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TRAUMA PATIENT HEMORRHAGE CONTROL INCLUDING RAPID AUTOTRANSFUSION

Abstract

A method for onsite hemorrhage control in trauma patients using a portable rapid autotransfusion device can involve recovering a first portion of patient blood from an extravascular space into a fluid reservoir of the device. A negative internal pressure can be applied to the blood. The blood can be conditioned, such as by oxygenating and removing carbon dioxide. The conditioned blood can be returned to the patient intravenously at a rate that matches the rate of blood recovery, ensuring that the net volume of returned blood is maintained substantially equal to the net volume of removed blood.

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Background/Summary

CLAIM OF PRIORITY [0001] This application is a continuation-in-part of U.S. application Ser. No. 18/673,116 filed on May 23, 2024, which claims priority to and the benefit of U.S. Provisional Application Ser. No. 63/417,574 filed on Oct. 19, 2022 and PCT application Serial No. PCT/US2023/035517 filed on Oct. 19, 2023, each of which is hereby incorporated herein by reference, and the benefit of priority of each of which is claimed herein.

BACKGROUND
[0002] Severe blood loss of a trauma patient can cause irreversible damage to vital organs that can lead to morbidity or death. Replacement of lost tissue fluid with plasma, blood, or other extracellular fluid can be performed to maintain the patient's blood pressure. Generally, a trauma treatment protocol can involve rapid transportation of the patient to a hospital setting for fluid resuscitation, blood transfusion, or surgical control of bleeding. Once the patient has lost a significant amount of tissue fluid, prevention of hemorrhagic shock can become a primary concern.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0003] In the drawings, which are not necessarily drawn to scale, like numerals can describe similar components in different views. Like numerals having different letter suffixes can represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.
[0004] FIG. **1**A depicts an example of a system for performing extracorporeal blood treatment of blood recovered from a subject.
[0005] FIG. **1**B depicts an example of a system for performing extracorporeal blood treatment of blood recovered from a subject.
[0006] FIG. **1**C depicts an example of a system for performing extracorporeal blood treatment of blood recovered from a subject.
[0007] FIG. **2**A depicts an example of a blood treatment device.
[0008] FIG. **2**B depicts an example of a blood treatment device arranged within an enclosure.
[0009] FIG. **2**C depicts an example of a vacuum puck of a blood treatment device.
[0010] FIG. **3** depicts an example of an integration of the temperature regulator with the oxygenator in an example of a blood conditioner.
[0011] FIG. **4**A depicts an example of a system for performing mobile, extracorporeal blood treatment of recovered blood.
[0012] FIG. **4**B depicts an example of a system for performing mobile, extracorporeal blood treatment of recovered blood.
[0013] FIG. **4**C depicts an example of a system for performing mobile, extracorporeal blood

treatment of recovered blood.
[0014] FIG. **5**A depicts an example of a system for performing extracorporeal blood treatment of recovered blood.
[0015] FIG. **5**B depicts an example of a system for performing extracorporeal blood treatment of recovered blood, showing various blood heating modalities along the fluid circuit.
[0016] FIG. **5**C depicts an example of a system for performing extracorporeal blood treatment of recovered blood, including batch-mode dialysis for trauma resuscitation.
[0017] FIG. **6** is a schematic of an air blender for providing a fresh gas line to an oxygenator.
[0018] FIG. **7** is a flowchart showing a method for performing extracorporeal blood treatment of recovered blood.
[0019] FIG. **8** is a block diagram of an example of a machine.

DETAILED DESCRIPTION

[0020] This document relates to treatment of a trauma victim, and more specifically, blood treatment to mitigate coagulopathy, hypothermia, or acidosis of the trauma patient. Generally, hemorrhagic shock is a common cause of death among trauma patients. This condition occurs when severe blood loss leads to inadequate tissue perfusion, causing a decrease in oxygen and nutrient delivery to vital organs. As a result, the body enters a state of shock and can quickly lead to multi-organ failure and death. In severe trauma cases, such as from a gunshot wound or motor vehicle accident, the body can quickly lose a significant amount of blood volume, complicating the body's ability to maintain normal blood function.
[0021] Coagulopathy, hypothermia, and acidosis are interrelated factors that can lead to hemorrhagic shock. Coagulopathy is an imbalance between the body's pro-coagulant pathway, responsible for clot formation at the injury site, and the mechanisms that inhibit clotting away from the injury site. As the body loses blood in a trauma situation, blood flow is decreased causing hypoperfusion. Hypoperfusion results in a simultaneous lack of clotting factor replacement at the wound site (hemorrhage) and an increase in clotting in the extremities (thrombosis), both of which can cause damage to extremities and organs. Trauma Induced Coagulopathy (TIC), is an impairment of hemostasis and activation of fibrinolysis that occurs early after injury and is biochemically evident prior to, and independent of, the development of significant acidosis, hypothermia, or hemodilution. The risk of TIC increases with hypotension, higher injury severity score, worsening base deficit, and head injury. In addition, impaired liver function due to shock can also contribute to coagulopathy as the liver is responsible for producing many of the clotting factors. Hypothermia is a decrease in body temperature, which can also result from blood loss, and can further impair the body's ability to maintain normal blood function. Acidosis, referring to an abnormal increase in acidity in the body, can also result from inadequate tissue perfusion and impair the body's ability to regulate blood function. These three conditions can exacerbate one another, creating a positive feedback loop leading to severe shock and eventually death if not promptly addressed. For example, disseminated intravascular coagulation (DIC) is a systemic process producing a consumptive coagulopathy in concert with diffuse microvascular thrombosis. DIC can increase acidosis through the production of lactic acid and can also worsen hypothermia by impairing blood flow to vital organs. Hypothermia can further worsen coagulopathy, since enzymes and proteins for forming clots become less active and less effective at lower temperatures. Acidosis can also contribute to coagulopathy since the body's normal clotting processes are disrupted and become less effective at lower pH levels. Also, acidosis can further decrease body temperature, exacerbating the effects of hypothermia.
[0022] One approach to mitigating these factors and improving outcomes for trauma patients is to administer blood components, such as plasma, platelets, or red blood cells in an attempt to provide nutrients and support for the body to maintain blood functions. Such treatment involves early and aggressive treatment of a trauma patient in an attempt to restore and maintain adequate blood volume until the patient can undergo surgery or other recovery procedure. This approach can be

challenging, as such treatment alone may not sufficiently address coagulopathy, hypothermia, and acidosis, particularly in severe trauma cases. For example, administering large amounts of blood products can further contribute to coagulopathy or lead to additional complications, such as fluid overload. Additionally, the use of blood products can be limited by availability, time constraints, or potential incompatibilities. Even the largest healthcare facilities can quickly become depleted of blood units in response to a large crisis, e.g., resulting from terrorism, violent crime, or natural disaster. Such crises can result in preventable deaths due to blood shortages or a lack of sufficient resources to treat the large number of trauma patients requiring immediate medical attention.

[0023] Another approach for improving outcomes for trauma patients involves administering clotting agents, such as tranexamic acid or a similar agent, to help minimize bleeding and promote clot formation. As a result, clotting agents alone will not sufficiently mitigate coagulopathy to prevent progression to severe shock but worsen shock if given at an inappropriate time. However, clotting agents at the inappropriate time can worsen coagulopathy, such as the location of the clotting. Appropriate timing for clot formation after repairing injured vessels is paramount following injury. Due to the consumptive nature of DIC, the patient's injury site where repaired vessels and grafts are sewn into place leads to poor clotting because these suture sites usually are larger vessels (higher blood flow) and micro clotting in the smaller vessels due to hypoperfusion (lower blood flow) causing decreased oxygen to the tissue and furthering acidosis. Clotting agents do not address hypothermia and acidosis, which can further impair the body's normal clotting processes.

[0024] The present inventor has recognized a need for a technique to treat or preserve a trauma patient without relying on ideal or preferred treatment conditions, e.g., availability of externally sourced blood components or rapid transportation of the patient to a large medical facility. Further, the present inventor has recognized a blood treatment technique for intervening in an initial blood treatment protocol, such as limiting tissue damage of a patient rapidly approaching hemorrhagic shock. Such an intervention can help delay the onset of cell death (necrosis) in trauma patients with a declining condition, such as providing the patient with more time to receive definitive medical treatment. A method for trauma management can include drawing blood from a body cavity, such as an intrathoracic or intra-abdominal area, of a subject via a fluid inlet of a blood treatment device. The drawn blood can be received within the device's reservoir and pumped toward an extracorporeal blood conditioner. For example, the extracorporeal blood conditioner can include an oxygenator for reoxygenating hemoglobin (Hb) or removing carbon dioxide CO2 included in the blood received from the reservoir. Also, the extracorporeal blood conditioner can include a blood temperature regulator for controlling the temperature of the blood received from the reservoir. The treated blood from at least one extracorporeal blood conditioner can be administered back to the subject, such as to help replace lost blood volume in the subject. For example, the treated blood can be intravenously administered back to the subject via the subject's internal jugular vein. An indication of a blood parameter such as volume of received blood, blood lactate, or arterial blood gas (ABG) can be monitored, and at least one operating parameter of the extracorporeal blood conditioner can be established or adjusted based on the indication. For example, the device can regulate oxygenation, flow rate, or blood temperature according to different operating modes, and an individual operating mode can be selected based on the medical condition of a subject. In operation and use, an anticoagulant can be administered to induce an anti-clotting state, and the device can be operated according to a series of modes, each mode progressively corresponding with a declining subject's medical condition. Thus, such a blood treatment technique can help monitor and inhibit coagulopathy (at least via the anticoagulant), acidosis (at least via the oxygenator), and hypothermia (at least via the blood temperature regulator) of the subject and, therefore, reduce hemorrhagic shock.

[0025] FIG. **1**A, FIG. **1**B, and FIG. **1**C each depict an example of a system for performing extracorporeal blood treatment of blood recovered from a subject. The system **100** can include a

blood treatment device **150** including at least one first fluid inlet **102**, a reservoir **104**, a pump **106**, a conditioner **108**, and a first fluid outlet **110**. The system can be configured to perform according to a plurality of different operating modes, and an individual mode can be selected based at least in part on a medical condition of the subject. For example, the system **100** can include a processing unit **160** included in, or otherwise communicatively coupled with, the blood treatment device **150**. The processing unit **160** can include processing circuitry for monitoring at least one parameter of the blood recovered from the subject and to establish or adjust an operating parameter of the blood treatment device **150** based on the monitored blood. Ultimately, the plurality of different operating modes can be serially performed such as to progressively escalate treatment of the subject. Selection of an individual operating mode can at least in part be based on an indication of blood volume recovered, arterial blood gas (ABG), or an indication of blood lactate of the subject.

[0026] As depicted in FIG. **1**A, the system **100** can perform according to an initial operating mode. The initial operating mode, also referred to herein as the "assist" mode, can be considered a standard or default operating mode of the system **100** and can be performed as a starting point for blood conditioning. For example, the initial operating mode can be initiated before receiving any indications of blood parameters. Blood can be received from a first blood transfer location **116** of the subject. Herein, "blood" can refer to mammalian whole blood, mammalian blood components such as red blood cells, platelets, and blood plasma, or another formulation of components which includes, at least in part, mammalian blood components. In an example, the first blood transfer location **116** can be a wound, an open surgical location, a bleeding site, or other type of fluid loss or hemorrhage location. In an example, the first blood transfer location **116** can correspond with an intrathoracic or intra-abdominal space of the subject, such as in the pleural cavity, the peritoneum, the retroperitoneal space, the thoracic or abdominal cavities. The first blood transfer location **116** can also correspond with a surgical location or an injury site in the extremities, such as a limb of the subject.

[0027] The system **100** can facilitate blood recovery from an intrathoracic area where the subject has sustained a wound or other pericardial or lung injury where access from exterior regions of the subject's body is undesired or unfeasible. For example, the system **100** can include or use a trocar **115** configured for tissue perforation and fluid or blood management. In an example, the trocar **115** can be sized and shaped to be inserted into the subject at the first blood transfer location **116**. For example, the trocar **115** can include a diaphragm portion and a removable cannula. The diaphragm portion can be seated, via insertion of the cannula, at the first blood transfer location **116**. The diaphragm portion can be expandable via inflation, vacuum, spring bias, or a similar mechanism to substantially secure and seal the diaphragm portion within the subject at the first location **116**. In an example, the cannula can be removed following the seating of the diaphragm portion, and the diaphragm portion can establish a port into the intrathoracic or the intra-abdominal space of the subject. The system **100** can include or use a tube or conduit **117** sized and shaped to be inserted into the port for drawing blood from the subject and toward the blood treatment device **150**.

[0028] The at least one first fluid inlet **102** of the blood treatment device **150** can be fluidly coupled to the tube or conduit **117**. In an example, the system **100** can include or use a source of suction, e.g., a vacuum pump, to facilitate drawing of the blood from the first blood transfer location **116** and toward the reservoir **104**. Alternatively or additionally, blood can be drawn from the first blood transfer location **116** passively, e.g., via gravity. For example, the blood treatment device **150** can be positioned such that the first blood transfer location **116** is at or near about or above a level of the reservoir **104**, and such that gravitational forces can assist in directing the blood at least toward the first fluid inlet **102**. As depicted, the first blood transfer location **116** can be accessed by a plurality of lines, such as via a plurality of trocars **115** or cannulas, for receiving blood into the reservoir **104**. Multiple lines for drawing blood from the first blood transfer location **116** can be helpful, e.g., when an internal bleed spans a relatively wide area.

[0029] The reservoir **104** can collect the drawn blood, and an inline pump **106** fluidly coupled with

the reservoir can move the blood toward the conditioner **108**. In an example, the conditioner **108** can facilitate removal of carbon dioxide (CO_2) from the blood before redistribution of the conditioned blood out of the first fluid outlet **110** and back to the subject. Alternatively or additionally, the conditioner **108** can regulate a temperature of the blood before similar redistribution. In the initial operating mode, the conditioned blood can be administered to the subject intravenously at a first return location **118** of the subject, e.g., into an internal jugular vein of the subject. Components of the blood treatment device **150**, such as the reservoir **104**, the inline pump **106**, and the conditioner **108**, are discussed in greater detail below with reference to each substantially similar component depicted in FIG. **2***a* and FIG. **2**B.

[0030] In an example, the system **100** can include or use a reservoir bypass circuit **112**. The reservoir bypass circuit **112** can be fluidly coupled to a primary fluid circuit of the blood treatment device **150**. The reservoir bypass circuit **112** can be arranged such as to provide recovered blood from the subject, via a second fluid inlet **122**, drawn from the subject via an auxiliary pump **107** toward the conditioner **108** and without entering the reservoir **104**. For example, the reservoir bypass circuit can include or use the auxiliary pump **107** located in the reservoir bypass circuit **112** to help move recovered blood from the second fluid inlet **122** toward the conditioner **108**. Alternatively or additionally, the system **100** can use a single pump, the inline pump **106**, both for the primary fluid circuit and the reservoir bypass circuit **112**. As depicted in FIG. **1**A, the initial operating mode can involve the reservoir bypass circuit **112** being disengaged, disconnected, or otherwise not used, such that the inline pump **106** moves the entirety of the blood recovered from the subject through the reservoir **104**. As depicted in FIG. **1**A, FIG. **1**B, and FIG. **1**C, various circuits and fluid lines can be selectively engaged or disengaged via one or more actuators arranged to control respective valves of the circuit. For example, as shown in FIG. **1**A and FIG. **1**B, the processing unit **160** can control the one or more actuators such as to selectively engage or disengage the reservoir bypass circuit **112** and to initiate a particular operating mode. Alternatively, the various circuits and fluid lines can be manually clamped or disconnected from the primary fluid circuit at one or more locations, e.g., by a user, to selectively engage or disengage rather than be controlled by valves and actuators. In the initial operating mode, the second fluid inlet **122** is not used for blood recovery, no auxiliary pump **107** (if included) is active, and the entirety of the conditioned blood is received from the subject at the first blood transfer location **116**, passed through the reservoir and exclusively through the inline pump **106** before being conditioned and distributed back to the subject exclusively at the first return location **118**. In an example, the system **100** can condition blood at a flow rate within a range of about 1 liter per minute (L/min) and about 5 L/min while in accordance with the initial operating mode.

[0031] The blood treatment device **150** can be communicatively coupled with the processing unit **160**. For example, the processing unit **160** can be located onboard the blood treatment device **150**, or instead can be communicatively linked such as via wired or wireless connection. The processing unit **160** can include or use software for implementing one or more algorithms to monitor blood received from the subject and to establish or adjust at least one operating parameter of the conditioner **108** based on the monitored blood. For example, the at least one operating parameter can include a flow rate of the pump **106**, a temperature regulation parameter of the conditioner **108**, an oxygenation parameter of the conditioner **108**, or an alert for an operator to move from the initial operating mode of the system **100** toward a different operating mode. In an example, the processing unit can include or use a machine learning model to determine an optimal set of parameter settings for the blood treatment device **150**, conditioner **108**, or other components (e.g., a sensor, valve, or pump). The machine learning method can continuously take measurement of data from the components over time, or when the device is turned on or re-initialized, in order to continuously iteratively improve the estimate to an optimal set of parameter settings. For example, the optimal set of parameter settings can include one or more desired blood flow rate settings or one or more granularity levels for the blood volume lost, temperature, oxygenation, or pH levels of

the blood from the subject. Also, the processing unit **160** can predictively model blood or therapy requirements of the subject. For example, the processing unit **160** can include or use stored data to extrapolate, interpolate, or otherwise estimate likely future diagnosis or blood requirement of the subject. Such an estimation can be iteratively revised with subsequently received data.

[0032] FIG. **1**B depicts an optional, intermediate operating mode of the system **100**. The intermediate operating mode, also referred to herein as the "acidosis mode", is substantially similar to the initial operating mode described above with reference to FIG. **1**A. In an example, during performing the initial operating mode, the processing unit **160** can determine that a lactate concentration of the subject is worsening beyond a threshold parameter, such as a lactate concentration measured or predicted within a range of about 3 millimoles per liter (mmol/L) and about 5 mmol/L. Such a worsening trend can indicate that a subject is moving toward (or is in) a dangerous situation such as approaching lactic acidosis or an oxygen demand for blood that the subject will be unable to meet under the present operating parameters. Therefore, the processing unit **160** can generate or output a signal to the pump **106** or conditioner **108** to shift toward the intermediate operating mode. Here, the intermediate operating mode can involve temporarily increasing or intensifying the amount of therapy delivered via the system **100** in response to the determination that the lactate concentration is worsening beyond the threshold parameter. For example, the processing unit **160** can output a signal to the pump **106** or conditioner **108** to adjust a flow rate, temperature, oxygenation, or sweep gas parameter such as to increase a therapeutic effect of the system **100** on the subject. For example, the intermediate operating mode can involve the system **100** adjusting one or more operating parameters such as to condition the blood at a flow rate within a range of about 0.5 liters per minute (L/min) and about 7 L/min.

[0033] In an example, to help counteract a worsening trend in lactate concentration of the subject, performing the intermediate operating mode can involve drawing intravenous blood from the subject, such as via an intravenous cannula inserted at a second blood transfer location **120**. For example, blood can be received from a femoral vein of the subject, e.g., to increase a fluid throughput and conditioning capacity of the system **100**. As depicted in FIG. **1**B, the intravenous blood drawn from the second blood transfer location **120** can be received at the second fluid inlet **122** and can enter the blood treatment device **150** via the reservoir bypass circuit **112**. Alternatively or additionally, the intermediate operating mode can involve drawing intravenous blood from the subject at the second blood transfer location **120** and receiving the drawn intravenous blood at the at least one first fluid inlet **102** (according to the alternative depiction via phantom lines at **113**). Here, the intravenous blood drawn from the second blood transfer location **120** can pass through the inline **106** without a need for the auxiliary pump **107** and without entering the reservoir bypass circuit **112**. Both a blood volume received from the first blood transfer location **116** and a blood volume received from the second blood transfer location **116** can be conditioned via the conditioner **108** and administered back to the subject via the cannula into an internal jugular vein.

[0034] FIG. **1**C depicts a controlled preservation mode of the system **100**. Generally, the controlled preservation mode can be initiated to temporarily slow biological function of the subject such as to help preserve organ tissue. In an example, a controlled preservation mode of the system **100** can condition the subject's blood such as to induce a state of deep hypothermic arrest. Without being bound by theory, inducing a state of deep hypothermic arrest in the subject, toward a state of suspended animation, can lower a cardiac demand and can slow an increase of intercranial pressure for a subject experiencing TBI (Traumatic Brain Injury) and lactic acidosis.

[0035] In an example, during the performing of at least one of the initial operating mode or the intermediate mode, the processing unit **160** can determine, based on an indication that at least one of lactate concentration or ABG levels are worsening beyond a threshold parameter such that the subject is at or near a state of uncompensated shock or lactic acidosis. The transitioning to the controlled preservation mode can be based at least in part on a determination of a blood volume loss at a value between about 500 mL and about 1600 mL or at a value between about 750 mL and

about 1500 mL. In an example, the transitioning to the controlled preservation mode can be based at least in part on a determination of a lactate concentration at or approaching a threshold value between about 1 millimole per deciliter (mmol/dL) and about 3 mmol/dL, such as a lactate concentration at or approaching less than about 2 mmol/dL. The transitioning to the controlled preservation mode can be based at least in part on a determination of ABG pH level at or less than around 7.2. Similarly, the transitioning to the controlled preservation mode can be based on a determination of blood pH at or approaching a threshold value between about 7.2 and 7.35, such as between about 7.25 and 7.3. The transitioning to the controlled preservation mode can be based at least in part on a determination of the subject's partial pressure of arterial oxygen (PaO2) at or approaching a threshold value less than about 60 millimeters of mercury (mmHg). Further, the transitioning to the controlled preservation mode can be based at least in part on a determination of the subject's partial pressure of CO.sub.2 (PCO.sub.2) at or approaching a threshold value greater than about 45 mmH g.

[0036] Before implementation of the controlled preservation mode, the system **100** can administer an alert or a prompt for a user, such as a technician or medical professional, to initiate a transition toward the controlled preservation mode by preparing 1) the second blood transfer location **120** at a femoral vein of the subject (if not yet used for intravenous drawing of blood) and 2) a second return location **124** at a femoral artery of the subject for intra-arterial return of conditioned blood. For example, the alert or prompt can instruct the user to cannulate the second blood transfer location **120** and the second return location **124** before authorizing implementation of the controlled preservation mode. As depicted in FIG. **1**C, the blood treatment device **150** can draw blood from the second blood transfer location **120** via the reservoir bypass circuit, through the second fluid inlet **122**. Here, the drawn blood can be introduced to the conditioner **108** via the auxiliary pump **107**. Alternatively or additionally, the blood treatment device **150** can receive blood from the second blood transfer location **120** through the at least one first fluid inlet **102**, into the reservoir, and via the inline pump **106** (according to the alternative depiction via phantom lines at **113**). Thus, here a single pump (the inline pump **106**) can move blood from the first blood transfer location **116** and the second blood transfer location **120** into the reservoir and toward the conditioner during operation of the controlled preservation mode.

[0037] In an example, the processing unit **160** can receive confirmation that the second blood transfer location **120** and the second return location **124** have been prepared to initiate the controlled preservation mode. Upon initiation of the controlled preservation mode, the processing unit can adjust operating parameters such as to lower a temperature of the conditioned blood toward a target first temperature within a range of about 30° C. and about 40° C. (e.g., toward a target first temperature of about 33° C.) via a heater/cooler **128** included in the blood conditioner **108**. Returning blood to the subject at or near the target first temperature can lower the subject's myocardial oxygen demand and provide the subject's body at least temporary relief in an attempt to pull the subject out of uncompensated shock or lactic acidosis. The processing unit **160** can continue to monitor A B G levels and blood lactate concentration, following initiation of the controlled preservation mode, such as to determine whether a subject's state is improving or deteriorating. If the subject's state continues to deteriorate, the processing unit **160** can further adjust operating parameters such as to lower a temperature of the conditioned blood toward a target second temperature with a range of about 10° C. and about 25° C. (e.g., toward a target second temperature of about 18° C.) via the heater/cooler **128** and such that the conditioned blood is supplied to the subject at a relatively low target flow rate within a range of about 1 L/min and about 3 L/min, or within a range of about 1.5 L/min and about 2 L/min. The processing unit **160** can also facilitate administration of one or more pharmaceutical agents, selected to extend a time the subject can be suspended via deep hypothermic arrest and to limit ischemia-reperfusion injury (IRI) or reoxygenation injury. For example, the processing unit **160** can facilitate the administration of at least one of lidocaine, magnesium, nicardipine, milrinone, mannitol, calcium, magnesium, a pH-

stat, or an alpha-stat. During suspension of the subject in deep hypothermic arrest, the processing unit **160** can continue to monitor a subject's condition. For example, the processing unit **160** can monitor at least one of body temperature, activated clotting time (ACT), ABG levels, or blood lactate concentration.

[0038] Operating the system **100** in the controlled preservation mode can afford a surgeon or other medical professional time to perform damage control physiological resuscitation (DCPR). For example, surgery can be performed during maintenance of temporary circulatory arrest via the processing unit **160** and via control of the conditioned blood supplied to the subject at the target second temperature and at the target flow rate. Once adequate surgical control of bleeding is achieved, a user can employ the blood treatment device **150** to slowly bring the subject back out of the induced state of deep hypothermic arrest and return the subject toward normal body temperature and blood flow rate. For example, the processing unit **160** can facilitate rewarming of the blood returned to the subject at the first return location **118** and the second return location **124**. For example, the processing unit can monitor at least one of a temperature of the blood being intravenously returned to the first return location **118** or the temperature of the conditioned blood exiting an oxygenator **126** of the blood conditioner. In an example, the processing unit can calculate a target blood rewarming speed, such as to minimize air embolization. For example, the target blood rewarming speed can be within a range of about 0.1 degrees Celsius per minute (° C./min) and about 0.7° C./min, such as within a range of about 0.25° C./min and about 0.5° C./min.

[0039] FIG. **2**A and FIG. **2**B each depict an example of a blood treatment device **250**. The blood treatment device **250** is substantially similar to the blood treatment device **150** of FIG. **1**A, FIG. **1**B, and FIG. **1**C. The components, structures, configurations, functions, etc. of the blood treatment device **250** can therefore be the same as or substantially similar to that described in detail above with reference to the blood treatment device **150**. In an example and as depicted in FIG. **2**A, the intravenous blood received via the second blood transfer location **120** (e.g., the femoral vein of the subject) can be incorporated into the primary fluid circuit **270** upstream of the pump **206**. The blood treatment device **250** can further include an enclosed flexible bag, bladder, vesica, or sac **230** fluidly coupled with the blood conditioner **208** and arranged to receive conditioned, recovered blood therefrom. The enclosed flexible bag **230** can facilitate air purging from the primary fluid circuit **270** concurrent with blood treatment via the conditioner **208** and without stopping fluid flow or employing an air lock. For example, the enclosed flexible bag **230** can include a permeable or semipermeable membrane configured to contain fluid such as blood products while allowing diffusion of air and other gases through the membrane. In an example, the semipermeable membrane can include at least one of a microporous, nanoporous, chemical semi resistant, chemical resistant, anti-fouling polymer based material or other material or combination of materials having desired gas exchange or diffusion qualities while not permitting blood to permeate from the bag **230**. The gas diffused from the bag **230** can be transported to an air evacuation port of the bag **230** and into the gas headspace of the reservoir **204**. In another example, the gas diffused from the bag **230** can be released to the ambient environment. The enclosed flexible bag **230** can also be fluidly coupled to the reservoir **204**, such as establishing an open loop hydraulic circuit with the recovered blood. Herein, an “open loop” circuit refers to configurations in which fluid is recirculated and selectively supplied to different locations while not fully recirculating the fluid to its original source. For example, the bag **230** can be fluidly coupled directly to an outlet of the reservoir **204** and fluidly coupled directly to an outlet of the conditioner **208**. Also, herein the term “fluidly coupled” permits intervening, openable two-way valves such as valves **252**, **254**, **256**, **258**, and **259** depicted in FIG. **2**. In an example, the primary fluid circuit **280** can include a valve **254** disposed between the bag **230** and conditioner **208**, and the valve **254** can be operable to divert recovered blood exiting the bag **230** toward a blood outlet for redistribution back to the subject (e.g., via the internal jugular vein of the subject). For example, the valve **254** can be a diverter valve, a Y-valve, or a single two-way valve disposed on one end of a three-way or Y-shaped

junction disposed between the bag **230** and the conditioner **208**. The fluid circuit **270** can include a reservoir valve **252** and a cannulated blood line valve **259** which can be respectively engaged to allow a first portion of recovered blood from the reservoir and a second portion of recovered blood from the second blood transfer location **120** to be introduced into the primary circuit **270**. In an example, the bag **230** can include a plurality of fluid connections with the primary circuit **270** and at least one bridge valve **256** disposed between the plurality of fluid connections. The bridge valve **256** can be opened to help equalize any pressure buildup within the bag **230** across the fluid circuit **270**. For example, the bridge valve **256** can be temporarily opened when the reservoir valve **252** is closed to relieve excess volume accumulated in the bag **230**. Thus, the reservoir valve **252** can facilitate protection of the red blood cells and H b of the blood volume in the bag **230**, such as preventing or limiting collapsed Hb from excess pressure. The fluid circuit **270** can also include a drainage valve **258**. The drainage valve **258** can generally remain in an open position during operation of the device **250**. However, when the reservoir valve **252** is opened and blood is being received by the fluid circuit **270** from the reservoir **204**, the drainage valve **258** can be closed to help ease drainage from the reservoir **204**. Also, when the drainage valve **258** is open, recovered blood from the bag **230** can reenter the circuit directly downstream of the reservoir **204** and be again circulated via the pump **206**. Each of the valves **252**, **254**, **256**, **258**, and **259** can be independently engaged with respect to one another and can each be operated via a mechanical actuator, an electro-mechanical actuator, a pneumatic actuator, a solenoid actuator, a motorized actuator, a hydraulic actuator, a magnetic actuator, a computer actuator or microcontroller, a bimetallic strip, or a combination thereof.

[0040] In an example, the enclosed flexible bag **230** can be arranged in an at least partially open-to-air blood conditioning circuit (e.g., the circuit of the blood treatment device **250**, an ECMO circuit, etc.) and be operated to mitigate air entrainment that develops from cycling blood through such a circuit. In certain other blood treatment systems it can be challenging to prevent unwanted air from entering the fluid system (e.g., air entrainment, cannula dislodgement or circuit disruption). For example, in certain other ECMO devices and circuits, it may become necessary to stop circulation and dispose of recovered blood upon detection of air entrainment exceeding a desired or tolerable level. The present inventor has recognized that the inclusion of the enclosed flexible bag **230** within the circuit can mitigate such undesired air entrainment, such as via temporarily pausing or stopping blood circulation in the conditioning circuit and “de-airing” the fluid circuit via the enclosed flexible bag **230** before resuming blood circulation and extracorporeal blood treatment. In an example, such a technique can facilitate air purging from the fluid circuit without having to dispose of blood that had previously accumulated greater than a desired or tolerable amount of air.

[0041] In an example, the enclosed flexible bag can include or includes a dedicated air purging line, e.g., connected to a source of pressure (e.g., a vacuum), such as connected via a one-way valve. The one-way valve can remain typically remain closed during circulation of blood through the fluid circuit and can be configured to open only upon in response to a detection of air by a microbubble sensor integrated within the one-way valve. Here, the one-way valve can divert entrained air safely away from the circulation pathway and preserving circuit integrity without exposing blood to ambient air. Alternatively or additionally, the one-way valve can be user-operable (e.g., manually opened and closed) such as to allow for user-initiated air purging. In an example, either of the reservoir valve **252** or the drainage valve **258** can be replaced with (or coupled inline with) an additional roller pump, such as to assist in drawing blood from the first blood transfer location **116** of the subject. In an example, such as where valve **252** is closed or not present in the primary circuit **270**, the blood can be received from the first blood transfer location **116** of the subject, into the reservoir **204**, and directly to the enclosed flexible bag **230** via the connection **272**. In an example, the blood treatment device **250** can include one or more sensors (e.g., an analyte sensor, a flow volume sensor, a flow velocity sensor, a temperature sensor, or a combination thereof, such as embedded within or near the reservoir **204**, the enclosed flexible bag

230, the pump **206**, or any of valves **252**, **254**, **256**, **258**, or **259**) to provide monitoring data of the blood during cycling through the blood treatment device **250**. For example, the device **250** can include at least one sensor located upstream the conditioner **208** (e.g., embedded within or near the enclosed flexible bag **230**, such as including the connection **272** being implemented). Also, the device **250** can include at least one sensor (e.g., an analyte sensor, a flow volume sensor, a flow velocity sensor, a temperature sensor, or a combination thereof) located downstream the oxygenator (e.g., embedded at or near an output of the oxygenator **208**) to measure at least one of ABG, lactate, or temperature and to provide an indication of a blood quality that will be delivered from the device **250** back to the subject after conditioning. In an example, the enclosed flexible bag **230** can also include or be arranged adjacent to a heating element or radiator for adjusting a temperature of the blood within the enclosed flexible bag **230**. In an example, the enclosed flexible bag **230** can include a sensor for closed loop control of heating using a sensed temperature and the heating element.

[0042] FIG. **2**B depicts the blood treatment device **250** arranged within an enclosure. Such a compact arrangement can facilitate blood treatment methods described herein in non-hospital settings or in resource-poor environments. In an example, the blood treatment device can include or use a vacuum puck **203** arranged adjacent to the reservoir **204** and connected to a fluid headspace of the reservoir **204**. As shown in the detail view in FIG. **2**C, blood entering the vacuum puck **203** via the first blood transfer location **116** or the second blood transfer location **120** (depicted in FIG. **1**B) can run down a side of the vacuum puck **203** toward the reservoir. In an example, the vacuum puck **203** can include a ramp or tilt such as to force blood down the side of the reservoir. In an example, a source of suction, such as an onboard vacuum unit, can facilitate suction of the blood into the reservoir **204** at a flow rate within a range of about 1 L/min and about 10 L/min, or within a range of about 2 L/min and about 6 L/m, e.g., at or near a flow rate of about 4 L/min. In an example, the source of suction can be disabled or impeded during an emptying of the reservoir **204** into the fluid circuit **270**, such as when the valve **252** is opened (as depicted in FIG. **2**A). In an example, the valve **252** can include an actuator or an additional intermittent pump that pulls blood from the reservoir.

[0043] The reservoir **204** can include or use a first filter for separating out larger particulates or unwanted materials, e.g., dirt, or metallic fragments from the blood or other fluid being transported into the reservoir. The first filter can also be arranged to prevent clots or larger proteins, such as fibrin, from progressing further along a fluid circuit of the primary circuit **270**. The reservoir can also include a second filter for filtering ambient air that is drawn into the reservoir, such as to help maintain a sterile environment. The reservoir can also include or use windage tray, bubble-trap, or air separation chamber arranged to block or divert gases (e.g., bubbles or foam) away from the reservoir and to prevent gases from progressing further along the primary circuit **270**. For example, the windage tray can provide a physical barrier between gases and blood or other fluid, and the windage tray can have openings arranged to allow lower density gases or air to rise and be vented or removed to an external atmosphere or be collected and processed. In situations where the reservoir becomes canted or inverted during the drawing of the blood from the first blood transfer location **116** into the reservoir, the windage tray can establish or maintain a desired or predetermined surface level of the fluid, e.g., the blood or other body fluid being processed or treated. For example, the windage tray can facilitate that the drawn blood or other body fluid is held at or above a predetermined surface level (e.g., corresponding with the dotted boundary **205** as shown in FIG. **2**A) in the reservoir **204**. This can help prevent unwanted bubbles or gases from entering the suction source or suction line, thereby preventing unwanted pressure surges and sudden flow increases. In an example, the windage tray can include or use one or more physical separation elements, such as baffles, vanes, grates, or textured surfaces.

[0044] The reservoir **204** can be sterile and fluidly sealed relative to an external ambient environment. The reservoir **204** can maintain a negative internal pressure relative to the external

ambient environment, and the negative internal pressure can be provided at least in part by the source of suction. In an example, the reservoir **204** can include a reservoir pressure relief valve for the source of suction, and the pressure relief valve can be selectively engageable in response to detection of a clogging or obstruction at the trocar or chest tube. The reservoir pressure relief valve can help prevent damage to the reservoir **204** or to the tissue at the first blood transfer location **116** (as depicted in FIG. **1**A). The reservoir **204** can include one or more filtration or air separation elements arranged therein to limit air bubbles, contaminates, or other unwanted components from further traveling in the fluid circuit of the blood treatment device **250**. In an example, the reservoir **204** can be filled with blood toward a maximal internal volume, the maximum internal volume being within a range of about 500 cubic centimeters (cc) and about 2000 cc. In an example, the reservoir **204** can include or contain an anticoagulant such as heparin, bivalirudin, argatroban, enoxaparin sodium, a tissue-type plasminogen activator (tPA) or another anticoagulant or antiplatelet. Here, the anticoagulant can prevent subsequent clotting or clot formation within the blood treatment device **250**. The anticoagulant, for example, can be added to the reservoir **204** prior to the blood being conveyed into the reservoir, mixed with the blood, or otherwise distributed with the blood within the blood treatment device **250**.

[0045] The pump **206** can be arranged inline and spaced apart from (e.g., located upstream) the conditioner **208**. The pump **206** can include a centrifugal blood pump (CBP) such as a magnetically levitated (maglev) pump, an impeller pump, a vaneless pump, a bearingless pump, or a combination thereof. The pump **206** can be configured to facilitate continuous pumping and delivery of blood from the reservoir toward and through the oxygenator. Herein, “continuous flow” can refer to blood flow over a significant period (e.g., greater than about 5 seconds) wherein the blood flow curve is substantially free of discontinuities (e.g., less than about 10% fluctuation in flow rate). When the fluid circuit of the blood treatment device **250** is subject to greater than a threshold flow resistance (e.g., greater than 200 mmH g/L/hr) downstream of the pump **206** (e.g., caused by a kink or obstruction in a fluid line), a CBP can respond by decreasing its speed or decreasing the rate at which it propels the blood until the flow resistance decreases. As such, a CBP can be advantageous to certain other blood pumps, such as in reducing damage to the blood by avoiding g-forces or transmembrane pressure gradients caused by high accelerations or decelerations. A CBP can also be advantageous in a fluid circuit in that it can withstand kinks or obstructions to the fluid line without bursting a fluid line or otherwise breaking a fluid seal of the fluid circuit. Alternatively or additionally, the pump **206** can include a pulsatile pump such as a roller pump, a diaphragm pump, or a peristaltic pump configured to facilitate pulsatile flow of the blood. The pulsatile pump can be configured to emulate a physiologic pulsatile flow of blood, e.g., a flow having a pulse waveform in a range of physiological pulse waveforms. W here the pump includes a pulsatile pump such as a roller pump, the primary circuit **270** can include one or more pressure sensors and the roller pump can be controlled (e.g., via a processing unit) to slow or stop a pumping operation where the system detects greater than a threshold line pressure caused by a kink or and obstruction. Moreover, if desired, when the system detects a decrease in blood flow caused by kinking or obstruction of a downstream fluid line, the system can either operate the pulse pump to increase flow from a zero (or minimum pulse volume) or have the system transition to a continuous-flow mode of operation.

[0046] As depicted in FIG. **2**B, the blood conditioner **208** can include an oxygenator **226**, a temperature regulator **228**, or both. For example, an oxygenator **226** of the blood conditioner can include a silicon oxygen membrane or polymethylpentene (PMP) membrane for removing carbon dioxide (CO2) from the recovered blood. Once CO2 is removed, the recovered blood can cleave to hemoglobin (Hb) supplied in the oxygenator at a sweep gas rate within a range of about 2 L/min to about 6 L/min or about 4 L/min, and at a fraction of inspired oxygen (FiO2) between about 10% and about 50% or an FiO2 between about 21% and about 100%. In an example, the recovered blood passed through the oxygenator **226** of the blood conditioner can be hyper oxygenated, such

as having a PaO2 greater than about 100 millimeters of mercury (mmHg) or greater than about 200 mmHg. In an example, the blood conditioner **208** can use ambient air, such as ambient air exhausted from a vacuum pump or other source of suction, to help oxygenate the recovered blood. For example, the blood conditioner **208** can regulate a flow of ambient air between about 6 L/min and about 10 L/min, or at about 8 L/min. Also, supplemental O2 can be supplied, e.g., via an external or onboard tank, in addition to the ambient air. For example, the supplemental O2 can be supplied to help increase a net flow of air or sweep gas rate. Here, the supplemental O2 can be supplied at a rate within a range of about 1 L/min and about 2 L/min. As such, the blood conditioner **208** can provide a net sweep gas rate between about 0.1 L/min and about 10 L/min, such as between about 7 L/min and about 9 L/min, while relying on supplemental O2, provided via the external or onboard tank, being supplied a flow rate of less than 2 L/min.

[0047] The blood conditioner **208** can also include one or more heater/cooler units, such as a Peltier thermocouple **228***a* and a coil unit **228***b*. In an example, the Peltier thermocouple **228** can facilitate preheating of the recovered blood before it enters the oxygenator **226**, such as to improve the oxygenation of the blood. This is because increased temperature has an inverse relationship to reaction time (e.g., removal of CO2 and cleaving to hemoglobin (Hb)) and increases the rate of reaction, such that as the temperature increases, the number of molecules existing at higher energy levels increases. Also, the recovery blood may need to be cooled, involving the Peltier thermocouple **228***a* and a coil unit **228***b* to heat exchange the recovered blood from room temperature to a desired temperature range. For example, with reference to the controlled preservation mode of FIG. **1**C, the coil unit **228***b* can be used by the blood treatment device **250** to induce a state of deep hypothermic arrest or ventricular fibrillation in the subject. This can range from, for example, a targeted temperature within a range of about 10° C. and about 30° C. The Peltier thermocouple **228***a* and the coil unit **228***b* can work in conjunction with each other or alone. In an example, the temperature regulator **228** can be physically separate from the oxygenator **226**, with the recovered blood passed back and forth, or the temperature regulator and oxygenator can be physically integrated.

[0048] FIG. **3** shows an example of an integration of the temperature regulator **228** with the oxygenator **226** in a blood conditioner **208**. For example, the blood conditioner **208** can include or use the oxygenator **226**, an oxygenator pump **362**, an oxygenator heat sink **364**, an ice block **366**, a cold block **368**, a temperature regulator pump **370**, a temperature regulator heat sink **372**, a Peltier block **374** disposed between an oxygenator circuit and a temperature regulator circuit, and a thermostat **376**. The oxygenator pump **362** can draw the recovered blood, e.g., from the reservoir **204** (as depicted in FIG. **2**B). As the recovered blood passes through the oxygenator **226**, CO2 gas can be extracted from the recovered blood by diffusion across the oxygenator membrane. The rate of removal of CO2 can be enhanced by concentrating a CO2 sweep gas close to the surface of the membrane.

[0049] The Peltier block **374** can provide both heating and cooling output through separate interfaces via manipulation of electrical potential difference. Further, the Peltier block **374** can be compact, reliable, and efficient in thermoelectric cooling and heating applications involving heat exchange. Thus, the Peltier block **374** can be integrated in the blood conditioner **208** to operate in both cooling and heating modes, thereby providing an integrated cooling warming platform that can be used in a blood treatment device. In an example, the Peltier block **374** can function as a stand-alone heating element or cooling element utilizing temperature gradient with power provided to the Peltier block **374**. Activation can be bi-directional to both heat and cool the functional blocks with switching capability. This can be accomplished via an electrical power controller system, which can direct the electrical current to the Peltier block **374** resulting in a change of direction of heat transfer and thus exchange. Such an arrangement can yield an efficient, rapid time response for blood heating and cooling operations to the desired temperature (e.g., within a range of about 10° C. and about 30° C.).

[0050] In an example, the temperature regulator **228** can include a heating element circuit **378**. While the example in FIG. **3** shows the temperature regulator **228** as integrated with the oxygenator **226** (e.g., where the oxygenator **226** is embedded within a heating element circuit **378**), the temperature regulator **228** can be similarly be integrated with one or more other components of the blood treatment device **250**. For example, the heating element circuit **378** can include a tubing (e.g., formed of vinyl, polyethylene, silicone, polyvinyl chloride, etc.) that can at least partially enwrap or enclose a plurality of the components in the primary circuit **270** of the device **250** (each depicted in FIG. **2**A), such as the reservoir **204**, the pump **206**, the blood conditioner **208**, or the enclosed flexible bag **230**. The heating element circuit **278** of the temperature regulator **228** can also at least partially enwrap or enclose an air blender **604**, such as described with respect to FIG. **6** and FIG. **6**B, and can also at least partially surround conduit connecting any of components such as the reservoir **204**, the pump **206**, the conditioner **208**, the flexible bag **230**, or the air blender **604**.
[0051] In an example, the temperature regulator **228** can provide heat exchange over a surface area interface with blood in the primary circuit **270** of the blood treatment device **250** between about 2 meters squared (m.sup.2) and about 15 m.sup.2. In an example, the temperature regulator **228** can provide such heat exchange over a surface area between about 5 m.sup.2 and about 12 m.sup.2, such as greater than about 8 m.sup.2. In an example, the temperature regulator **228** can provide such heat exchange over a surface area between about 2.5 m.sup.2 and about 3 m.sup.2, such as at about 2.78 m.sup.2. For example, the surface area interface can include a heating element embedded within or wrapped around a tubing or conduit included in the primary circuit **270**, e.g., to add heat at least before blood in the circuit **270** enters the blood conditioner **208**.
[0052] In an example, the temperature regulator **228** can be controlled (e.g., via a processing unit **160** as depicted in FIG. **1**A, FIG. **1**B, and FIG. **1**C) the based on an indication of patient blood temperature. For example, the temperature regulator **228** can be controlled based on monitored or received sensor data via first and second temperature probes of the blood treatment device **250**. In an example, the first temperature probe can measure a first indication of blood temperature at or near a first blood transfer location **116**, such as at or near the fluid inlet **102** or in the reservoir **104** (e.g., as depicted in FIG. **1**A). The second temperature probe can measure a second indication of blood temperature at or near a first return location **118**, such as at or near the first fluid outlet **110** or at an outlet of the conditioner **108** (e.g., as depicted in FIG. **1**A). Monitoring of patient blood temperature entering and exiting the blood treatment device **250** can provide monitored temperature data to a control system to help enable the control system to accurately manipulate fluid flow rates and heat exchange mechanisms as improve regulation of patient body temperature. For example, the first and second temperature probes can be included in a thermostat of the temperature regulator **228**, and data from the first and second temperature probes can be used to condition blood, e.g., received from a hemorrhage of a patient, toward a specified, desired temperature.
[0053] FIG. **4**A, FIG. **4**B, and FIG. **4**C depict another example of a system for performing extracorporeal blood treatment of recovered blood. As shown in FIG. **4**A, the system described with respect to FIG. **1**A, FIG. **1**B, and FIG. **1**C as well as the devices described with respect to FIG. **2**A, FIG. **2**B, and FIG. **2**C can be integrated into a mobile trauma management system. For example, such a mobile trauma management system can enable a medic or other technician to assist an injured person in the field, such as away from a hospital operating room setting. For example, the field may be a battlefield, a war zone, a remote area, an ambulance, or a conflict-affected area. In an example, the mobile trauma management system can include a system for blood treatment that is substantially similar to that described with respect to FIG. **1**A, FIG. **1**B, and FIG. **1**C. As shown in FIG. **4**A and FIG. **4**B, the blood treatment device can be mounted on a carrier such as a backpack including straps. As shown in FIG. **4**C the carrier can include a lightweight frame e.g., fabricated with carbon fiber, aluminum, heat-treated thermoplastic polymers, ABS (acrylonitrile butadiene styrene), polystyrene (PS), polycarbonate (PC), or polypropylene (PP). Such a carrier can

weigh less than about 10 pounds (lbs) to promote ease of transport. The carrier can optionally also include an internal battery or battery pack operatively engaged with the blood treatment device. As depicted in FIG. **4**A, a back panel of the carrier can define recesses sized and shaped to receive components such as an oxygenator, a source of suction, one or more pumps, and a temperature regulation unit. When the mobile trauma management system is removed from the back of the medic or technician, opened, and laid out, the carrier can form a sterile surface from which to perform the procedures described herein.

[0054] FIG. **5**A depicts an example of a system for performing extracorporeal blood treatment of recovered blood. The system **500**A can include the blood treatment device **250**, e.g., connected in parallel to an ECMO circuit **540** for concurrent, dual oxygenation of blood received from (e.g., at or near a hemorrhage of) a human subject. For example, the system **500**A can include an ECMO pump **504**, an ECMO oxygenator **506**, a reservoir **204**, an enclosed flexible bag **230**, and a conditioner **208**. The combination of the respective circuits of the device **250** and the ECMO circuit **504** can, in some instances, facilitate hyperoxygenation of blood received from and distributed back to the subject.

[0055] The ECMO circuit **540** includes the ECMO pump **504**, which can be configured as a centrifugal pump, a magnetically levitated centrifugal pump (e.g., configured with magnets made of neodymium and/or other suitable materials), a roller pump, or a combination thereof. The ECMO pump **504** can include a port to receive (e.g., facilitate removal of) blood from the human subject (e.g., via a vein, internal bleed, or a hemorrhage of the subject) and a fluid conduit to introduce the removed blood to the ECMO oxygenator **506**. The ECMO oxygenator **506** can include a gas-tight confinement (e.g., a secure housing or enclosure) where fresh gas is introduced to the ECMO oxygenator. For example, the fresh gas can be induced, e.g., via an air blender, to flow within the ECMO oxygenator **506** in a direction counter-current to blood introduced to the circuit and can flow over, through, or otherwise associated with a gas-permeable membrane or other diffusion structure of the oxygenator **506**. For example, with the ECMO pump **504** rotating in a first or forward direction, blood can flow from a blood inlet of the ECMO oxygenator **506** toward a blood outlet of the ECMO oxygenator **506**, while fresh gas can flow from a gas inlet (e.g., arranged opposite the blood inlet) in the ECMO circuit to a gas outlet of the ECMO oxygenator **506**. Here, the blood can flow over the gas-permeable membrane (e.g., a gas-permeable hollow fiber, a gas-permeable capillary structure, a gas-permeable flat sheet, a diffuser present outside a membrane material, etc.) carrying oxygen from the gas to the blood, while by-products (e.g., carbon dioxide) of blood are transported from the blood to the gas. The blood can exit the oxygenator **506** at an outlet to be returned to the circulation of the subject, and the used gas can be discarded or scrubbed for remaining oxygen before being eventually discarded as exhaust.

[0056] As depicted in FIG. **5**A, the blood treatment device **250** (as described with respect to FIG. **2**A, FIG. **2**B, and FIG. **2**C) can be connected with the ECMO circuit **540** to establish the system **500**A for performing extracorporeal blood treatment of recovered blood. For example, concurrent with the ECMO pump **504** moving blood from the human subject toward the ECMO oxygenator **506**, a reservoir **204** can receive blood from the human subject (e.g., via a port into and a fluid conduit from a vein, internal bleed or a hemorrhage of the subject). The reservoir **204** and the ECMO pump **504** can each receive blood from the same patient location (e.g., each from the first blood transfer location **116** of FIG. **1**A), or alternatively can each receive blood from a different patient location, such as one from a vein and the other from a hemorrhage of the subject. In an example, the blood treatment device **250** can include a roller pump **530** connected in line with the reservoir **204** (such as directly upstream or directly downstream the reservoir). The roller pump **530** can facilitate removal (e.g., via suction) of blood from the human subject and collection thereof into the reservoir. In an example, blood can pass from the reservoir directly toward the enclosed flexible bag **230** (such as via the connection **272**). The pump **206** can facilitate movement of blood in the enclosed flexible bag **230** toward the conditioner **208**. In an example, the blood can be

recirculated, such as through the enclosed flexible bag **230** and the conditioner **208**, in a loop **546**. In an example, the loop **546** can further include a filter **510** arranged inline between the conditioner **208** and a return port to the enclosed flexible bag **230**. For example, the filter (e.g., a hemoconcentrator, a potassium-removing or other chemical constituent-removing filter, a mechanical screen, etc.) can selectively remove blood impurities, particulates, or other contaminants from the conditioned blood.

[0057] Following conditioning via the conditioner **208**, (e.g., following at least one recirculation within the loop **546**), the blood from the blood treatment device **250** can be selectively introduced to the ECMO circuit **540** via a valve **254**. For example, an operator or a technician can determine when the conditioned blood from the blood treatment device **250** ought to be introduced to the ECMO circuit **540** based on sensor data or a flow rate within at least one of the primary circuit fluid circuit **270** (as depicted in FIG. **2**A) or the ECMO circuit **540**. The valve **254** can additionally or alternatively be operated based on a trigger or command from the processing unit **160** (as depicted in FIG. **1**A), such as via an actuator controlled by a microcontroller. Introduction of the blood, conditioned via the blood treatment device **250**, e.g., upstream the ECMO pump **504** for further oxygenation via the ECMO oxygenator can help facilitate an additive effect or synergistic effect in which oxygenation is enhanced, providing the subject with an improved or optimized amount of oxygen (e.g., as measurable via the saturation level of oxygen in their blood). For example, the additive effect, or the concurrent or parallel operation of the blood treatment device **250** and the ECMO circuit **540**, can result in more oxygen being available for improving the physiological function or preservation of the subject.

[0058] FIG. **5**B depicts an example of a system for performing extracorporeal blood treatment of recovered blood, showing various blood heating modalities along the fluid circuit. Similar to that previously described with respect to FIG. **3**, certain portions of the fluid circuit in the blood treatment device **250** (e.g., portions of the system **500**A, as depicted in FIG. **5**B) can include or use a heat exchanger configured to at least heat patient blood concurrently with conditioning and delivering the blood back to the patient. Despite the heating modalities described below and depicted with respect to system **500**A of FIG. **5**B include and describe the ECMO circuit **540** of FIG. **5**A, they can similarly be applied to the blood treatment device **250** as shown and described with respect to FIG. **2**A and FIG. **2**B, e.g., where no ECMO circuit **540** is present in the blood conditioning circuit. In an example, the system **500**A can include one or more heat exchangers, respectively arranged for at least one of resistive heating **584**, magnetic heating **586**, or thermoelectric heating **588**. For example, portions of the fluid circuit depicted in FIG. **5**B with the thin dotted line indicating the resistive heating **584**, such as the reservoir **204**, the pump **567**, the enclosed bag **230**, the conditioner **208**, the valve **254**, and various conduits therebetween (and notably, a final conduit through which the conditioned blood is ultimately delivered back to the patient) can each be enwrapped or otherwise contacted with coil or tubing for transferring electrical energy (e.g., current) into heat which ultimately warms the blood during the circulation of blood through the system **500**A. Portions of the fluid circuit depicted in FIG. **5**B with the bold solid line indicating magnetic heating **586** (e.g., the filter **558**) can include or be contacted with a magnetic heat exchanger (e.g., an electromagnetic heat exchanger, a magnetic turbulator, an inducting heater, etc.) arranged to transfer heat, e.g., via thermomagnetic convection such as via ferrofluids. Portions of the fluid circuit depicted in FIG. **5**B with the bold dotted line indicating the thermoelectric heating **588** (e.g., the enclosed bag **230**) can include or be contacted with a thermoelectric heat exchanger (e.g., a Peltier heater/coolers such as the Peltier block **374** as depicted in FIG. **3**), arranged to transfer heat, e.g., via electrical current or a temperature difference in thermoelectric materials. For example, the system **500**A including a plurality discrete heat exchangers, each configured to provide one of the resistive heating **584**, the magnetic heating **586**, and the thermoelectric heating **588** can facilitate energy-efficient blood warming that provides dynamically controllable heating, e.g., based on a severity of hypothermia of the patient. Such dynamic control

over heating can be especially important during extracorporeal blood treatment in hypovolemic or coagulopathic trauma patients.

[0059] In an example, the system **500**A can include processing circuitry (e.g., the processing unit **160** of FIG. **1**A or the processor **802** of FIG. **8**) for controlling operation of the plurality of discrete heat exchangers (e.g., each of the resistive heating **584**, the magnetic heating **586**, and the thermoelectric heating **588** elements) such as to operate the heating of the blood concurrent with extracorporeal treatment and delivery of the blood back to the patient, in a plurality of different operating modes. For example, based on an indication of a normothermic patient state (e.g., indicative of mild or no present patient hypothermia, such as a patient having an average core temperature less than about 35° C.) the processing circuitry can activate the thermoelectric heating **588** element, such as via the heat exchanger integrated with the enclosed bag **230**. Here, the resistive heating **584** and the thermoelectric heating **588** elements can remain inactive or operated at reduced power. Such operation can provide relatively low-power thermal regulation to promote battery efficiency, which can be helpful for prolonged casualty care e.g., in resource-limited or prehospital environments.

[0060] Based on an indication of a moderate hypothermia patient state (such as a patient having an average core temperature within a range of about 32° C. to about 35° C.), the processing circuitry can activate a) one or more the resistive heating **584** elements (e.g., one or more coils or tubes enwrapping portions of the fluid circuit) and concurrently, b) the thermoelectric heating **588** element. H ere, the resistive heating **584** elements can be arranged in direct thermal contact with the blood in the fluid circuit during storage in the reservoir **204**, conditioning, and throughout various points of travel through the circuit and back to the patient, providing rapid heat transfer while still maintaining a relatively conservative energy profile. Here, the resistive heating **584** elements and the thermoelectric heating **588** element can be independently operable to each other, such as to facilitate scalable response based on flow rates and target rewarming speed (e.g., scaling heating via changing a heating intensity via the resistive heating **584** while maintaining a relatively constant level of heating via the thermoelectric heating **588**).

[0061] Based on an indication of a sever hypothermia patient state (such as a patient having an average core temperature greater than about 32° C.), the processing circuitry can activate a) one or more the resistive heating **584** elements (e.g., one or more coils or tubes enwrapping portions of the fluid circuit) b) the thermoelectric heating **588** element, and the magnetic heating **586** elements concurrently, such that all three heating modalities become activated. Such collective, concurrent heating via each of the resistive heating **584**, magnetic heating **586**, and thermoelectric heating **588** modalities can provide relatively aggressive, life-sustaining rewarming therapy during the extracorporeal conditioning (e.g., oxygenation) and delivery of the conditioned back to the patient. Here, the magnetic heating **586**, while relatively power-intensive, can facilitates deep and rapid volumetric heat delivery to the blood via magnetic the exchanger core. Such a mode can prioritize heat delivery over energy conservation, such as to reflect an urgency of restoring normothermia in certain cases of profound thermal injury.

[0062] In an example and in addition to the blood warming via the any of the resistive heating **584**, the magnetic heating **586**, or the thermoelectric heating **588**, the system **500**A can include a first chemical heating apparatus. The chemical heating apparatus can include a plurality of chemicals selected such that, when combined, facilitate an exothermic reaction from a buffered solution. In an example, such a chemical heating apparatus can help warm blood that is passing through an interior of the conditioner **208** (e.g., at or near an inner plate of a blood oxygenator). Alternatively or additionally, the system **500**A can include a second chemical heating apparatus, arranged to contact the surface area of certain components of the fluid circuit, such as the reservoir, the enclosed bag, the conditioner, conduits provided therebetween, or a combination thereof. Here, the second chemical heating apparatus can be operated in a similar fashion to that described above with respect to the first chemical heating apparatus, resulting in an exothermic reaction that provides

heat to certain portions of the fluid circuit. In an example, the second chemical heating apparatus can be operated (e.g., reagents mixed to cause the chemical reaction) as a part of an initial device startup sequence, such as to prime or prewarm certain components of the circuit before subsequent heating via at least one of the resistive heating **584**, magnetic heating **586**, or thermoelectric heating **588** elements. During such an initial device startup sequence, the second chemical heating apparatus can be activated, and a priming fluid (e.g., saline, dextrose 5%, or other sterile fluid) can be circulated through the fluid circuit before blood is drawn from the patient, such as to help prewarm the circuit to subsequently receive and treat the blood. In an example, such an initial startup sequence can involve warming the priming fluid (and in turn, certain components of the fluid circuit through which the priming fluid is passing) from about 70° C. to about 104° C. Such a preheating or priming of the fluid circuit in the system **500**A can help avoid a need to use battery power to initially bring the system **500**A up to an appropriate operating temperature for processing human blood.

[0063] FIG. **5**C depicts an example of a system for performing extracorporeal blood treatment of recovered blood, including batch-mode dialysis for trauma resuscitation. Combat trauma, hemorrhagic shock, rhabdomyolysis, and battlefield-induced acute kidney injury (AKI) can be often accompanied by lethal acid-base and metabolic derangements. Elevated serum lactate (e.g., ≥4 mmol/L) can provide an indicator of shock severity and mortality, and rising lactate can reflect both tissue hypoperfusion and inflammatory-driven mitochondrial dysfunction. Certain other renal replacement therapies (RRT) can be unsuitable for the prehospital or field-deployed setting, such as being too slow or impractical. The present inventor has recognized the benefits of an extracorporeal blood conditioning system that provides significant lactate clearance as well as clearance of certain other toxic solutes in the early phase of trauma resuscitation, such as to avoid or mitigate damage to renal and cellular systems. In certain situations where the patient is exhibiting acute lactic acidemia (lactate level >5), it can be challenging to provide blood conditioning to sufficiently clear lactate through oxygenation alone. Implementation of rapid batch-mode dialysis alongside the extracorporeal blood treatment can help facilitate additional lactate clearance. For example, the system **500**B can be similar in many respects to the system **500**A described with respect to FIG. **5**A and FIG. **5**B. Here, the system **500**B can include a dialysis filter **596**, such as fluidly coupled to a dialysate source **598** and an effluent fluid bag **590** or other purge location. The system **500**B can, at least partially via the dialysis filter **596**, facilitate high-efficiency clearance of blood lactate, potassium, urea, myoglobin, and inflammatory cytokines, e.g., concurrent with blood conditioning via the conditioner **208** and over specified period of time (e.g., within about 15 minutes, about 20 minutes or about 30 minutes).

[0064] In an example, the system **500**B can include processing circuitry (e.g., the processing unit **160** of FIG. **1**A or the processor **802** of FIG. **8**) for controlling a rate of dialysate intake, such as to facilitate relatively high-dose, intermittent hemodialysis of the blood in batches. For example, the processing circuitry can operate the system **500**B such as to provide dialysis treatment to a specified volume of blood (e.g., at a volume within a range of about 0.6 liters (L) to about 3.0 L, such as about 1.5 L), to promote scalable and predictable solute removal. Unlike certain other approaches to dialysis which primarily targets uremia, the system **500**B can include at dialysis filter **596**, a dialysate source **598**, and be controlled via the processing circuitry to instead primarily target early lactate reduction such as to reverse metabolic acidosis, blunt systemic inflammation, and restore certain mitochondrial function and immune regulation in the patient. For example, the dialysis filter **596** can include a diffusion-optimized high-flux membrane. Also for example, the processing circuitry can control batch dialysis with relatively high dialysate-to-blood flow ratios (e.g., ratio of dialysate flow rate to blood flow rate (Qd:Qb) greater than about 1:1). In an example, the system **500**B can be arranged such that the dialysate flows from the dialysate source **598** in an opposite direction to the direction of blood flow, such as to provide counterflow between the blood and the dialysate across the dialysis filter **596**.

[0065] In an example, the system **500**B can facilitate greater than about 40% lactate reduction per blood circulation cycle, where starting lactate is greater than about 6 millimoles per liter (mmol/L). Table 1 below depicts certain operating parameters of the system **500**B, such as controlled by the processing circuitry, to facilitate a desired dialysis during extracorporeal treatment of blood.
TABLE-US-00001 TABLE 1 Blood Flow Rate (Qb) 60-1500 mL/min via magnetically levitated pump Dialysate Flow Rate (Qd) 60-3000 mL/min (motorized, countercurrent) Treated Blood Volume 0.6-3.0 L per batch Treatment Time 2-25 minutes Target Solutes Lactate, K.sup.+, Creatinine, Urea, Myoglobin, Cytokines Lactate Reduction >40% per batch cycle Filter Type High-flux polysulfone or cytokine-absorptive membrane Safety Inline pressure, air trap, auto flow shutoff
[0066] The dialysis filter **596** and the administration of the dialysate from the dialysate source **598** can clear lactate during the extracorporeal blood treatment, such as to promote positive patient outcomes and to mitigate acute kidney injury e.g., due to metabolic derangement that often accompanies traumatic injury. For example, the processing circuitry can facilitate mixing of certain reagents to form or replenish the dialysate. In an example, the system **500**B can facilitate formation, mixing, or replenishing of the dialysate at or near the dialysate source **598**. For example, a specified portion (e.g., about 1,000 mL) of sterile IsoLyte or saline can be received in an IV bag, and a specified portion (e.g., about 50-100 mL) of Sodium Bicarbonate can be added to thereto to promote buffering capacity. In an example, a specified portion (e.g., about 50 mL) of Dextrose 50% can be further added such as to limit or prevent hypoglycemia and aid diffusion. In an example, a specified portion (e.g., about 2-3 mL) of Heparin can also be added to the IV bag to reduce clotting risk in circuit filters. In an example, the system **500**B (e.g., the processing circuitry or any of the pump **530**, pump **206**, ECMO pump **504**, valve **254**, etc.) can facilitate counterflowing of the formed or replenished dialysate at the dialysis filter **596** in an opposing direction to that of the blood flow from the blood conditioner **208**. For example, at least one of pump **530** or pump **206** can be activated to control blood flow in the fluid circuit at a flow rate of about 1.5 L/min. H ere, the blood can repeatedly recirculate from the enclosed bag **30**, through the conditioner **208**, through the dialysis filter **596**, and back toward the enclosed bag **230**. The system **500**B can receive dialysate from the dialysate source **598** (e.g., via gravity or alternatively or additionally via a motor or pump). As such, the dialysate can flow through the dialysis filter **598** on an opposite side of a membrane of the dialysis filter **598** than that of the flow of blood. In an example, a specified amount of dialysate (e.g., between about 2.5 and 3.5 L of dialysate) can be received via the dialysis filter **596** during counterflow of the dialysate and the blood in the fluid circuit. Such a counter flow of the dialysate from the dialysate source **598** in an opposing direction to and on an opposite side of the dialysis filter membrane than that of the conditioned blood from the fluid circuit can facilitate removal of between ˜70-85% of certain small solutes such as urea, potassium, lactate. Such a process can be repeated (e.g., after a specified period between about 20-70 minutes, such as after about 45 minutes) where additional solute removal is desired. FIG. **6** is a schematic showing portions of an air blender **600** for providing a fresh gas line to an oxygenator. For example, the air blender **600** can provide the sweep gas for use in the blood conditioner **208**, such as the oxygenator **126** included therein (as depicted in FIG. **1**C). The air blender **600** can also provide a sweep gas for the E C M **0** oxygenator **506** or other components in the system **500**A (as depicted in FIG. **5**A).
[0067] Certain approaches to providing a sweep gas to an oxygenator can involve mixing a supply of compressed ambient air and compressed oxygen (O2). Such an approach can involve a challenge of supplying each type of compressed air, which can be unfeasible in certain mobile, point-of-trauma (or similar onsite hemorrhage control) circumstances. Further, such approaches may not provide for any function of an oxygenator to condition blood from the subject once a store of compressed ambient air or compressed oxygen becomes depleted. The present inventor has recognized the benefit of an air blender that does not necessarily rely on compressed ambient air for supplying a sweep gas to a blood oxygenator.

[0068] The air blender **600** can include, use, or be connected to a regulator **604**, a first air pump **610**, an oxygenator **126**, a second air pump **612**, a scrubber **616**, and a reservoir airbag **618**. The air blender **600** can receive compressed or concentrated O.sub.2 **606**, uncompressed ambient air **608**, or both and mix them via the regulator **604** to establish a desired sweep gas. In an example, where the compressed or concentrated O.sub.2 **606** is unavailable or has become depleted, the air blender **600** can facilitate production of a sweep gas, including uncompressed ambient air **608**, such as for temporary (e.g., less than about 20 minutes) operation of the oxygenator **126**.
[0069] As described with respect to FIG. **1**C, FIG. **2**A, FIG. **2**B, and FIG. **5**A, an extracorporeal blood conditioning device or system can include the oxygenator **126** to condition blood removed from a human subject, e.g., by oxygenation and removal of carbon dioxide. The oxygenator can operate based on a sweep gas, e.g., established within a specified fraction of inspired oxygen (FiO2) and at constant flow rate. Parameters of the sweep gas can be important for maintaining a desired gas exchange with the subject blood during the oxygenation process in the oxygenator **126**. In an example, the regulator can include a FiO2 sensor **620** configured to measure the FiO2 of the sweep gas. Data from the FiO2 sensor **620** can be received by an operator or a processing unit (e.g., unit **160** as depicted in FIG. **1**C) such as to help control e.g., via activation of one or more valves, the regulator **604** based on the received data. Control of the one or more valves of the regulator **604** can assist in managing a volume mixing proportion of the sweep gas including oxygen **606** and the sweep gas including uncompressed ambient air **608**. In an example, the regulator **604** can include a three-way valve, such as can include a solenoid, gate, or other type of valve that can be configured to route a sweep gas including both the compressed or concentrated O.sub.2 **606** and the uncompressed ambient air **608** to the oxygenator **126** in such a proportion that provides a desired FiO.sub.2. In an example, the data (such as a display of the data via a user interface) from the FIO2 sensor **620** can be used by an operator or the processing unit to help conserve the volume or supply of the relatively more dense compressed or concentrated O.sub.2 **606** (e.g., limited compressed oxygen resources), such can be as based on at least in part on an oxygen content of the ambient air. Thus, the FiO2 sensor **620** can monitor and modulate the supply of the compressed or concentrated O.sub.2 **606** resource. The regulator **604** can be similarly controlled based at least in part on other sensor data (e.g., data from one or more sensors embedded within or near the reservoir **204**, the enclosed flexible bag **230**, the pump **206**, or any of valves **252**, **254**, **256**, **258**, or **259**, as depicted in FIG. **2**A), such that FiO2 is modulated based on a patient condition or determined physiological need. Further the regulator **604** can be manually controllable (e.g., via a dial or other user interface) such as to establish the specified FiO.sup.2 based on a determination from an operator.
[0070] In an example, the air blender **600** can include or use an air filter **614** for filtering the ambient air before introduction to the regulator **604**. In addition to filtering the ambient air **608**, the air filter **614** can help remove water, other liquids, or undesirable particulates. For instance, the air filter **614** can include one or more of activated carbon or HEPA filters for filtering the plausible presence of one or more of undesired chemicals, undesired microorganism, fungi, virus or other bioaerosol.
[0071] Optionally, the air blender **600** can include an auxiliary compressor **624** for compressing the ambient air **608** before introduction to the regulator **604**. In an example, such auxiliary compression can help compensate for flow rate differences for a supply of compressed O.sub.2 **606** and for the supply of ambient air **608**. The air filter **614** can be placed before (upstream from) or after (downstream from) the auxiliary compressor **624**. Additionally, in an example, the auxiliary compressor **624** can include one or more of an electrically driven compressor, a mechanical crank driven air supply, or any other type of air compressor.
[0072] The first air pump **610** and the second air pump **612** can pump the sweep gas to and from oxygenator **126**, respectively. For example, the first pump **610**, the second pump **612**, or both can include or be coupled to a respective airflow sensor for measuring airflow of sweep gas and controlling pump operation to maintain a constant airflow of sweep gas at a constant flow rate

between 7 liters per minute (L/min) and 9 L/min. Herein, “constant flow rate” means a flow rate that is selected by an operator or a processing unit and is maintained within a range that does not allow the volume of sweep gas traveling through the oxygenator **126** to vary more than a threshold variability amount, such as more than +/−0.25 L/min. In an example where the constant flow rate is about 8 L/min, an operator or the processing unit determines the air blender **600** needs to push about 1 L/min of the compressed or concentrated O.sub.2 **606** (based on the FiO2 concentration measured prior to (e.g., upstream from) the regulator **604** and via the FiO2 Sensor **620**), and the regulator **604** the facilitates mixing of the remaining ˜7 L/min as ambient air **608**.

[0073] In an example, one or both of the first air pump **610** and the second air pump **612** can operate as a compressor to compress the blended air such as to increase flow across the oxygenator. For example, the first air pump **612** can produce or use a vacuum to pull blended air from the regulator **604** and toward the oxygenator. The blended air can pass through the oxygenator to oxygenate the blood, the CO.sub.2 can be swept off the blood in the oxygenator. In an example, the second air pump **612** can produce or use vacuum to pull used air (e.g., at least partially depleted of O.sub.2) out of the oxygenator can facilitate discarding of the CO.sub.2 out of the air blender and out of the device or system.

[0074] In an example, the air blender **600** can include, use, or be connected with a scrubber **616**. The scrubber **616** can receive used (e.g., at least partially deoxygenated) sweep gas from the second air pump **612** and recover a desired constituent, such as remaining O.sub.2, from the used sweep gas before discarding the recovered constituent of the sweep gas as exhaust. The scrubber **616** can include or use sodalime or a CO.sub.2 or other absorbent. For example, the sodalime can be a solid (e.g., hard granular) or powdered (e.g., fine particulate). The sodalime can include an active constituent selected from group I metals, barium, magnesium, calcium, carbon, copper, iron, cobalt and/or nickel. In an example, the active constituent of sodalime can be NaOH, KOH, Ba(OH)2, Mg(OH)2, Ca(OH)2, NaOH, KOH, or both. Further the ratio of the active constituent, which can be Na or KOH, can be set or otherwise specified to sufficiently extract CO.sub.2 in a removed volume of air. In an example, the ratio of the active constituent of ground sodalime can represent a weight of about 1.1-1.6:1. O.sub.2 recovered by the scrubber can be stored in the reservoir bag **618** and eventually introduced back into the regulator **604** as concentrated O.sub.2 **606**. In an example, the reservoir airbag **618** can house a volume between about 1000 mL of air and about 3000 mL of air, such as about 2000 mL of air. In an example, the scrubber **616** can be configured to facilitate recovery of at least 50% of the remaining oxygen from the at least partially deoxygenated air exiting the second air pump **612**, such as recovery of at least 60% of the remaining oxygen, recovery of at least 70% of the remaining oxygen, recovery of at least 80% of the remaining oxygen, or recovery of at least 90% of the remaining oxygen.

[0075] In an example, the scrubber **616** can be integrated with the oxygenator **126**, for example, as a sealed end cap on an outflow end of the oxygenator. Here, as excess gas exits the oxygenator **126** through a port of the sealed end cap. The gas can pass a recovery sensor arranged to provide an indication of a gas level, such as an amount of oxygen depletion or oxygen saturation, of the sweep gas exiting the oxygenator **126** (e.g., levels of NiO2 and CO2). The gas can be pulled via a vacuum of the second air pump **612** and through the sodalime of the scrubber **616** such that, e.g., water and CO2 can be separated out by the scrubber **616**. Recovered oxygen from the scrubber **616** can be propelled via the second air pump **612** through a fluid conduit toward the reservoir bag **618**.

[0076] FIG. **7** is a flowchart showing a technique for performing extracorporeal blood treatment of recovered blood. The technique **700** can be implemented using one or more devices or systems described herein, such as the system **100** of FIG. **1**A, FIG. **1**B, and FIG. **1**C, the blood treatment device **250** of FIG. **2**A and FIG. **2**B, etc.

[0077] The technique **700** includes an operation **710** to receive an indication of a patient state including a patient having lost greater than 500 milliliters (mL) of blood. Herein, indications and determinations of blood loss include blood “lost” into an internal cavity of the patient, such as an

internal bleed, and need not be limited to an actual volume of blood removed from the patient. For example, a patient losing greater than 500 mL of blood can indicate the patient is a trauma patient in need of intervention to avoid hemorrhagic shock. For example, operation **720** through operation **750** can be performed conditional upon a determination or receipt of indication that the patient state would otherwise qualify for a massive transfusion protocol.

[0078] The technique **700** includes an operation **720** to draw a first portion of the recovered blood from a body cavity of the subject and into a reservoir. For example, a trocar can be placed at the body cavity and connected via a tubing to the reservoir. In an example, the technique can include cutting or enlarging a hole at or near the body cavity to better facilitate access to an internal bleed of the subject. In an example, the reservoir can be sealed relative to an external ambient environment. Here, a negative internal pressure can be applied to the reservoir relative to the external ambient environment, e.g., via a source of suction. The source of suction can be selectively applied or disabled such as to facilitate drainage out of the reservoir when a reservoir valve is opened.

[0079] The technique **700** includes an operation **730** to regulate a flow rate of the first portion of the recovered blood. The flow rate can be maintained or regulated at a value greater than 200 milliliters per minute (mL/min). For example, regulating the flow rate can include modulating an inline pump, e.g., between about 1 liter per minute (L/min) and about 10 L/min. In an example, regulating the flow rate can include modifying a flow rate based on an established or adjusted blood treatment operating mode.

[0080] The technique **700** includes an operation **730** to condition the recovered blood. For example, conditioning the recovered blood can include reoxygenating hemoglobin (Hb) or removing carbon dioxide (CO.sup.2) from the recovered blood. Conditioning the recovered blood can also include controlling a temperature of the recovered blood. In an example, a temperature of the recovered blood can be controlled, e.g., heated, before reoxygenating Hb. In an example, regulating the temperature can include modifying a temperature based on an established or adjusted blood treatment operating mode.

[0081] The technique **700** includes an operation **740** to monitor an indication of blood state over time. For example, the indication of blood state can include monitoring a blood volume recovered from the patient over time. The indication of blood state can also include an indication of blood lactate concentration over time, e.g., received from a blood lactate sensor. The indication of blood state can also include an indication of arterial blood gas (ABG) over time, e.g., received from an ABG sensor.

[0082] The technique **700** includes an operation **750** to deliver the conditioned, recovered blood back to the subject at least intravenously. The technique **700**, in certain blood treatment operating modes, can include delivering the conditioned, recovered blood back to the subject both intravenously and intra-arterially. In an example, an anticoagulant can be administered to the subject prior to the drawing the first portion of the recovered blood from the body cavity of the subject into the reservoir. For example, the blood thinning agent can include heparin, bivalirudin, or argatroban.

[0083] In an example, the technique **700** can include establishing or adjusting a blood conditioner operating parameter based on blood state. For example, the blood conditioner operating parameter can be at least one operating parameter of an oxygenator or a temperature regulator. The blood conditioner operating parameter can be established or adjusted based on a monitored indication of blood lactate concentration of the subject over time.

[0084] In an example, the technique **700** can include establishing or adjusting a blood treatment operating mode, determined at least in part based on the monitored indication of blood state over time. For example, the blood treatment operating mode can be selected between an assist mode, an acidosis mode, and a controlled preservation mode. For example, in the assist mode, blood can be regulated at a first temperature and reoxygenated blood can be delivered intravenously back to the

subject after the reoxygenating Hb. In the acidosis mode, the flow rate of the first portion of the recovered blood can be increased and a second portion of the recovered blood can be received via intravenous cannulation of the subject. In an example, the flow rate of both the first portion and the second portion of the recovered blood can be regulated via the same pump. In the controlled preservation mode, a biological function of the subject can be slowed to help preserve organ tissue. The controlled preservation mode can include cooling the recovered blood toward a second temperature lower than the first temperature before delivering the cooled blood back intra-arterially to the subject. For example, in the controlled preservation mode, an internal body temperature can of the patient can be induced to a temperature between about 10° C. and 20° C. Also, in the controlled preservation mode, controlled hypothermic arrest can be induced in the patient. In an example, the assist mode, the acidosis mode, and the controlled preservation mode of blood treatment can be performed sequentially, such as to escalate a blood treatment protocol based on a declining patient condition. For example, the declining patient condition can be determined based on the measured indication of blood state, such a monitored indication of blood lactate concentration.

[0085] FIG. **8** illustrates generally an example of a block diagram of a machine **801** upon which any one or more of the techniques (e.g., methodologies) discussed herein may perform in accordance with some examples. In alternative embodiments, the machine **801** may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine **801** may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine **801** may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine **801** may be a personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0086] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations when operating. A module includes hardware. In an example, the hardware may be specifically configured to carry out a specific operation (e.g., hardwired). In an example, the hardware may include configurable execution units (e.g., transistors, circuits, etc.) and a computer readable medium containing instructions, where the instructions configure the execution units to carry out a specific operation when in operation. The configuring may occur under the direction of the executions units or a loading mechanism. Accordingly, the execution units are communicatively coupled to the computer readable medium when the device is operating. In this example, the execution units may be a member of more than one module. For example, under operation, the execution units may be configured by a first set of instructions to implement a first module at one point in time and reconfigured by a second set of instructions to implement a second module.

[0087] Machine (e.g., computer system) **801** may include a hardware processor **802** (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory **803** and a static memory **804**, some or all of which may communicate with each other via an interlink (e.g., bus) **805**. The machine **801** may further include a display unit **806**, an alphanumeric input device **807** (e.g., a keyboard), and a user interface (UI) navigation device **808** (e.g., a mouse). In an example, the display unit **806**, alphanumeric input device **807** and UI navigation device **808** may be a touch screen display. The machine **801** may additionally include a storage device (e.g., drive unit) **809**, a signal generation device **810** (e.g., a

speaker), a network interface device **811**, and one or more sensors **812**, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine **801** may include an output controller **816**, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[0088] The storage device **809** may include a machine readable medium **813** that is non-transitory on which is stored one or more sets of data structures or instructions **814** (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions **814** may also reside, completely or at least partially, within the main memory **803**, within static memory **804**, or within the hardware processor **802** during execution thereof by the machine **801**. In an example, one or any combination of the hardware processor **802**, the main memory **803**, the static memory **804**, or the storage device **809** may constitute machine readable media.

[0089] While the machine readable medium **813** is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, or associated caches and servers) configured to store the one or more instructions **814**.

[0090] The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine **801** and that cause the machine **801** to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine-readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine-readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks.

[0091] The instructions **814** may further be transmitted or received over a communications network **815** using a transmission medium via the network interface device **811** utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LA N), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 702.16 family of standards known as WiMax®), IEEE 702.15.4 family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device **811** may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network **815**. In an example, the network interface device **811** may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine **801**, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0092] The above Detailed Description can include references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention can be practiced. These embodiments are also referred to herein as "examples." Such examples can include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or

described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[0093] In the event of inconsistent usages between this document and any documents so incorporated by reference, the usage in this document controls. In this document, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Also, in the following claims, the terms “including” and “comprising” are open-ended, that is, a system, device, article, composition, formulation, or process that can include elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim.

[0094] In this document, the terms “a” or “an” are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of “at least one” or “one or more.” In this document, the term “or” is used to refer to a nonexclusive or, such that “A or B” can include “A but not B,” “B but not A,” and “A and B,” unless otherwise indicated. In this document, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Also, in the following claims, the terms “including” and “comprising” are open-ended, that is, a system, device, article, composition, formulation, or process that can include elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[0095] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) can be used in combination with each other. Other embodiments can be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is provided to comply with 37 C.F.R. § 1.72(b), to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features can be grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter can lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description as examples or embodiments, with each claim standing on its own as a separate embodiment, and it is contemplated that such embodiments can be combined with each other in various combinations or permutations. The scope of the invention should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

Claims

1. A method for point-of-injury or similar onsite hemorrhage control in a trauma patient via a portable rapid autotransfusion device, the method comprising: recovering a first portion of patient blood, from an extravascular space of a patient into which the first portion of the patient blood has hemorrhaged, into a fluid reservoir of the rapid autotransfusion device; applying a pressure to the first portion of patient blood in the fluid reservoir; conditioning the first portion of patient blood, the conditioning including oxygenating the first portion of patient blood via an oxygenator, and removing carbon dioxide (CO.sup.2) from the first portion of patient blood to produce conditioned blood; and while recovering patient blood from the patient, returning the conditioned blood back to the patient intravenously; wherein the conditioned blood is returned to the patient at at least a substantially equal rate to a rate at which the blood is concurrently being recovered from the

patient, such that a net returned blood volume is capable of being maintained substantially equal to a net removed blood volume.

2. The method of claim 1, wherein the conditioning includes: regulating a sweep gas including at least one of uncompressed ambient air, compressed oxygen (O.sup.2), or compressed ambient air, at a specified fraction of inspired oxygen (FiO2) and at a specified constant flow rate; and flowing the sweep gas via the oxygenator to remove the CO.sup.2 from the first portion of blood.

3. The method of claim 2, wherein the flowing the sweep gas includes supplying the sweep gas, at or near the specified fraction of inspired oxygen, at the specified constant flow rate between 0.1 liters per minute (L/min) and 10 L/min.

4. The method of claim 3, comprising compressing uncompressed ambient air to form the compressed ambient air, wherein the sweep gas includes a mixture of concentrated oxygen O.sup.2 with the compressed ambient air.

5. The method of claim 4, comprising: sensing an FiO2 of the uncompressed ambient air; and adjusting the regulation of the flow of the uncompressed ambient air based on the sensed FiO2 of the uncompressed ambient air.

6. The method of claim 1, comprising monitoring, following the conditioning, at least one of blood lactate or arterial blood gas (ABG) of the first portion of patient blood and establish or adjust at least one parameter of the conditioning or the controlling a temperature of the first portion of blood.

7. The method of claim 1, comprising controlling, via a heat exchanger, a temperature of the removed first portion of patient blood.

8. The method of claim 1, wherein the controlling includes heating the first portion of blood at a heat exchange coefficient greater than 5 Watts per squared meter kelvin W/(m.sup.2 K) via battery power.

9. The method of claim 1, comprising recirculating at least part of the conditioned first portion of patient blood, following the conditioning of the first portion of the patient blood, the recirculating including filtering and removing additional CO.sup.2 from the at least part of the conditioned first portion of patient blood.

10. A portable rapid autotransfusion device for point-of-injury or similar onsite hemorrhage control in a trauma patient, the device comprising: a blood intake fluid circuit, at least partially open to air in an ambient environment of the device, the blood intake fluid circuit including: a fluid reservoir for recovering a first portion of patient blood, from an extravascular space of a patient into which the first portion of the patient blood has hemorrhaged; and an enclosed flexible bag, fluidly connected to an outlet of the fluid reservoir permitting outgassing of gas from the first portion of patient blood out of the enclosed flexible bag; wherein a negative internal pressure is applied to at least one of the fluid reservoir or the enclosed flexible bag; and a conditioning fluid circuit, including or fluidly connected to the enclosed flexible bag of the blood intake fluid circuit and fluidly sealed from the air in the ambient environment of the device, the conditioning fluid circuit including: a blood conditioner configured to condition the first portion of patient blood including oxygenating, and removing carbon dioxide (CO.sup.2) from the first portion of patient blood to produce conditioned blood; wherein the conditioning fluid circuit is configured to: concurrent with recovering patient blood from the patient via the blood intake circuit, return conditioned blood back to the patient intravenously via a fluid outlet of the conditioning fluid circuit; and condition the first portion of the patient blood for returning to the patient at at least a substantially equal rate to a rate at which the blood is concurrently being recovered from the patient via the blood intake fluid circuit, such that a net returned blood volume is capable of being maintained substantially equal to a net removed blood volume.

11. The device of claim 10, wherein the enclosed flexible bag is formed of a membrane is semipermeable configured to permit gas exchange while not permitting blood to permeate from the enclosed flexible bag.

12. The device of claim 11, comprising a conduit disposed between the fluid reservoir and the enclosed flexible bag, the conduit arranged to allow the gas outgassed from the first portion of patient blood out of the enclosed flexible bag to be purged into the fluid reservoir.
13. The device of claim 10, wherein the oxygenator is configured to: regulate a sweep gas including at least one of uncompressed ambient air, compressed oxygen (O.sup.2), or compressed ambient air, at a specified fraction of inspired oxygen (FiO2) and at a specified constant flow rate; and flow the sweep gas via the oxygenator to remove the CO.sup.2 from the first portion of blood.
14. The device of claim 13, wherein the flow of the sweep gas is at a rate at or near the specified fraction of inspired oxygen, at the specified constant flow rate between 0.1 liters per minute (L/min) and 10 L/min.
15. The device of claim 14, comprising a compressor for compressing uncompressed ambient air before flowing the sweep gas via the oxygenator, wherein the sweep gas includes a mixture of the compressed O2 with the compressed ambient air.
16. The device of claim 15, comprising: a sensor for sensing an FiO2 of the uncompressed ambient air; and circuitry for adjusting the regulation of a flow rate of the uncompressed ambient air based on the sensed FiO2 of the uncompressed ambient air.
17. The device of claim 10, comprising a sensor for monitoring, following the conditioning, at least one of blood lactate or arterial blood gas (ABG) of the first portion of patient blood and establish or adjust at least one parameter of the conditioning or the controlling a temperature of the first portion of blood.
18. The device of claim 10, comprising a heat exchanger for controlling, concurrently with the oxygenating, a temperature of the first portion of patient blood.
19. The device of claim 18, wherein the heat exchanger includes a heating element circuit, the heating element circuit arranged to least partially enwrap the fluid reservoir, the enclosed flexible bag, and the blood conditioner.
20. The device of claim 18, wherein the heat exchanger is configured to heat the first portion of blood at a heat exchange coefficient greater than 5 Watts per squared meter kelvin W/(m.sup.2 K) via battery power.
21. The device of claim 10, wherein the conditioning fluid circuit comprises a bridge valve configured to recirculate at least a portion of the blood conditioned blood having passed through the blood conditioner, back toward the enclosed flexible bag for additional blood conditioning.