angle, in a two dimensional physiological parameter space, for animal study data relating to the animal study of FIG. 11. In some examples, higher CPP may correspond with more effective chest compressions and better patient oxygenation. In the heatmap 1500, a circumferential position 1506 corresponds with convex hull length and the radial position 1508 corresponds with convex hull angle, with reference to a 2D space, with O2 sat. represented by the X axis and total Hb conc. represented by the Y axis, as shown in previous figures. With reference to the cluster of points 1510 in the upper half of the heatmap 1500, each point corresponds with a CPP (calculated as the different between aortic pressure and right atrial pressure during diastole) for each compression of eight epochs of chest compressions, for all nine of the animals of the animal study of FIG. 11. As indicated by key 1520, CPP value (in mm Hg) is represented by the shade of each of the points, where black corresponds with 0 mm Hg, black corresponds with 40 mm Hg, and shades of grey indicate values between 0-40 mm Hg. As indicated by the group of points generally indicated by feature 1512, for larger convex hull lengths, higher CPP was typically found at angles of between 70-85 degrees, and, as indicated by feature 1514, for smaller convex hull lengths, higher CPP was typically found at between approx. 30-60 degrees. In some examples, it is observed that chest compressions associated with small convex hull lengths and angles, and, in turn, optimal CPPs may be compressions that generate relatively small pulse pressures that are predominantly driven by arterial blood volume.

[0182] FIG. 16 includes plots 1600 illustrating tracking of convex hull centroid movement during CPR chest compressions performed on each of the nine animals of the animal study of FIG. 11. In each plot, the light color curve represents centroid total Hb conc. and the dark color curve represents centroid O2 sat. In the 2D space, the X axis represents the compression number and the Y axis represents, for the light curve, total Hb conc. and, for the dark curve, O2 sat., each having a value that is normalized relative to the value associated with the first compression. Plot 1602 relates to animal nine, which is the same animal that is associated with FIG. 12. In plot 1602, lighter color curve 1604 represents oxyHb conc. and

darker color curve 1606 represents deoxyHb conc. In some embodiments, it is observed that tracking of the O2 sat. and total Hb conc. over time during chest compressions, relative to their values at the first compression, may be useful in tracking responsiveness to the chest compressions. For example, as described previously, in some embodiments, measurements (which may include estimations), such as for O2 sat. and total Hb conc., may be expressed relative to a determined baseline, rather than in absolute units, and be expressed, for example, in arbitrary units (A.U.s) or in other ways.

[0183] As described previously, in some embodiments, spectral or optical brain monitoring, such as NIRS monitoring, is used in determining brain-associated physiological parameters, including O2 sat., total Hb conc., oxyHb conc. and deoxyHb conc. The following provides some details relating to monitoring and calculations used, in some embodiments. However, in other embodiments, other types of monitoring and calculations may be used.

[0184] Optical data, such as recorded in optical brain monitoring (OBM), can be acquired by frequency-domain or continuous wave NIRS systems/devices. The physical implementation of these systems can either be to record light transmittance or reflectance. Some embodiments include a focus on continuous wave systems and reflectance.

[0185] Raw optical intensity may be measured, for example, by projecting light via either a light emitting diode (LED) or laser diode into human tissues, and measuring the light reflected back to the surface via a photodiode (PD). As light interacts with mediums such as human tissues, the light is either absorbed by absorbing species or scatters when transitioning at the boundary of two differing mediums.

[0186] Optical density (OD), or absorbance, reflects the ability for a medium or material to absorb the power of a given light (radiant power). Larger OD values indicate less measured light. OD may be given by equation 1, as follows:

(Equation 1)

$$OD = \log_{10}\left(\frac{I_0}{I}\right)$$

Where:

OD = optical density

I_0 = radiant flux received by material (incident light)

I = radiant flux transmitted by material (measured light)

[0187] Filtering may be performed of the OD data from each wavelength of light to remove noise or to separate the effects of low or high frequency content. An LP filter may be

applied on raw data before applying either the AC or DC filters, as indicated by Table 1, as follows.

Table 1:

FilterName	FilterType	PassBand (Hz)	Purpose
LP	IIR Lowpass	0 - 5	Remove high frequency noise
AC	IIR Highpass	1 - 5	Isolate high frequency content
DC	IIR Lowpass	0 - 0.1	Isolate low frequency content

[0188] In some embodiments, an optical model is used that makes use of the Beer-Lambert law and associated equations, including Equation 2, as follows.

(Equation 2)

$$FM\,HbO = DPF \cdot [\varepsilon o_1 \ldots \varepsilon o_m]^T \cdot [SDD_1 \ldots SDD_k] FM\,HbR = DPF \cdot [\varepsilon r_1 \ldots \varepsilon r_m]^T \cdot [SDD_1 \ldots SDD_k]$$

[0189] In some embodiments, FM oxyHb (HbO) / deoxyHb (HbR) is [m, k] = [4, 4], where m is number of wavelengths and k is number of source-detector distances (SDD). DPF is fixed at 5. E is the extinction coefficient for each chromophore (HbO or HbR) and is obtained for each wavelength from published measured values.

(Equation 3)

$$NIRS\,fwdMdl = \begin{bmatrix} FM\,HbO_{1,1} & FM\,HbR_{1,1} \\ \cdots & \cdots \\ FM\,HbO_{m,1} & FM\,HbR_{m,1} \\ \cdots & \cdots \\ FM\,HbO_{m,k} & FM\,HbR_{m,k} \end{bmatrix}$$

[0190] In equation 3, above, NIRS fwdMdl is [m*k, 2] = [16, 2].

[0191] A window of data may be used to compute noise variance, which may be subtracted from OD data.

(Equation 4)

$$OD = \begin{bmatrix} OD_{1,1} & OD_{1,n} \\ \cdots & \cdots \\ OD_{m\cdot 1,1} & OD_{m\cdot 1,n} \\ \cdots & \cdots \\ OD_{m\cdot k,1} & OD_{m\cdot k,n} \end{bmatrix}$$

[0192] In equation 4, above, n is the number of samples at a rate of 100 samples/second.

[0193] The smoothed version of OD may be computed by taking a 3 second window average (w). The smoothed version of OD is then subtracted from the original OD data. Using the variance of the difference, the inverse noise covariance weights are computed as a diagonal matrix, as illustrated in equations 5-7, below.

(Equation 5)

$$OD_{smooth} = \begin{bmatrix} OD_{1,1} & OD_{1,n} \\ \cdots & \cdots \\ OD_{m*1,1} & OD_{m*1,n} \\ \cdots & \cdots \\ OD_{m*k,1} & OD_{m*k,n} \end{bmatrix} * \begin{bmatrix} 1/w & 1/w \\ \cdots & \cdots \\ \cdots & \cdots \\ \cdots & \cdots \\ 1/w & 1/w \end{bmatrix}$$

(Equation 6)

$$OD_{noisevar} = variance(OD - OD_{smooth})$$

(Equation 7)

$$OD_{inv\,nv} = \begin{bmatrix} 1/OD_{noisevar}(1) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1/OD_{noisevar}(m*k) \end{bmatrix}$$

[0194] Equation 8, below, is then solved, where M is inverse model, S is the forward model, and N is noise variance matrix.

(Equation 8)

M = N*S'*inv(S'*N*S)

(Equation 9)

$$a = NIRS\,fwdMdl^T \cdot OD_{inv\,nv} \cdot NIRS\,fwdMdl$$

(Equation 10)

$$b = NIRS\,fwdMdl^T$$

(Equation 11)

$$NIRS\,invMdl = x \cdot OD_{inv\,nv}$$

[0195] Linear matrix equation ax=b is then solved, for a and b as defined above, in accordance with equations 9-11.

[0196] In various embodiments, singular values may or may not be removed from data, or the first singular value may be removed.

[0197] In some embodiments, O2 sat. (below, "Sat (%)" and total Hb conc. (below, "Hb") may be computed in accordance with equations 12 and 13, below. Scale factor for total Hb conc. may be approximately 1/(6e-6), which attempts to center the values near 1, partially normalizing the value as compared to O2 sat.

(Equation 12)

$$Hb = (HbO + HbR) \cdot scale$$

(Equation 13)

$$Sat\,(\%) = \frac{HbO}{HbO + HbR} \cdot 100$$

[0198] Equations 12 and 13 conceptually illustrate the relationship between total Hb conc., oxyHb conc. and O2 sat. Specifically, total Hb conc. represents the sum of oxyHb conc. and deoxyHb conc., and O2 sat represents a ratio of oxyHb conc. to total Hb conc.

[0199] The following relates to an optical model which may be utilized in some embodiments. OD may be obtained from three wavelengths (760, 800, and 840nm) at one SDD (30mm) and the least squares solution may be computed of Ax=b where A is a matrix with column 1 having 760nm data, column 2 having 840nm data, and column 3 being all 1s while b is the 800nm data. The solution from this fit results in a vector normal to the plane, $n^{\rightarrow}$.

[0200] A rotation matrix may be computed using the normal vector and the Z-axis (800nm axis). Normalized versions of these vectors may be used, to have unit lengths, and it may be ensured that the vector, as given below by equation 14, points positively for consistency.

(Equation 14)

$$R^{\rightarrow} = 2\left(\frac{(z^{\rightarrow} + n^{\rightarrow}) \cdot (z^{\rightarrow} + n^{\rightarrow})^T}{(z^{\rightarrow} + n^{\rightarrow})^T \cdot (z^{\rightarrow} + n^{\rightarrow})}\right) - eye(3)$$

[0201] The rotation matrix only defines a way for translating between the 3D space and 2D plane but does not guarantee any specific rotation. vectors in the 3D space can be computed that lie in the plane that have useful interpretations such as iso-volume (concentration) and iso-saturation, in accordance with equations 15 and 16, below. These vectors would have the interpretations that along their vector the concentration or saturation do not change, respectively.

(Equation 15)

$$iso\ vol\ =\ z^{\rightarrow} \times n^{\rightarrow}$$

(Equation 16)

$$iso\ sat\ =\ n^{\rightarrow} \times iso\ vol^{\rightarrow}$$

[0202] The matrix may be computed to rotate iso-volume (concentration) to the Y axis in the 2D plane. The data may be sheared so that the true iso-saturation and iso-volume (concentration) vectors are 90 degrees from each other. Experimentally, it has been found that the initial saturation angle of 46 degrees is approximately correct. As such, the data must be sheared to correct the angle difference.

[0203] Some embodiments utilize a non-linear model where volume (concentration) (JV) and saturation (S) are solved using extinction coefficients for oxyHb (Eo) and deoxyHb (Ed), in accordance with equations 17-19, below.

(Equation 17)

JV * (Eo[760] * S + Ed[760] * (1 - S)) - OD[760]

(Equation 18)

JV * (Eo[802] * S + Ed[802] * (1 - S)) - OD[802]

(Equation 19)

JV * (Eo[847] * S + Ed[847] * (1 - S)) - OD[847]

[0204] In various embodiments, various parameters (e.g., oxyHb and deoxyHb concentrations and changes in concentrations) can be measured (such as estimated) and represented in various different ways.

[0205] In some embodiments, use is made of the Beer-Lambert law (which may

include, e.g., use of modifications/recasting/re-expressing to, or modified/recasted/re-expressed versions of, the Beer-Lambert law or certain expressions thereof, such as for application to measurements in tissue, such as to account for, e.g., light scattering and geometric uncertainly, for example), in which it may be used to predict the absorption of light due to the presence of one or more chromophores (light absorbing molecules, such as, e.g., oxyHb and deoxyHb,) in a test sample, such body or brain tissue. The Beer-Lambert law for a single wavelength of light may be written,

(Equation 20)

$$\log\frac{I_o}{I} = OD = \sum \varepsilon_i l C_i$$

Where I_o is the intensity of light emitted into the sample, I is the light reflected back from the sample, OD is the optical density of the sample, ε_i is the extinction coefficient for the ith chromophore and wavelength of light, l is the path length of the light through the sample and C is the concentration of the ith chromophore in the sample.

[0206] In the case of Near Infrared Spectroscopy of biological tissue, chromophores of interest may include oxyHb and deoxyHb. For each wavelength of light Eqn. 20 can be written as,

(Equation 21)

$$OD = l\left(\varepsilon_{oxy} C_{oxy} + \varepsilon_{deoxy} C_{deoxy}\right)$$

where the subscript oxy refers to oxyHb and the subscript deoxy refers to deoxyHb. If there is more than one wavelength being used the measure the sample, then Eqn. 21 is used for each wavelength of light. In this case the values of the extinction coefficients change for each wavelength of light as shown below in Eqn. 22.

(Equation 22)

$$OD_{\lambda_1} = l\left(\varepsilon_{\lambda_1 oxy} C_{oxy} + \varepsilon_{\lambda_1 deoxy} C_{deoxy}\right)$$
$$OD_{\lambda_2} = l\left(\varepsilon_{\lambda_2 oxy} C_{oxy} + \varepsilon_{\lambda_2 deoxy} C_{deoxy}\right)$$

Where λ_1 and λ_2 represent the two wavelengths of light being used to measure the sample. If there are more than two wavelengths of light, there will be one version of Eqn. 21 for each

wavelength of light.

[0207] In some embodiments, another approach is employed, using multiple path lengths. In the event of two path lengths and two wavelengths of light, Eqn. 22 is rewritten as

(Equation 23)

$$OD_{\lambda_1 l_1} = l_1\left(\varepsilon_{\lambda_1 oxy} C_{oxy} + \varepsilon_{\lambda_1 deoxy} C_{deoxy}\right)$$
$$OD_{\lambda_2 l_1} = l_1\left(\varepsilon_{\lambda_2 oxy} C_{oxy} + \varepsilon_{\lambda_2 deoxy} C_{deoxy}\right)$$
$$OD_{\lambda_1 l_2} = l_2\left(\varepsilon_{\lambda_1 oxy} C_{oxy} + \varepsilon_{\lambda_1 deoxy} C_{deoxy}\right)$$
$$OD_{\lambda_2 l_2} = l_2\left(\varepsilon_{\lambda_2 oxy} C_{oxy} + \varepsilon_{\lambda_2 deoxy} C_{deoxy}\right)$$

[0208] In spectroscopy, the Beer-Lambert law is inverted so that the concentration of the chromophores (e.g., oxyHb and deoxyHb, noting that total Hb conc. represents the sum of oxyHb conc. and deoxyHb conc., and O2 sat. represents a ratio of oxyHb conc. to total Hb conc.) are expressed as a function of the optical densities. In matrix form, equation 22 is written as

(Equation 24)

$$l\begin{bmatrix}\varepsilon_{\lambda_1 oxy} & \varepsilon_{\lambda_1 deoxy}\\ \varepsilon_{\lambda_2 oxy} & \varepsilon_{\lambda_2 deoxy}\end{bmatrix}\begin{bmatrix}C_{oxy}\\ C_{deoxy}\end{bmatrix} = \begin{bmatrix}OD_{\lambda_1} & OD_{\lambda_2}\end{bmatrix}$$

And be inverted to solve for the concentrations

(Equation 25)

$$\begin{bmatrix}C_{oxy}\\ C_{deoxy}\end{bmatrix} = \frac{1}{l} * \begin{bmatrix}\varepsilon_{\lambda_1 oxy} & \varepsilon_{\lambda_1 deoxy}\\ \varepsilon_{\lambda_2 oxy} & \varepsilon_{\lambda_2 deoxy}\end{bmatrix}^{-1}\begin{bmatrix}OD_{\lambda_1} & OD_{\lambda_2}\end{bmatrix}$$

[0209] Eqn. 25 can be used for more than two wavelengths of light. The number of rows in the extinction coefficient matrix and the number of columns in optical density matrix will match the number of wavelengths used in the measurement.

[0210] In various embodiments, there are different ways to include multiple path lengths, as shown in Eqn. 23, to estimate chromophore concentration (e.g., concentration of Hb, oxyHb and deoxyHb). For example, one method is two use Eqn. 25 independently for each pathlength. This method allows for the chromophore concentration to vary in the different pathlength measurements. Another other method is to turn the $\frac{1}{l}$ into a vector and

solve all the equations simultaneously. This method assumes that the chromophore concentration is the same in all pathlength measurements.

[0211] FIG. 17 illustrates an example of components of various devices described with reference to prior figures. It will be appreciated that not all of the components shown may be necessary for a particular embodiment or use case to function and therefore one or more examples may only include components necessary for their operation with the other components being optional. The components 2808, 2810, 2812, 2814, 2816, and 2818 are communicatively coupled (directly and/or indirectly) to each other for bi-directional communication. Similarly, the components 2820, 2822, 2824, 2826, and 2828 are communicatively coupled (directly and/or indirectly) to each other for bi-directional communication.

[0212] In some implementations, the components 2808, 2810, 2816, and/or 2818 of the therapeutic medical device 2802 may be combined into one or more discrete components and components 2816 and/or 2818 may be part of the processor 2808. The processor 2808 and the memory 2810 may include and/or be coupled to associated circuitry in order to perform the functions described herein. Additionally, the components 2820, 2822, and 2828 of companion device 2804 may be combined into one or more discrete components and component 2828 may be part of the processor 2820. The processor 2820 and the memory 2822 may include and/or be coupled to associated circuitry in order to perform the functions described herein.

[0213] In some implementations, the therapeutic medical device 2802 may include the therapy delivery control module 2818. For example, the therapy delivery control module 2818 may be an electrotherapy delivery circuit that includes one or more high-voltage capacitors configured to store electrical energy for a pacing pulse or a defibrillating pulse. The electrotherapy delivery circuit may further include resistors, additional capacitors, relays and/or switches, electrical bridges such as an H-bridge (e.g., including a plurality of insulated gate bipolar transistors or IGBTs), voltage measuring components, and/or current measuring components. As another example, the therapy delivery control module 2818 may be a compression device electro-mechanical controller configured to control a mechanical compression device. As a further example, the therapy delivery control module 2818 may be an electro-mechanical controller configured to control drug delivery, temperature management, ventilation, and/or other type of therapy delivery.

[0214] The therapeutic medical device 2802 may incorporate and/or be configured to couple to one or more patient interface devices 2830 and patient interface devices that may be

coupled with a patient 2849. The patient interface devices 2830 may include one or more therapy delivery component(s) 2832a and one or more sensor(s) 2832b. Similarly, the companion device 2804 may be adapted for medical use and may incorporate and/or be configured to couple to one or more patient interface device(s) 2834. The patient interface device(s) 2834 may include one or more sensors 2836. The sensor(s) 2836 may be substantially as described herein with regard to the sensor(s) 2832b.

[0215] The sensor(s) 2832b and 2836 may include sensing electrodes (e.g., the sensing electrodes 2838), ventilation and/or respiration sensors (e.g., the ventilation and/or respiration sensors 2830), temperature sensors (e.g., the temperature sensor 2842), chest compression sensors (e.g., the chest compression sensor 2844), etc. In some implementations, the information obtained from the sensors 2832b and 2836 can be used to generate information displayed at the therapeutic medical device 2802 and simultaneously at the display views at companion device 2804 and described above. In one example, the sensing electrodes 2838 may include cardiac sensing electrodes. The cardiac sensing electrodes may be conductive and/or capacitive electrodes configured to measure changes in a patient's electrophysiology to measure the patient's ECG information. The sensing electrodes 2838 may further measure the transthoracic impedance and/or a heart rate of the patient. The ventilation and/or respiration sensors 2830 may include spirometry sensors, flow sensors, pressure sensors, oxygen and/or carbon dioxide sensors such as, for example, one or more of pulse oximetry sensors, oxygenation sensors (e.g., muscle oxygenation/pH), O2 gas sensors and capnography sensors, impedance sensors, and combinations thereof. The temperature sensors 2842 may include an infrared thermometer, a contact thermometer, a remote thermometer, a liquid crystal thermometer, a thermocouple, a thermistor, etc. and may measure patient temperature internally and/or externally. The chest compression sensor 2844 may include one or more motion sensors including, for example, one or more accelerometers, one or more force sensors, one or more magnetic sensors, one or more velocity sensors, one or more displacement sensors, etc. The chest compression sensor 2844 may provide one or more signals indicative of the chest motion to the therapeutic medical device 2802 via a wired and/or wireless connection. The chest compression sensor 2844 may be, for example, but not limited to, a compression puck, a smartphone, a hand-held device, a wearable device, etc. The chest compression sensor 2844 may be configured to detect chest motion imparted by a rescuer and/or an automated chest compression device (e.g., a belt system, a piston system, etc.). The chest compression sensor 2844 may provide signals indicative of chest compression data including displacement data, velocity data, release velocity data,

acceleration data, force data, compression rate data, dwell time data, hold time data, blood flow data, blood pressure data, etc. In an implementation, the defibrillation and/or pacing electrodes may include or be configured to couple to the chest compression sensor 2844.

[0216] In various implementations, the sensors 2832b and 2836 may include one or more sensor devices configured to provide sensor data that includes, for example, but not limited to ECG, blood pressure, heart rate, respiration rate, heart sounds, lung sounds, respiration sounds, end tidal CO_2, saturation of muscle oxygen (SMO_2), oxygen saturation (e.g., SpO_2 and/or PaO_2), cerebral blood flow, point of care laboratory measurements (e.g., lactate, glucose, etc.), temperature, electroencephalogram (EEG) signals, brain oxygen level, tissue pH, tissue fluid levels, images and/or videos via ultrasound, laryngoscopy, and/or other medical imaging techniques, near-infrared spectroscopy, pneumography, cardiography, and/or patient movement. Images and/or videos may be two-dimensional or three-dimensional, such a various forms of ultrasound imaging.

[0217] The one or more therapy delivery components 2832a may include electrotherapy electrodes (e.g., the electrotherapy electrodes 2838a), ventilation device(s) (e.g., the ventilation devices 2838b), intravenous device(s) (e.g., the intravenous devices 2838c), compression device(s) (e.g., the compression devices 2838d), etc. For example, the electrotherapy electrodes 2838a may include defibrillation electrodes, pacing electrodes, and combinations thereof. The ventilation devices 2838b may include a tube, a mask, an abdominal and/or chest compressor (e.g., a belt, a cuirass, etc.), etc. and combinations thereof. The intravenous devices 2838c may include drug delivery devices, fluid delivery devices, and combinations thereof. The compression devices 2838d may include mechanical compression devices such as abdominal compressors, chest compressors, belts, pistons, and combinations thereof. In various implementation, the therapy delivery component(s) 2832a may be configured to provide sensor data and/or be coupled to and/or incorporate sensors. For example, the electrotherapy electrodes 2838a may provide sensor data such as transthoracic impedance, ECG, heart rate, etc. Further the electrotherapy electrodes 2838a may include and or be coupled to a chest compression sensor. As another example, the ventilation devices 2838b may be coupled to and/or incorporate flow sensors, gas species sensors (e.g., oxygen sensor, carbon dioxide sensor, etc.), etc. As a further example, the intravenous devices 2838c may be coupled to and/or incorporate temperature sensors, flow sensors, blood pressure sensors, etc. As yet another example, the compression devices 2838d may be coupled to and/or incorporate chest compression sensors, patient position sensors, etc. The therapy delivery control modules 2818 may be configured to couple to and control the

therapy delivery component(s) 2832a, respectively.

[0218] The one or more sensor(s) 2832b and 2836 and/or the therapy delivery component(s) 2832a may provide sensor data. The patient data provided at the display screens of the therapeutic medical device 2802 and companion device 2804 may display the sensor data. For example, the therapeutic medical device 2802 may process signals received from the sensor(s) 2832b and/or the therapy delivery component(s) 2832a to determine the sensor data. Similarly, the companion device 2804 may process signals received from the sensor(s) 2836 and/or sensor data from the sensors 2832b received via the therapeutic medical device 2802to determine the sensor data.

[0219] While certain embodiments have been described, these embodiments have been presented by way of example only and are not intended to limit the scope of the present disclosures. Indeed, the novel methods, apparatuses and systems described herein can be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods, apparatuses and systems described herein can be made without departing from the spirit of the present disclosures. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the present disclosures.

WHAT IS CLAIMED IS:

1. A system for providing feedback to a care provider relating to resuscitation treatment being provided to a patient, the system comprising:

at least one device configured to provide a display;

a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of oxygen delivery to the brain; and

at least one controller, comprising at least one processor and at least one memory, coupled with the NIRS system, the at least one controller being configured to:

receive the signals,

based at least in part on the signals, estimate physiological parameters comprising:

an oxygen saturation relating to the brain of the patient, and

a hemoglobin concentration relating to the brain of the patient,

based at least in part on at least one relationship between the oxygen saturation and the hemoglobin concentration, determine feedback relating to the resuscitation treatment being provided to the patient, and

display the feedback for the care provider at least during the resuscitation treatment on the at least one device.

2. The system of claim 1, wherein the at least one controller is configured to compute the at least one relationship.

3. The system of claim 1, wherein the at least one relationship comprises a relationship in a computed at least two dimensional space comprising at least two axes, wherein each axis of the at least two axes is associated with at least one of: the oxygen saturation and the hemoglobin concentration.

4. The system of claim 1, wherein the signals are associated with a volume of the brain of the patient.

5. The system of claim 1, wherein the at least one device is incorporated into at least one of: the NIRS system, a device communicatively coupled with the NIRS system, a portable computing device, a medical device, a mechanical chest compression system, a defibrillator, and a ventilator.

6. The system of claim 1, wherein the resuscitation treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter.

7. The system of claim 6, wherein chest compression feedback relates to at least one of: chest compression location, chest compression depth, chest compression force, chest compression rate, and chest compression angle.

8. The system of claim 1, wherein the signals relate to each of a plurality of wavelengths of electromagnetic radiation, wherein each of the plurality of wavelengths is within a range of between 640 and 900 nanometers, and wherein the plurality of wavelengths comprises a wavelength of between 750-770 nanometers, a wavelength of between 840-860 nanometers, and a wavelength of between 800-820 nanometers.

9. The system of claim 1, wherein the hemoglobin concentration is a total hemoglobin concentration.

10. The system of , wherein the at least one optical sensor is configured to be coupled to the patient's head.

11. The system of claim 1, wherein the at least one controller comprises at least one of: a controller of the NIRS system, a controller of a device communicatively coupled with the NIRS system, a controller of a portable computing device, a controller of a medical device, a controller of a mechanical chest compression system, a controller of a defibrillator, and a controller of a ventilator.

12. The system of claim 1, comprising a flexible structure comprising a plurality of capacitive cells, the flexible structure configured to be positioned on at least a portion of a torso of the patient during the treatment being provided to the patient, and wherein the at least one controller is configured to:

receive second signals associated with a plurality of capacitance values associated with at least a portion of the plurality of capacitive cells,

based at least in part on the received second signals, estimate a change in a three

dimensional shape of the flexible structure over a period of time during the providing of the treatment to the patient, and

based at least in part on the estimated change in the three dimensional shape of the flexible structure, determine the feedback.

13. The system of claim 1, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second axis is associated with the hemoglobin concentration, and wherein the first axis is orthogonal to the second axis.

14. The system of claim 13, wherein the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter.

15. The system of claim 14, wherein the at least one controller is configured to:

determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxygen saturation and the hemoglobin concentration over a period of time during the CPR chest compressions; and

based at least in part on at least one parameter of the path, determine the chest compression feedback.

16. The system of claim 15, wherein, based at least in part on the at least one parameter of the path, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient.

17. The system of claim 16, wherein the determined path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles.

18. The system of any one of claim 17, wherein the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycles of the multiple CPR chest compression cycles.

19. The system of claim 18, wherein the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement.

20. The system of claim 19, wherein the at least one calculated shape comprises at least one convex hull.

21. The system of claim 20, wherein the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull.

22. The system of claim 21, wherein the one or more physiological parameters comprise at least one of: coronary perfusion pressure and pulse pressure.

23. The system of claim 20, wherein the chest compression feedback comprises a display of an animated shape representative of the at least one convex hull, wherein the animated shape varies over the period of time.

24. The system of claim 21, wherein the one or more convex hull parameters comprise at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude.

25. The system of claim 24, wherein, based at least in part on the one or more convex hull parameters, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient.

26. The system of claim 17, wherein at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

27. A system for managing mechanical chest compressions being provided to a patient, the system comprising:

a mechanical chest compression system;

a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of the patient's brain oxygenation; and

at least one controller, comprising at least one processor and at least one memory, coupled with the NIRS system and the mechanical chest compression system, the at least one controller being configured to:

receive the signals,

based at least in part on the optical signals, estimate physiological parameters comprising:

an oxygen saturation relating to the brain of the patient, and

a hemoglobin concentration relating to the brain of the patient,

based at least in part on at least one relationship between the oxygen saturation and the hemoglobin concentration, determine at least one adjustment to at least one mechanical chest compression parameter of the mechanical chest compressions being provided to the patient, and

implement the at least one adjustment to the at least one mechanical chest compression parameter of the mechanical chest compressions being provided to the patient.

28. The system of claim 27, wherein the at least one adjustment comprises at least one automatic adjustment.

29. The system of claim 27, wherein the at least one adjustment is implemented following at least one confirmation by a care provider.

30. The system of claim 28, wherein the at least one automatic adjustment comprises a plurality of periodic automatic adjustments.

31. The system of claim 30, wherein the at least one controller is configured to:

monitor the at least one mechanical chest compression parameter of the mechanical chest compressions being provided to the patient, and

determine the plurality of automatic adjustments such that the at least one mechanical chest compression parameter is maintained within a specified range.

32. The system of claim 28, wherein the at least one adjustment is for at least one of: improving patient oxygenation resulting from the mechanical chest compressions, and improving a probability of survival of the patient following the mechanical chest compressions.

33. The system of claim 27, wherein the at least one mechanical chest compression parameter comprises at least one of: chest compression location, chest compression depth, chest compression force, chest compression rate, and chest compression angle.

34. The system of claim 27, wherein the at least one controller comprises at least one of: a controller of the NIRS system, a controller of a device communicatively coupled with the NIRS system, a controller of a portable computing device, a controller of a medical device, a controller of a mechanical chest compression system, a controller of a defibrillator, and a controller of a ventilator.

35. The system of , wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second axis is associated with the hemoglobin concentration, wherein the first axis is orthogonal to the second axis.

36. The system of claim 35, wherein the at least one controller is configured to:

determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxygen saturation and the hemoglobin concentration over a period of time during the CPR chest compressions; and

based at least in part on at least one parameter of the determined path, determine the at least one adjustment.

37. The system of claim 36, wherein, based at least in part on the at least one parameter of

the determined path, the at least one adjustment is determined to comprise at least one of: depth of compressions, angle of compressions, and position of application of compressions on the patient.

38. The system of claim 36, wherein the determined path relates to multiple CPR chest compression cycles, wherein the at least one parameter of the determined path comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles.

39. The system of claim 38, wherein the at least one parameter of comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycles of the multiple CPR chest compression cycles.

40. The system of claim 39, wherein the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement.

41. The system of claim 40, wherein the at least one calculated shape comprises at least one convex hull.

42. The system of claim 41, wherein the at least one adjustment is determined based at least in part on one or more parameters of the convex hull comprising at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude.

43. A method for providing output relating to treatment being provided to a patient, the method comprising:

sensing signals indicative of the patient's brain oxygenation with a near infrared spectroscopy (NIRS) system comprising at least one optical sensor;

receiving the signals by at least one controller; and

based at least in part on the signals, estimating, by the at least one controller,

physiological parameters comprising:

an oxygen saturation relating to the brain of the patient, and

a hemoglobin concentration relating to the brain of the patient; and

based at least in part on at least one relationship between the oxygen saturation and the hemoglobin concentration, providing, by the at least one controller, output relating to the treatment at least during the treatment being provided to the patient.

44. The method of claim 43, wherein providing the output comprises:

determining at least one adjustment to the treatment being provided to the patient, and

implementing the at least one adjustment.

45. The method of claim 44, wherein the treatment comprises mechanical chest compressions, and wherein the adjustment is to at least one mechanical chest compression parameter of the mechanical chest compressions.

46. The method of claim 43, wherein providing the output comprises:

based at least in part on the at least one relationship, determining feedback relating to the treatment being provided to the patient, and

presenting the feedback for the care provider on at least one presentation device.

47. The method of claim 46, wherein the treatment comprises chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter.

48. The method of claim 43, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second axis is associated with the hemoglobin concentration, and wherein the first axis is orthogonal to the second axis.

49. The method of claim 43, wherein the treatment comprises chest compressions, wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter, and wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxygen saturation and a second axis is associated with the hemoglobin concentration, and wherein the first axis is orthogonal

to the second axis.

50. The method of claim 49, comprising:

determining a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxygen saturation and the hemoglobin concentration over a period of time during the CPR chest compressions; and

based at least in part on at least one parameter of the path, presenting the chest compression feedback.

51. The method of claim 50, wherein the path relates to multiple CPR chest compression cycles, wherein the at least one parameter of the path comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles.

52. The method of claim 51, wherein the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycle of the multiple CPR chest compression cycles.

53. The method of claim 52, wherein the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement.

54. The method of claim 53, wherein the at least one calculated shape comprises at least one convex hull.

55. The method of claim 54, wherein the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull.

56. The method of claim 51, wherein at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

57. A system for providing feedback to a care provider relating to treatment being provided to a patient, the system comprising:

at least one presentation device;

a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of the patient's brain oxygenation; and

at least one controller, comprising at least one processor and at least one memory, coupled with the NIRS system, the at least one controller being configured to:

receive the signals,

based at least in part on the signals, estimate physiological parameters comprising:

an oxyhemoglobin concentration relating to the brain of the patient, and

a deoxyhemoglobin concentration relating to the brain of the patient; and

based at least in part on at least one relationship between the oxyhemoglobin concentration and the deoxyhemoglobin concentration, determine feedback relating to the treatment being provided to the patient, and

present the feedback for the care provider at least during the resuscitation treatment on the at least one presentation device.

58. The system of claim 57, wherein the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter of the CPR chest compressions.

59. The system of claim 57, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the deoxyhemoglobin saturation, and wherein the first axis is orthogonal to the second axis.

60. The system of claim 57, wherein the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the

deoxyhemoglobin concentration, and wherein the first axis is orthogonal to the second axis.

61. The system of claim 60, wherein the at least one controller is configured to:

determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxyhemoglobin concentration and the deoxyhemoglobin concentration over a period of time during the CPR chest compressions; and

based at least in part on at least one parameter of the path, determine the chest compression feedback.

62. The system of claim 61, wherein the path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles.

63. The system of claim 62, wherein the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycles of the multiple CPR chest compression cycles.

64. The system of claim 63, wherein the at least one micro path related parameter relates to at least one calculated shape associated with the high frequency movement.

65. The system of claim 64, wherein the at least one calculated shape comprises at least one convex hull.

66. The system of claim 65, wherein the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull.

67. The system of claim 66, wherein the one or more convex hull parameters comprise at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude.

68. The system of claim 67, wherein, based at least in part on the one or more convex hull parameters, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient.

69. The system of claim 62, wherein at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

70. A method for providing output relating to treatment being provided to a patient, the method comprising:

sensing signals indicative of the patient's brain oxygenation with a near infrared spectroscopy (NIRS) system comprising at least one optical sensor;

receiving the signals by at least one controller; and

based at least in part on the received signals, estimating, by the at least one controller, physiological parameters comprising:

an oxyhemoglobin concentration relating to the brain of the patient, and

a deoxyhemoglobin saturation relating to the brain of the patient; and

based at least in part on at least one relationship between the oxyhemoglobin concentration and the deoxyhemoglobin concentration, providing, by the at least one controller, output relating to the treatment at least during the treatment.

71. The method of claim 70, wherein providing the output comprises:

determining at least one adjustment to the treatment being provided to the patient, and

implementing the at least one adjustment.

72. The method of claim 71, wherein the treatment comprises mechanical chest compressions, and wherein the adjustment is to at least one mechanical chest compression parameter of the mechanical chest compressions.

73. The method of claim 70, wherein providing the output comprises:

based at least in part on the at least one relationship, determining feedback relating to the treatment being provided to the patient, and

presenting the feedback for the care provider on at least one presentation device.

74. The method of claim 73, wherein the treatment comprises chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter of the chest compressions.

75. The system of claim 70, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the deoxyhemoglobin concentration, and wherein the first axis is orthogonal to the second axis.

76. The method of claim 70, wherein the treatment comprises chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one chest compression parameter, wherein the at least one relationship is associated with a two dimensional space for which a first axis is associated with the oxyhemoglobin concentration and a second axis is associated with the deoxyhemoglobin concentration, and wherein the first axis is orthogonal to the second axis.

77. The method of claim 76, comprising:

determining a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the oxyhemoglobin concentration and the deoxyhemoglobin saturation over a period of time during the CPR chest compressions; and

based at least in part on at least one parameter of the path, presenting the chest compression feedback.

78. The method of claim 77, wherein the path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one macro path parameter that relates to low frequency movement through the two dimensional space, wherein the low frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles.

79. The method of claim 78, wherein the at least one parameter comprises at least one

micro path parameter that relates to high frequency movement through the two dimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycle of the multiple CPR chest compression cycles.

80. The method of claim 79, wherein the at least one micro path parameter relates to at least one calculated shape associated with the high frequency movement.

81. The method of claim 80, wherein the at least one calculated shape comprises at least one convex hull.

82. The method of claim 81, wherein the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull.

83. The method of claim 78, wherein at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the two dimensional space over the period of time.

84. A system for providing feedback to a care provider relating to treatment being provided to a patient, the system comprising:

at least one presentation device;

a near infrared spectroscopy (NIRS) system, comprising at least one optical sensor, configured for sensing signals indicative of the patient's brain oxygenation; and

at least one controller, comprising at least one processor and at least one memory, coupled with the NIRS system, the at least one controller being configured to:

receive the signals,

based at least in part on the received signals, estimate at least two physiological parameters associated with the brain of the patient,

based at least in part on at least one relationship between the at least two physiological parameters, determine feedback relating to the treatment being provided to the patient,

wherein the at least one relationship is associated with a multidimensional space comprising at least two axes, wherein each of the at least two axes is associated with a physiological parameter of the at least two physiological parameters, and

present the feedback for the care provider at least during the treatment on the at least one presentation device.

85. The system of claim 84, wherein the at least one controller is configured to compute the at least one relationship.

86. The system of claim 84, wherein each of the at least two axes is orthogonal to each of the other of the at least two axes.

87. The system of claim 86, wherein the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relating to at least one adjustment to at least one CPR chest compression parameter of the CPR chest compressions.

88. The system of claim 84, wherein the at least two physiological parameters comprise a first physiological parameter and a second physiological parameter, and wherein the at least two axes comprises a first axis associated with the first physiological parameter and a second axis associated with the second physiological parameter, and wherein the at least one relationship is associated with a two dimensional space represented by the first axis and the second axis.

89. The system of claim 88, wherein the treatment comprises CPR chest compressions, and wherein the feedback comprises chest compression feedback relates to at least one CPR chest compression parameter of the CPR chest compressions.

90. The system of claim 89, wherein the at least one controller is configured to:

determine a path relating to a set of points in the two dimensional space, the set of points relating to tracking of the first physiological parameter and the second physiological parameter over a period of time during the CPR chest compressions; and

based at least in part on at least one parameter of the path, determine the chest compression feedback.

91. The system of claim 90, wherein the path relates to multiple CPR chest compression cycles, wherein the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the multidimensional space, wherein the high

frequency movement comprises movement that is independent of positional variation within each compression cycle of the multiple CPR chest compression cycles.

92. The system of claim 91, wherein the at least one parameter comprises at least one micro path parameter that relates to high frequency movement through the multidimensional space, wherein the high frequency movement comprises positional variation during each of one or more chest compression cycles of the multiple CPR chest compression cycles.

93. The system of claim 92, wherein the at least one micro path related parameter relates to at least one calculated shape associated with the high frequency movement.

94. The system of claim 93, wherein the at least one calculated shape comprises at least one convex hull.

95. The system of claim 94, wherein the chest compression feedback comprises display of one or more physiological parameters associated with one or more convex hull parameters of the at least one convex hull.

96. The system of claim 95, wherein the one or more convex hull parameters comprise at least one of: area, length, width, a first proportion associated with the length and the width, a first magnitude along the first axis, a second magnitude along the second axis, and a second proportion associated with the first magnitude and the second magnitude.

97. The system of claim 96, wherein, based at least in part on the one or more convex hull parameters, the chest compression feedback is determined to comprise at least one of: a recommendation relating to increasing depth of compressions, a recommendation relating to decreasing depth of compressions, a recommendation relating to changing an angle of compressions, and a recommendation relating to changing position of application of compressions on the patient.

98. The system of claim 94, wherein at least a first macro path parameter of the at least one macro path parameter relates to convex hull centroid movement through the multidimensional space over the period of time.