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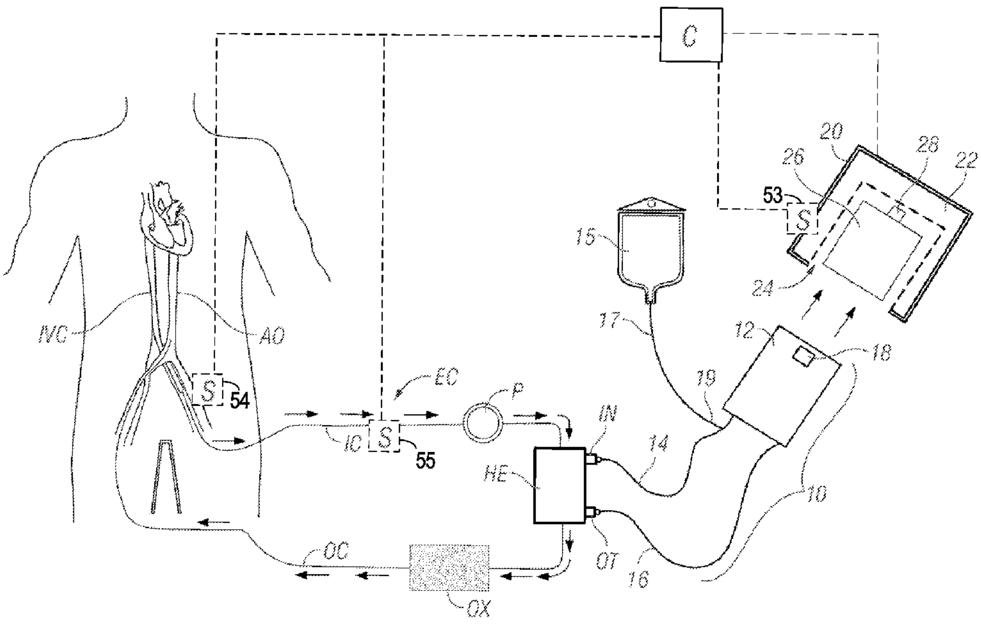


FIG. 1

(57) **Abstract:** Devices, systems and methods for warming or cooling blood or other fluids as they circulate through an extracorporeal circuit.

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*[Continued on next page]*

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# HEAT EXCHANGE IN EXTRACORPOREAL SYSTEMS

## Claim of Priority

[0001] This application claims priority under 35 U.S.C. §119(e) to U.S. Patent Application Serial No. 62/799,731, filed on January 31, 2019, and to U.S. Application Serial No. 62/748,328, filed on October 19, 2018, the entire contents of each of which are hereby incorporated by reference.

## Technical Field

[0002] The present disclosure relates generally to the fields of medicine and engineering and more particularly to devices, systems and methods for controlling the temperature of blood or other fluids that are being circulated through an extracorporeal system for blood oxygenation, circulatory support or other treatment.

## Background

[0003] Pursuant to 37 CFR 1.71(e), this patent document contains material which is subject to copyright protection and the owner of this patent document reserves all copyright rights whatsoever.

[0004] Numerous types of extracorporeal systems are used for blood oxygenation, blood purification, circulatory support and other blood treatment. Such extracorporeal systems include, but are not limited to, extracorporeal membrane oxygenation (ECMO) systems; cardiopulmonary bypass (CPB) systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems.

[0005] ECMO systems are typically used to oxygenate a patient's blood for extended periods of time (e.g., days) while CPB systems are used for relatively short periods (e.g., hours). CPB systems have traditionally been used to provide blood oxygenation and circulatory support during cardiac and aortic surgical procedures in which the heart is temporarily stopped. In ECMO, vascular access is typically achieved by inserting cannulas into peripheral blood vessels using percutaneous technique or superficial surgical cut and then advancing the cannulas to locations in the central vasculature (e.g., vena cava, right atrium, and aorta). In CPB, vascular access is typically accomplished by intraoperative connection of cannulas to surgically exposed intrathoracic blood vessels.

**[0006]** ECMO can be performed either as venoarterial ECMO (VA-ECMO) or venovenous ECMO (VV-ECMO). In VA-ECMO, deoxygenated blood is removed from a vein and the oxygenated blood is returned into an artery. In VA-ECMO the system typically pumps the blood under pressure to partially support the subject's cardiac output while VV-ECMO generally provides extracorporeal lung assist but does not support cardiac function.

**[0007]** Various extracorporeal systems, e.g., ECMO and CPB systems, utilize heat exchangers to control the temperature of blood circulating through the extracorporeal system. Such extracorporeal blood heat exchangers typically are connected to a heater-cooler unit which has a water tank, a heater, a cooler and a pump. The pump circulates warmed or cooled water from the water tank, through the extracorporeal blood heat exchanger and back into the water tank. Although the circulating water does not directly contact the patient's blood, microbial contamination of water within the tank has been associated with certain hospital acquired infections. For example, some publications have suggested that post-surgical infections with the water-borne pathogen *Mycobacterium chimaera* are attributable to water tank contamination in heater–cooler units used with CPB systems during cardiac surgery. See, for example, Walker, J., et al., *Microbiological Problems and Biofilms Associated with* Mycobacterium Chimaera *in Heater–Cooler Units Used for Cardiopulmonary Bypass,* Journal of Hospital Infection, Volume 96, Issue 3, Pages 209–220 (2017). Also see, Perkins, K.M., et al., *Notes From the Field. Mycobacterium Chimaera Contamination of Heater-Cooler Devices Used in Cardiac Surgery — United States*. MMWR Morbidity and Mortality Weekly Reports, Volume 65, Pages 1117–1118 (2016).

## Summary

[0008] The present disclosure describes devices, systems and methods useable for controlling the temperature of blood that is being circulated through an extracorporeal system for blood oxygenation, circulatory support or other treatment of the blood, such as controlling the temperature of blood that is being circulated through an extracorporeal system for blood oxygenation, circulatory support or for controlling the temperature of other fluids being processed in sanitary or sterile environments.

[0009] In accordance with one aspect of the present disclosure, there is provided a system which comprises an extracorporeal blood circuit having an extracorporeal blood heat exchanger and a heat exchange fluid circulation apparatus useable to circulate a heat exchange fluid through the extracorporeal blood heat exchanger. The heat exchange fluid circulation apparatus may comprise a first tube connectable to the extracorporeal blood heat exchanger, a second tube connectable to the extracorporeal blood heat exchanger; and a heat exchange fluid container that is configured to connect to the first and second tubes, said container configured to be positioned in thermal contact with warmable or coolable fluid or surface such that heat exchange fluid circulating through the container will be warmed or cooled by said warmable or coolable fluid or surface. Such system may further comprise a pumping apparatus. Connection of the first and second tubes to the extracorporeal blood heat exchanger and to the container establishes a closed loop heat exchange fluid flow path through which the pumping apparatus may cause the heat exchange fluid to circulate from the container, through the first tube, through the extracorporeal blood heat exchanger, through the second tube and back into the container. The warmable or coolable fluid or surface may comprise one or a plurality of warmable or coolable members and the heat exchange fluid container may be positionable in contact with, in heat exchanging proximity to, in thermal contact with, or between such warmable or coolable member(s). The warmable or coolable fluid or surface may comprise a warmable or coolable fluid in which the heat exchange fluid container is fully or partially submersed. The system may

further comprise a filling port through which the closed heat exchange fluid flow path may be filled with a heat exchange fluid. The system may further comprise a sensor positioned to monitor patient temperature or blood temperature. The system may further comprise a controller configured to control the patient temperature or blood temperature based on patient temperature or blood temperature feedback from the sensor. The pumping apparatus may comprise a peristaltic pump tube configured to undergo repetitive peristaltic compression by a roller or other peristaltic compressor. The heat exchange fluid container may be positioned within a container receiving space of a heater/cooler device. Such receiving space may be between thermal exchange plates which comprise warmable or coolable surfaces such that a heat exchange fluid circulating through the heat exchange fluid container will be warmed or cooled by said warmable or coolable surfaces. The heat exchange fluid container may be positioned within a container receiving space of a heater/cooler device that is configured to alternatively receive a different container configured for circulating heat exchange fluid through an endovascular heat exchange catheter or body surface heat exchanger. The heat exchange fluid container may be fully or partially submersed in the warmable or coolable fluid such that a heat exchange fluid circulating through the container will be warmed or cooled by said warmable or coolable fluid. The heat exchange fluid container may comprise a housing having an internal heat exchange fluid flow path defined within the housing. Such internal heat exchange fluid flow path of the heat exchange fluid container may be coiled, serpentine, or circuitous. The heat exchange fluid container may have an outer surface that is textured and/or configured to deter sticking of that outer surface to separate warmable or coolable surfaces. The system may be configured to be disposable after a single use. At least one of the first and second tubes may be braided or otherwise constructed so as not to collapse or substantially flatten during up to thirty days of continuous use. The extracorporeal blood circuit may comprise a system selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems. The heat exchange fluid circulation apparatus may further comprise one or more sensors for providing feedback regarding one or more of: heat exchange fluid temperature; heat exchange fluid pressure; heat exchange fluid flow; whether the heat exchange fluid circulation apparatus is approved for use; and whether the heat exchange fluid circulation apparatus has been previously used. The system may include a sterile heat exchange fluid within the closed heat exchange fluid flow path. The closed heat exchange fluid flow path and pumping apparatus are configured to circulate heat exchange fluid at a flow rate of 5 ml/min to 30 ml/min. The first and second tubes may have inner diameters in the range of from 3/8 inch to 5/8 inch.

**[0010]** In accordance with another aspect of the present disclosure, there is provided a system for warming or cooling blood flowing through an extracorporeal system, such system comprising: an extracorporeal blood heat exchanger configured for connection to the extracorporeal system; a heat exchange fluid supply tube configured for connection to the extracorporeal blood heat exchanger, a heat exchange fluid return tube configured for connection to the extracorporeal blood heat exchanger; and a heat exchange fluid container configured for connection to the supply and return tubes and a pumping apparatus. Connection of the supply and return tubes to the extracorporeal blood heat exchanger and heat exchange fluid container establishes a closed loop heat exchange fluid flow path through which the pumping apparatus causes the heat exchange fluid to circulate from the container, through the supply tube, through the extracorporeal blood heat exchanger, through the return tube, and back into the container. The heat exchange fluid container may be configured to be positioned in thermal contact with warmable or coolable fluid or surface such that heat exchange fluid which circulates though the container will become warmed or cooled by the warmable or coolable fluid or surface without contacting the warmable or coolable fluid or surface and blood which circulates through the extracorporeal blood heat exchanger will become warmed or cooled by the circulating heat exchange fluid. All components of the system, optionally including the extracorporeal blood heat exchanger, may be constructed of materials suitable for disposal after a single use. The extracorporeal system may be selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems. The heat exchange fluid container or other portion(s) of the system may comprise one or more temperature, pressure and/or flow sensors for providing feedback regarding the temperature, pressure and/or flow of the heat exchange fluid to a controller coupled to the container. The system may comprise one or more sensors for providing feedback regarding one or more of: heat exchange fluid temperature; heat exchange fluid pressure; heat exchange fluid flow; whether the heat exchange fluid circulation apparatus is approved for use; and whether the heat exchange fluid circulation apparatus has been previously used.

**[0011]** In accordance with another aspect of the present disclosure, there is provided a system for circulating a heat exchange fluid through an extracorporeal blood heat exchanger, such system comprising: a container; a heat exchange fluid supply tube; a heat exchange fluid return tube; and a pumping apparatus. The supply tube and return tube are connected or connectable to the container and the extracorporeal blood heat exchanger so as to establish a closed heat exchange fluid circulation path through which the pumping apparatus may cause heat exchange fluid to circulate from the container, through the supply tube, through the extracorporeal blood heat exchanger, through the return tube and back into the container. The container may be configured to be positioned in thermal contact with a warmable or coolable fluid or surface so that heat exchange fluid circulating through the container will become warmed or cooled without directly contacting the warmable or coolable fluid or surface. The pumping apparatus and the closed heat exchange fluid circulation path may be configured to provide circulation of heat exchange fluid through the closed heat exchange fluid circulation path at a flow rate in the range of from 5 liters per minute to 30 liters per minute. The supply tube and return tube may have inner diameters in the range of from 3/8 inch to 5/8 inch. Components of the system, optionally including the extracorporeal blood heat exchanger, may be constructed of materials suitable for disposal after a single use. The system may comprise one or more sensors for providing feedback regarding one or more of: heat exchange fluid temperature; heat exchange fluid pressure; heat exchange fluid flow; whether the heat exchange fluid circulation apparatus is approved for use; and whether the heat exchange fluid circulation apparatus has been previously used.

**[0012]** In accordance with another aspect of the present disclosure, there is provided a system useable for extracorporeal treatment of a subject's blood, said system comprising: an extracorporeal blood flow circuit having an inlet that is connectable to vasculature of the subject and an outlet that is connectable to vasculature of the subject; a pump useable to pump blood from vasculature of the subject, through the inlet, through the extracorporeal blood flow circuit, through the outlet and into vasculature of the subject; a blood treatment device useable for treating blood that flows through the extracorporeal circuit; and a port through which a heat exchange device may be inserted into the extracorporeal blood flow circuit so as to exchange heat with blood flowing through the extracorporeal blood flow circuit. Such system may further comprise a hemostatic valving apparatus associated with the port to deter leakage of blood from the port. The inlet may comprise a first tube that is connectable to a cannula or catheter that is insertable into the subject's vasculature. The outlet may comprise a second tube that is connectable to a cannula or catheter that is insertable into the subject's vasculature. The blood treatment device may comprise an oxygenator which oxygenates blood flowing through the extracorporeal blood flow circuit. The port may be located upstream of the blood treatment device. The system may further comprise a reservoir or other air removing apparatus wherein any air bubbles within the blood are separated from the blood. The port may be located upstream of any such reservoir or other air removing apparatus. The system may be combined with a heat exchange device insertable through the port and useable to exchange heat with blood flowing through the extracorporeal circuit. Such heat exchange device may comprise a Peltier, resistance heater or other electrical device for warming or cooling the blood. The heat exchange device may comprise a heat exchanger which is insertable through the port and through which a warmed or cooled heat exchange fluid circulates to cause warming or cooling of the blood. The system may further comprise tubing and a heat exchange fluid container connected to the heat exchange device to form a closed heat exchange fluid recirculation loop wherein heat exchange fluid will circulate from the container, through a first tube, through the heat exchange device, through a second tube and back into the container. Such system may additionally comprise a device for warming or cooling heat exchange fluid as it circulates through the container.

**[0013]** In accordance with another aspect of the present disclosure, there is provided a heat exchanging conduit located within an extracorporeal blood flow circuit, said heat exchanging conduit comprising a lumen through which blood flows and least one of a) at least one heat exchange fluid lumen, b) at least one warming device and c) at least one cooling device, for warming or cooling blood as it flows though said lumen. The heat exchanging conduit may have heat exchange fluid lumen(s) disposed at location(s) around the blood flow lumen. Such heat exchange fluid lumen(s) may be connected, by way of a first tube and a second tube, to a heat exchange fluid container so as to establish a closed heat exchange fluid flow path through which heat exchange fluid will circulate from the container, through the first tube, through said at least one heat exchange lumen, through the second tube and back into the container, said container being positionable at an operating location in or sufficiently near a warmable or coolable fluid or surface to cause heat exchange fluid circulating through the container to become warmed or cooled by the warmable or coolable fluid or surface. At least one resistance heater may be positioned on or in the heat exchanging conduit so as to warm blood flowing through the blood flow lumen. Such heat exchanging conduit may be located within an extracorporeal system. Such extracorporeal system may be selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems.

**[0014]** In accordance with another aspect of the present disclosure, there is provided a system for circulating heat exchange fluid through an extracorporeal blood heat exchanger that has a heat exchange fluid inflow port and a heat exchange fluid outflow port. Such system may comprise a first tube connectable to the heat exchange fluid outflow port of the extracorporeal blood heat exchanger, a second tube connectable to the heat exchange fluid inflow port of the extracorporeal blood heat exchanger; a disposable heat exchange fluid cassette that is connected or connectable to the first and second tubes, said cassette being positioned or positionable in contact with or proximity to a warmable or coolable surface so as to warm or cool a heat exchange fluid circulating through the cassette or other heat exchange fluid container; and a pumping apparatus. The first tube is connected or connectable to the heat exchange fluid inflow port of the extracorporeal blood heat exchanger and the second tube is connected or connectable to the heat exchange fluid outflow port of the extracorporeal blood heat exchanger. The pumping apparatus is useable to circulate a heat exchange fluid from the heat exchange fluid outflow port of the blood heat exchanger, through the first tube, through the cassette, through the second tube, through the inflow port and through the extracorporeal blood heat exchanger. Such circulation of the heat exchange fluid may occur without the heat exchange fluid being exposed to room air or blood while circulating through the system. The pumping apparatus may be engageable with a pump drive apparatus so as to circulate the heat exchange fluid through the system without the heat exchange fluid contacting the pump drive apparatus. The pumping apparatus may comprise a peristaltic pump tube and the pump drive apparatus comprises a roller or other tube compressing apparatus that causes peristaltic compression of the peristaltic pump tube. This system may include the blood heat exchanger. The blood heat exchanger may be part of an extracorporeal system. Such extracorporeal system may be selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems. This system may be in combination with a device having a heater or cooler for heating or cooling heat exchange fluid circulating through the cassette or other heat exchange fluid container. This system may also be in combination with a pump drive apparatus for driving the pumping apparatus. The cassette or other heat exchange fluid container or other part(s) of the system may comprise one or more temperature, pressure and/or flow sensors for providing feedback regarding temperature, pressure and/or flow of the heat exchange fluid to a controller coupled to the cassette. The system may comprise a controller that controls the operation of the pumping apparats based on such feedback. The system may be combined with a heater and/or cooler device which comprises a housing having an opening through which the cassette is insertable to an inserted position, a heater and/or cooler for heating and/or cooling fluid circulating through the cassette when in the inserted position and a pump drive apparatus that engages and drives the pumping apparatus when the cassette is in the inserted position. Such heater and/or cooler device may be alternately or concurrently useable with a different cassette for circulating heated and/or cooled heat exchange fluid through a heat exchange catheter or body surface heat exchanger. The system may be useable for at least thirty days. The system may be in combination with a sterile heat exchange fluid within the system. One or more portions of the system may be coated with or comprise an antimicrobial or microbiostatic substance to deter microbial growth. Tubing of the system may be constructed to remain patent for at least thirty days.

**[0015]** In accordance with yet another aspect of the present disclosure, there is provided a cannula for use in a system for extracorporeal blood treatment, said cannula being insertable into a subject's vasculature and useable for either withdrawing blood from the subject's vasculature into the extracorporeal blood treatment system or for returning blood from the extracorporeal blood treatment system into the subject's vasculature, wherein said cannula comprises a heat exchanger which exchanges heat with blood flowing through said cannula and/or through the patient's vasculature. Such cannula may be used for withdrawing blood from the subject's vasculature into the extracorporeal blood treatment system and the heat exchanger may be located on the cannula upstream of a location where blood enters the cannula such that the heat exchanger warms blood being withdrawn through the cannula into the extracorporeal blood treatment system. The cannula may be in combination with and connected or connectable to an extracorporeal blood treatment system. Such extracorporeal blood treatment system may comprise an extracorporeal membrane oxygenation system and the cannula effects both a) heat exchange with a subject's blood and b) either i) withdrawal of blood from the subject's vasculature into the extracorporeal membrane oxygenation system or ii) return of blood from the extracorporeal membrane oxygenation system into the subject's vasculature. The various systems as described above may further comprise a sensor positioned to monitor patient temperature or blood temperature. The various systems as described above may further comprise a controller configured to control the patient temperature or blood temperature based on patient temperature or blood temperature feedback from the sensor.

**[0016]** In accordance with yet another aspect of the present disclosure, there is provided a method which comprises: connecting, to a patient (Patient A), an extracorporeal system having a heat exchanger which comprises a blood flow path and a heat exchange fluid flow path; causing blood from patient A to circulate through the extracorporeal system including through the blood flow path of the heat exchanger; obtaining a heat exchange fluid circulation system A which comprises a container A, a supply conduit A connected to container A, and a return conduit A connected to container A; connecting supply conduit A and return conduit A to the heat exchange fluid flow path of the heat exchanger, thereby establishing a closed circulation loop A through which heat exchange fluid may circulate from container A, through supply conduit A, through the heat exchange fluid flow path of the heat exchanger, through return conduit A and back into heat exchange fluid container A; causing heat exchange fluid container A to be positioned in thermal contact with warmable or coolable fluid or surface; causing blood to circulate from Patient A, though the extracorporeal system, including through the blood flow path of the heat exchanger, and back into the vasculature of patient A; causing a heat exchange fluid to circulate through closed circulation loop A; and warming or cooling the warmable or coolable fluid or surface, thereby warming or cooling of the heat exchange fluid as it circulates through heat exchange fluid container A, thereby resulting in exchange of heat in the heat exchanger between the warmed or cooled heat exchange fluid and the blood of patient A. Thereafter, the method may further comprise stopping the circulation of heat exchange fluid through closed circulation loop A and disconnecting and disposing of heat exchange fluid circulation system A after a single use. The heat exchange fluid circulation system may be disposed of as non-hazardous waste. Such method may further comprise disconnecting and disposing of the heat exchanger after a single use. If the heat exchanger is disconnected and disposed of, such disposal of the heat exchanger may be as hazardous waste. The method may further comprise connecting to another patient (Patient B), the extracorporeal system which includes a heat exchanger (e.g., a second heat exchanger), which comprises a blood flow path and a heat exchange fluid flow path. Such extracorporeal system may comprise the same system used with Patient A except for replacement of disposable portion(s), which may include the blood heat exchanger. Blood from patient B may then be caused to circulate through the extracorporeal system including through the blood flow path of the heat exchanger. A heat exchange fluid circulation system B which comprises a container B, a supply conduit B connected to container B, and a return conduit B connected to Container B may be obtained and used.by a method that comprises: connecting supply conduit B and return conduit B to the heat exchange fluid flow path of the heat exchanger, thereby establishing a closed circulation loop B through which heat exchange fluid may circulate from container B, through supply conduit B, through the heat exchange fluid flow path of the heat exchanger, through return conduit B and back into heat exchange fluid container B; causing heat exchange fluid container B to be positioned in thermal contact with warmable or coolable fluid or surface; causing blood to circulate from Patient B, though the extracorporeal system, including through the blood flow path of the heat exchanger, and back into the vasculature of patient B; causing a heat exchange fluid to circulate through closed circulation loop B; and warming or cooling the warmable or coolable fluid or surface, thereby warming or cooling of the heat exchange fluid as it circulates through heat exchange fluid container B, thereby resulting in exchange of heat in the heat exchanger between the warmed or cooled heat exchange fluid and the blood of patient B.

**[0017]** In accordance with yet another aspect of the present disclosure, there is provided a method for warming or cooling a material flowing through a heat exchanger located in a sterile or sanitary area, said method comprising: obtaining a heat exchange fluid circulation system which comprises a container, a supply conduit connected to the container and a return conduit connected to the container; connecting the supply conduit and return conduit to a fluid flow path of the heat exchanger thereby establishing a closed circulation loop through which heat exchange fluid may circulate from the container, through the supply conduit, through the heat exchange fluid flow path of the heat exchanger, through return conduit and back into container; causing a heat exchange fluid to circulate through the closed circulation loop; causing the container to be positioned in thermal contact with a warmable or coolable fluid or surface; and warming or cooling the warmable or coolable fluid or surface, thereby warming or cooling the heat exchange fluid as it circulates through the heat exchange fluid container and resulting in exchange of heat in the heat exchanger between the warmed or cooled heat exchange fluid and the material.

**[0018]** Still further aspects and details of the present disclosure will be understood upon reading of the detailed description and examples set forth herebelow.

## Brief Description of the Drawings

**[0019]** The following detailed description and examples are provided for the purpose of non-exhaustively describing some, but not necessarily all, examples or embodiments of the invention, and shall not limit the scope of the invention in any way.

[0020] Figure 1 is a diagram of an extracorporeal blood circuit incorporating an extracorporeal blood heat exchanger along with a closed loop heat exchange fluid circulation system according to the present disclosure.

[0021] Figure 2 is a diagram of an extracorporeal blood circuit incorporating an extracorporeal blood heat exchanger along with a closed loop heat exchange fluid circulation system wherein the heat/cooler unit comprises a bath that contains a warmable or coolable fluid.

[0022] Figure 3 is a diagram of an extracorporeal blood circuit incorporating an extracorporeal blood heat exchanger along with a closed loop heat exchange fluid circulation system wherein the heat/cooler unit comprises thermal exchange members.

[0023] Figure 4 shows an extracorporeal blood circuit system incorporating an extracorporeal blood heat exchanger along with a closed loop heat exchange fluid circulation system wherein the heat exchange fluid container is insertable into a heat/cooler unit which may optionally be useable with a different type of container for circulating heat exchange fluid through an endovascular heat exchange catheter.

[0024] Figure 4A is a cross-sectional view through line 4A-4A of Figure 4.

[0025] Figure 4B is a cross-sectional view through line 4B-4B of Figure 4.

[0026] Figure 4C is a diagram of a thermal exchange plate of a heater-cooler device having a concave container-receiving area for receiving the heat exchange fluid container component of a closed loop heat exchange fluid circulation system as disclosed herein

[0027] Figure 4D is a diagram of a heat exchange fluid container configured to be received within the concave container receiving area of the thermal exchange place shown in Figure 4C.

[0028] Figure 5 is a diagram of an extracorporeal blood circuit having an insertable blood heat exchanger connected to a closed loop heat exchange fluid circulation system according to the present disclosure.

[0029] Figure 6A is a diagram of an extracorporeal blood circuit that incorporates a heat exchanging blood conduit according to the present disclosure.

[0030] Figure 6B is a cross-sectional view through Line 6B-6B of Figure 6A.

[0031] Figure 6C is a diagram of an extracorporeal blood circuit that has a heat exchanging member (e.g., a heated or cooled jacket) disposed on a blood-carrying conduit to warm or cool blood flowing through the extracorporeal circuit.

[0032] Figure 6D is a cross-section view through line 6D-6D of figure 6C. Figure 7 is a diagram of an extracorporeal blood circuit in which one of the vascular cannulas is equipped with an endovascular heat exchanger that is connected to a closed loop heat exchange fluid circulation system in accordance with the present disclosure.

[0033] Figure 7A is an enlarged view of region 7A-7A of Figure 7.

[0034] Figure 7B is a cross-sectional view through line 7B-7B of Figure 7.

[0035] Figure 8 is a flow diagram relating to one embodiment of a method according to the present disclosure.

## Detailed Description

[0036] The following detailed description and the accompanying drawings to which it refers are intended to describe some, but not necessarily all, examples or embodiments of the invention. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The contents of this detailed description and the accompanying drawings do not limit the scope of the invention in any way.

[0037] There exists a need for the development of new heater-cooler systems that employ closed loop heat exchange fluid circulation systems to reduce the potential for microbial infections in patients and staff.

[0038] Figure 1 shows a diagram of an extracorporeal blood circuit or system EC for blood oxygenation and/or circulatory support, e.g., a V-A ECMO system, which generally has a deoxygenated blood inflow conduit IC, a blood pump P, an extracorporeal blood heat exchanger HE, an oxygenator OX and an oxygenated blood outflow conduit OC. Such system may comprise additional components such as flow sensors, temperature sensors, filters, bubble detectors, sampling ports, bypass or cross-over lines, etc. Although, in the example shown the extracorporeal blood heat exchanger HE is positioned upstream of the oxygenator OX, it is to be appreciated that in some embodiments the extracorporeal blood heat exchanger HE may be positioned downstream of the oxygenator OX. The pre-oxygenator placement of the extracorporeal blood heat exchanger HE shown in the figures allows for warming of the blood and any resultant off gassing and bubble formation occurs before the blood enters the oxygenator OX. However, in some embodiments an alternative placement of the extracorporeal blood heat exchanger HE downstream of the oxygenator may be desirable. For example, in a neonatal ECMO circuit the low flow conditions can be associated with significant blood heat loss across the oxygenator OX membrane thereby making it more desirable to position the heat exchanger HE downstream of the oxygenator OX. In such embodiments where the heat exchanger HE is downstream of the oxygenator OX, the heat exchanger HE may be configured to itself perform a bubble trapping and/or air venting function and/or additional bubble detector(s), filters and/or apparatus for clearing bubbles may be provided downstream of the heat exchanger HE. Also, as shown, the heat exchanger HE is a discrete component, separate from the oxygenator and other functional components of the extracorporeal blood circuit or system HE. However, in some embodiments, the heat exchanger HE may be combined or integrated with the oxygenator OX and/or other components of the extracorporeal blood circuit or system EC.

**[0039]** In accordance with the present disclosure, a closed loop heat exchange fluid circulation system 10 is connected to the extracorporeal heat exchanger HE. This closed loop heat exchange fluid circulation system 10 comprises a heat exchange fluid container 12, a first conduit 14, a second conduit 16, and a pumping apparatus 18. The first conduit 14 extends from the heat exchange fluid container 12 to a heat exchange fluid inlet port IN of the extracorporeal blood heat exchanger HE and functions as a heat exchange fluid supply tube carrying heat exchange fluid from the container 12 into the extracorporeal blood heat exchanger HE. The second conduit 16 extends from the heat exchange fluid container 12 to a heat exchange fluid outlet port OT of the extracorporeal blood heat exchanger HE and functions as a heat exchange fluid return tube carrying heat exchange fluid from the extracorporeal blood heat exchanger HE back to the container 12.

**[0040]** The first and second conduits 14, 16 may be pre-attached to the container 12 at the time of manufacture or they may be attachable to the container 12 at the time of use. A fill port 19 may be provided at any suitable location in the closed loop heat exchange fluid circulation system 10. Connection of the first and second tubes to the extracorporeal blood heat exchanger HE and to the container 12 as shown in Figure 1 establishes a closed loop heat exchange fluid flow path through which a heat exchange fluid will circulate from the container 12, through the first tube 14, through the extracorporeal blood heat exchanger HE, through the second tube 16 and back into the container 12. Heat exchange fluid circulating though this closed loop heat exchange fluid flow path does not contact room air or other surfaces/objects outside of the closed loop heat exchange fluid flow path. This heat exchange fluid may or may not be sterile.

**[0041]** A heat exchange fluid pumping apparatus 18 may be provided in or extending from the container 12 and/or at other location(s). Such as on either of the first or second tubes 14, 16. Such pumping apparatus 18 serves to pump the heat exchange fluid through the closed loop heat exchange fluid flow path at a rate that is suitable for the desired warming or cooling of blood in the extracorporeal blood heat exchanger HE. For extracorporeal blood heat exchangers of the type typically used in adult ECMO or CPB systems a heat exchange fluid flow rate in the range of 5 liters per minute to 30 liters per minute may be desired. Additionally, the first and second tubes 14, 16 will be sized appropriately to accommodate the intended flow rate of heat exchange fluid. Typically, tubes 14, 16 having lumen inner diameters in the range of 3/8 inch to 5/8 inch will be used for adult applications.

**[0042]** Also, for some applications, such as ECMO treatment of critically ill patients, it may be desirable for all components of the system 10 to be designed for continuous use over a period of up to thirty (30) days. Accordingly, as explained more fully below, in some embodiments, tubes 14, 16 or a pump tubing extending from the container for a peristaltic pump may be braided or reinforced so as not to collapse or flatten over time.

**[0043]** A fill port 19 may be provided at any suitable location in the closed loop heat exchange fluid circulation system 10 to facilitate filling of the system 10 with a heat exchange fluid. Optionally, the components of the system 10 may be sterile and the system 10 may be filled with a sterile heat exchange fluid. For example, as shown in Claim 1, a bag 15 of sterile fluid (e.g., sterile 0.9 % NaCl solution) may be connected to fill port 19 by way of a tube 17 and sterile saline solution may flow from the bag into the system 10. The fill port 19 may perform an air venting function or, alternatively, air may be purged from the system through a stopcock, valve or other venting apparatus or by temporarily disconnecting or opening one end of the first and second conduits 14, 16 to allow purging of air during filling of the system.

**[0044]** The container 12 is positionable at an operating position located in or sufficiently near or in thermal contact with a warmable or coolable fluid or surface 26 such that heat exchange fluid circulating through the container 12 will be warmed or cooled by the warmable or coolable fluid or surface 12. In the non-limiting example shown in Figure 1, the warmable or coolable fluid or surface 26 is located in a heater-cooler unit 20 having a housing 22 with an opening 24 through which the container 12 may be inserted to an operating position next to the warmable or coolable fluid or surface 26. Additionally, in this example, the heat exchange fluid pumping apparatus 18 is located on the container 18 and when the container has been inserted to the operative location that pumping apparatus 18 will engage with a pump drive 28 located in the heater-cooler unit 20. For example, the pumping apparatus 16 may comprise a peristaltic pump tube configured to undergo repetitive peristaltic compression and the pump drive 28 may comprise a roller or other peristaltic compressor which causes peristaltic compression of the pump tube, thereby causing the heat exchange fluid to circulate through the closed loop fluid flow path as described. Alternatively, the pumping apparatus 18 could be a pump impeller, e.g., a disposable impeller, positioned in the container 12 or in conduits 14, 16 and the pump driver 28 could be a rotating driver that magnetically or otherwise engages and causes rotation of the pump impeller. In other embodiments, a heat exchange fluid pump pay be located elsewhere on the closed loop heat exchange fluid circulation system 10, such as on one or both of the first and second conduits 14, 16.

**[0045]** The container 12 is configured such that heat exchange fluid circulating through the container 12 becomes warmed or cooled to a desired temperature by the warmable or coolable fluid or surface 26. To facilitate this, in some embodiments, an internal heat exchange fluid flow path, such as a coiled, serpentine or circuitous flow path, may be defined within the container 12.

**[0046]** Optionally, a control unit C, such as a programmable controller or computer, may be connected by wired or wireless connection to the heater-cooler unit 20 and/or to component(s) of the extracorporeal circuit or system EC and one or more sensor(s) S may communicate by wired or wireless connection to the control unit C. Such sensor(s) S may be located at desired locations within the extracorporeal blood circuit system EC and/or within the closed loop heat exchange fluid circulation system 10 and/or in/on the body of the patient to provide feedback of information such as temperature and/or flow rate and/or pressure of blood, temperature and/or flow rate and/or pressure of heat exchange fluid and/or patient body temperature of other physiological patent variable or vital sign. For example, sensor S can be placed at the heater/cooler unit 20, as shown by position 53 of sensor S. For example, sensor S can be placed within or on the closed loop heat exchange fluid circulation system 10. Sensor S can be placed on the patient or in the patient, as shown by position 54 of sensor S. For example, the sensor S can be a temperature probe (or other sensor configuration) positioned inside the patient or inside the patient's vasculature. The sensor S can be a part of a catheter system or other temperature sensing system. For example, the sensor S can include a pad placed on a surface of the patient, or some combination of a pad, a temperature probe, and/or other sensor configuration. For example, sensor S can be positioned inside the patient's esophagus, rectum, or other location for sensing the patient's temperature. In an example, the sensor S can be placed within the extracorporeal blood circuit system EC, e.g., on or in the blood inflow conduit IC, shown by position 55 of the sensor S. Feedback from one or more of these sensors may be used to effect control of the heater / cooler to adjust warming or cooling of the patient in response to the feedback. Patient temperature or blood temperature may be controlled by the control unit C based on patient temperature or blood temperature feedback from a sensor placed in/on the patient or in the extracorporeal blood circuit or blood flow path. The control unit C may be configured to control the patient temperature or blood temperature so as to cause the sensed blood temperature or sensed patient temperature to be within a defined blood temperature target range or within a defined patient temperature target range or equal to a specific target blood temperature. Alternatively or additionally, such sensor(s) may comprise reader(s) which detect or read encoded information that is present on or in the heat exchange fluid circulation system 10 and the controller may be programmed to use such encoded information to identify, qualify, confirm or control the operation of heat exchange fluid circulation system 10. The encoded information may be stored in any suitable electronic storage medium and may be embedded in a chip or microchip mounted on or in the heat exchange fluid circulation system 10. Examples of the types of encoded information that may be stored include but are not limited to; unique identifier(s) for the changeable components of the heat exchange fluid circulation system (e.g., manufacturer identification, part number, lot number, etc.), indications of whether the changeable component(s) have previously been used (e.g., an encoded indication of first use), indications of whether the changeable component(s) is/are expired (e.g., encoded expiration date), operational characteristic(s) of the changeable component(s) (e.g., encoded indications of the size, type, volume, etc. of the changeable component(s). Examples of the types of information storage that may be utilized include but are not necessarily limited to: non-volatile random access memory (RAM), non-volatile flash memory, electrically erasable programmable read-only memory (EEPROM) or ferroelectric random access memory (FRAM). The controller C may be programmed to take one or more actions in response to the encoded information. For example, the controller C may be programmed to determine whether the encoded information meets a prerequisite requirement and to proceed with warming or cooling of the blood only if said prerequisite requirement is met. In embodiments where the heat exchange fluid circulation system 10 is intended to be disposable after a single use, the sensor S may sense encoded information which indicates that the heat exchange fluid circulation system 10 has been previously used (e.g., previously filled with heat exchange fluid and/or previously connected to a heat exchanger, etc.) If the sensor S senses information indicating that the heat exchange fluid circulation system 10 was previously used, the controller C may respond by issuing an alarm and/or issuing control signals which prevent or deter use of the system 10.

**[0047]** Optionally, one or more portion(s) of the closed loop heat exchange fluid circulation system 10 may be coated with or may otherwise comprise an antimicrobial or microbiostatic substance to deter microbial growth.

**[0048]** In a typical method of operation, the first conduit is connected to the inlet IN of the extracorporeal blood heat exchanger HE and the second conduit 16 is connected to the outlet port OT of the extracorporeal blood heat exchange HE. This establishes the closed loop heat exchange fluid flow path. Such closed loop flow path is then filled with heat exchange fluid and any excess entrapped air is purged from the closed loop flow path. The container 12 is inserted through opening 24 of the heater-cooler unit 20 to its operative position in contact with or near the warmable or coolable fluid or surface 26. When the container 12 is so positioned, the pumping apparatus 18 will engage the pump drive 28. The pump drive 28 then drives the pumping apparatus 18 causing heat exchange fluid to circulate through the closed loop heat exchange fluid flow path as described while becoming warmed or cooled by the warmable or coolable fluid or surface 26. This occurs without the heat exchange fluid contacting the room air or the warmable or coolable fluid or surface 26 or any other surface or item other than the inner surfaces of the closed loop heat exchange fluid flow path, thereby preventing contamination by bacteria or other foreign substance.

**[0049]** In Figure 1, the components of the closed loop heat exchange fluid circulation system 10 and heater-cooler unit 20 are shown in generic format.

Figures 2 through 4A show alternative embodiments of the system 10 that is shown generically in Figure 1.

**[0050]** Figure 2 shows an extracorporeal blood circuit system EC as described above in combination with another embodiment of a closed loop heat exchange fluid circulation system 10a and heater cooler unit 20a. In this embodiment, the heater cooler unit 20a comprises a bath 100 filled with warmable or coolable fluid 101. The container 12a of the closed loop heat exchange fluid circulation system 10a is configured to be submersed in the warmable or coolable fluid 101, as shown. A pump 18a is positioned on the first conduit 14. A refrigerant such as a chlorofluorocarbon (e.g., a Freon) or other suitable coolant circulates through chiller 104 to cool the warmable or coolable fluid 101 and a resistance heater 106 warms the warmable or coolable fluid 101 within the bath 100. A recirculation pump 103 circulates the warmable or coolable fluid 101 to minimize temperature gradients or zones within the bath 100. In this manner the temperature of fluid 101 within the bath 100 may be controlled to warm or cool heat exchange fluid being circulated by pump 18a from the container 12a, through the first conduit 14, through the extracorporeal blood heat exchanger HE, through the second conduit 16 and back into the container 12a, without the circulating heat exchange fluid coming into contact with the bath fluid 101, room air or other objects/personnel in the area. Since the bath fluid 101 does not circulate through the blood heat exchanger HE, bacteriostatic or antibacterial fluids like glycols could be used as the bath fluid to thereby avoid risks of bath contamination as with a water bath or water tank.

**[0051]** Figure 3 shows an extracorporeal blood circuit system EC as described above in combination with another embodiment of a closed loop heat exchange fluid circulation system 10b and heater cooler unit 20b. In this embodiment, the heater cooler unit 20b comprises first thermal exchange member 112 that is cooled by circulation of a Freon or other suitable coolant through chiller 104 and a second thermal exchange member 114 that is warmed by a resistance heater 106. Optionally, the chiller and resistance heater may be coupled to both thermal exchange members. A container receiving space 110 exists between the first thermal exchange member 112 and second thermal exchange member 114. The container 12b is configured to be inserted into the container receiving space 110 such that opposite sides of the container 12b are in contact with or sufficiently close to inner surface of the first and second thermal exchange members 112, 114 that heat exchange fluid circulating through the container 12b will be cooled by the first thermal exchange member 112 or warmed by the second thermal exchange member 114. Pump 18b is positioned on the first conduit 14. In this manner the temperatures of the first and second thermal exchange members 112, 114 may be controlled to warm or cool heat exchange fluid being circulated by pump 18b in a closed loop heat exchange fluid flow path from the container 12b, through the first conduit 14, through the extracorporeal blood heat exchanger HE, through the second conduit 16 and back into the container 12b, without the heat exchange fluid coming into contact with thermal exchange members 112, 114 or the room air or any other objects or personnel in the area. For extracorporeal blood heat exchangers of the type typically used in adult ECMO or CPB systems having a heat exchange fluid flow rate in the range of 5 liters per minute to 30 liters per minute, the container may utilize a heat exchange bag or membrane assembly. The bag or membrane assembly may have a surface area of 4 to 8 square feet and/or the bag or membrane may have a wall thickness of 0.003 inches to 0.020 inches, to provide efficient heating cooling of a heat exchange fluid at the stated flow rate.

**[0052]** The closed loop heat exchange fluid circulation systems and extracorporeal heat exchangers described herein may be constructed of materials suitable for disposal after a single use. For example, polycarbonate, polyvinylchloride, polyethylene terephthalate (PET), Pebax, Polyolefin, Polyurethane, and/or Nylon.

**[0053]** Figures 4 shows an extracorporeal blood circuit system EC as described above in combination with a closed loop heat exchange fluid circulation system 10d, which comprises a heat exchange fluid circulation system 10d, container 12, and pump apparatus 18 as shown in Figure 1 in combination with modified conduits 14d, 16d. The heat exchange fluid container 12 is insertable into a heater cooler unit 20d, which comprises a console having at least one opening 110a through which the heat exchange fluid container 12 is inserted. When so inserted, the heat exchange fluid container 12 becomes positioned in an operating position within heater-cooler unit 20d wherein the container 12 is in contact with or proximate to one or more thermal exchange fluids or surface(s) 26, for example one or more thermal exchange plates which warm or cool fluid circulating through the container. As shown in the cross-sectional view of Figures 4A and 4B, one or both of conduits 14d and/or 16d may be reinforced with braiding 15 to deter flattening or collapsing of such conduits during prolonged use, such as use for a period of up to 30 days which may be encountered in some ECMO applications. In this embodiment, the container 12 may comprise a cassette having side walls and an unobstructed heat exchange fluid flow path therein, or alternatively, a serpentine heat exchange fluid flow path therein. When the container 12 is inserted to its operating position within container receiving space 110a, side walls of the container 12 may contact directly and/or thermally adjacent surfaces of thermal exchange plates located within the heater/cooler unit 20d. Any portion of the container 12 that is in contact with the thermal exchange plate(s) of the heater-cooler unit 20d may be textured or may comprise anti-stick or release agents to deter sticking to the thermal exchange plate(s). As described above, when the container 12 is inserted through opening 110a to its operating position within the heater-cooler unit 20d, the pump apparatus 18 is engageable with a pump driver within the heater-cooler unit 20d. In some embodiments, this pump apparatus 18 may comprise a loop of peristaltic pump tubing that extends from the container 12. Such loop of pump tubing may then be engaged with a peristaltic roller within the heater-cooler unit 20d to cause peristaltic compression of the pump tubing so as to circulate warmed or cooled heat exchange fluid from the container 12, through the first conduit 14d, through the extracorporeal blood heat exchanger HE, through the second conduit 16d and back into the container 12. In some applications, such as the typical ECMO or CPB applications, the conduits and pumping components of this embodiment may be sized and constructed to provide the heat exchange fluid flow rates described above. Optionally, in some embodiments, this heater-cooler unit 20d may include one or more additional openings 110b through which other types of heat exchange fluid containers or cassettes may be inserted to provide warmed or cooled heat exchange fluid to other types of devices, e.g., catheters or pads.

**[0054]** Figure 4C shows an example of a thermal exchange surface in the nature of a plate 26a having a concave heat exchange container-receiving area 27 formed therein. Figure 4D shows an embodiment of the heat exchange fluid container 12 which is configured to be received within the heat exchange container-receiving area 27 formed in the plate 26a shown in Figure 4C. This fluid container may be a tubular container having a convoluted or serpentine shape corresponding to the shape of the container receiving area 27. Optionally, the tubular container may be flexible such that it may be manipulated into any desired shape. The container may include rigid restraining components for holding the tubular container in a desired shape or configuration.

**[0055]** Figure 5 shows an extracorporeal blood circuit system 70 which incorporates a closed loop heat exchanger circulation system 10 and heater cooler 20 as shown in Figure 1. However, this extracorporeal blood circuit system 70 does not include an extracorporeal blood heat exchanger connected to its extracorporeal circuit, as in Figures 1 through 4. Rather, in this extracorporeal blood circuit system 70, the blood inflow conduit IC is provided with a heat exchanger insertion port 71. When it is desired to warm or cool blood flowing through this ECMO system, a heat exchange probe 72, which may be rigid or flexible, is inserted through the heat exchanger insertion port 71 and into the lumen of the blood inflow conduit IC. The heat exchange probe 72 has a heat exchange fluid inflow connector 76 which connects to the first conduit 14 and a heat exchange fluid outflow connector 78 which connects to the second conduit 16. Optionally, a hemostatic apparatus 73, such as a Tuohy-Borst Adapter or other hemostasis valve, may be positioned on the heat exchanger insertion port 71 to deter leakage or backflow of blood. During operation, the container 12 is inserted to its operating position within the heater-cooler unit 20 as described above and the pump apparatus 18 circulates warmed of cooled heat exchange fluid from the container 12, through first conduit 14, through inflow connector 76, through the heat exchange probe or catheter 72 and its heat exchanger 74, through the outflow connector 78, through the second conduit 16 and back into the container or cassette 12. In this manner, the heat exchanger 74 will warm or cool blood flowing through the inflow conduit IC. Although, in this example, the heat exchanger insertion port 71 and the inserted heat exchanger 74 are located in the blood inflow conduit IC, it is to be appreciated that the heat exchanger insertion port 71 and the inserted heat exchanger 74 may additionally or alternatively be located in the blood outflow conduit OC (i.e., downstream of the pump P and oxygenator OX) or at any other suitable location in the ECMO circuit.

**[0056]** Figures 6A and 6B show another extracorporeal blood circuit system 80 which incorporates a closed loop heat exchanger circulation system 10 and heater cooler unit 20 as shown in Figure 1. However, this extracorporeal blood circuit system 80 does not include an extracorporeal blood heat exchanger connected to its extracorporeal circuit, as in Figures 1 through 4. Rather, in this extracorporeal blood circuit system 80, the blood inflow conduit 120 is itself a heat exchanger. This inflow conduit 120 has a blood carrying lumen 122 and one or more heat exchange fluid carrying lumen(s) 124. In this particular example, the heat exchange fluid lumens 124 are disposed around the blood lumen 122, but it is to be appreciated that other lumen shapes and configurations may be used, e.g., a heat exchange fluid lumen may run through the center of the inflow or outflow conduits and be surrounded by one or more blood lumens. The first conduit 14 of the closed loop heat exchange fluid circulation system 10 is connected to a heat exchange fluid inflow port 82 on the inflow conduit 120 and the second conduit of the closed loop heat exchange fluid circulation system is connected to a heat exchange fluid outlet port 84 on the blood inflow conduit 120. During operation, the container 12 is inserted to its operating position within the heater-cooler unit 20 as described above and the pump apparatus 18 circulates warmed of cooled heat exchange fluid from the container 12, through first conduit 14, through inflow connector 82, through the heat exchange lumen(s) 124 of inflow conduit 120, through outflow connector 84, through second conduit 16 and back into the container 12. In this manner, the heat exchange fluid circulating though the heat exchange lumens 124 of the inflow conduit 120 will warm or cool blood flowing through the inflow conduit 120. Although, in this example, the heat exchange lumens 124 and connectors 82, 84 are located in the blood inflow conduit IC, it is to be appreciated that the heat exchange lumens 124 and connectors 82, 84 may additionally or alternatively be located in the blood outflow conduit OC (i.e., downstream of the pump P and oxygenator OX) or at any other suitable location in the extracorporeal blood circuit. Also, instead of or in addition to the heat exchange lumens 124, any other suitable heater and/or cooler member or apparatus may be placed on or incorporated in either the blood inflow and/or blood outflow conduits to effect heat exchange with the flowing blood. For example, resistance heating elements may be embedded in the conduits to warm blood flowing therethrough.

**[0057]** Figures 6C and 6D show an alternative extracorporeal blood circuit system 80A wherein a separate heat exchanging member 140, such as a jacket or pad, is positionable on the inflow conduit IC, outflow conduit OC or other suitable blood-carrying prion of the extracorporeal circuit or system to warm or cool blood flowing through the circuit or system. In the particular example shown, the heat exchanging member 140 comprises a heat exchanging jacket that is wrapped around the inflow conduit IC to warm or cool blood flowing through the inflow conduit IC. In this example, the heat exchanging member 140 has heat exchange fluid lumens 142 which are connected to delivery and return conduits 14, 16 of the heat exchange fluid circulation system 10 so that warmed or cooled heat exchange fluid will circulate from the container 12, through delivery conduit 14, through the heat exchange lumens 142, through the return conduit 12 and back into the container 12, as described above. As an alternative to heat exchange lumens 142, any other suitable heater and/or cooler member or apparatus may be placed on or incorporated in the heat exchanging member 140 to effect heat exchange with the flowing blood when the heat exchanging member 140 is positioned on a suitable blood-carrying conduit or component. For example, instead of or in addition to the heat exchange fluid lumens 142, resistance heating elements may be embedded in the heat exchanging member 140. Also, as an alternative to a jacket that is positionable about the inflow conduit

IC and/or outflow conduit OC, the heat exchanging member 140 may comprise pad(s) or an elongate member (e.g., a tape or strand) that can be wrapped around a desired blood-carrying conduit or component.

**[0058]** Figures 7 through 7B shows an extracorporeal blood circuit system 200 which does not include an extracorporeal blood heat exchanger, but wherein at least one of the two vascular cannulas 202, 210 is equipped with an endovascular heat exchanger. Specifically, in the example shown the blood withdrawal cannula 202 is equipped with an endovascular heat exchanger 204. The blood withdrawal cannula 202 has a blood inlet port 206, a blood withdrawal lumen 206 and proximal blood outlet connector 211 to which the inflow conduit IC of the extracorporeal blood circuit system EC is attached. The extracorporeal blood circuit system's pump P pumps blood through blood inlet port 206, through blood withdrawal lumen 206, through proximal blood outlet connector 211, through the inflow conduit IC, through the oxygenator OX, through the outflow conduit OC through the blood return cannula 210 and back into the patient's vasculature. A heat exchanger 204 is positioned slightly distal to the blood inlet port 206 of the blood withdrawal cannula 202. Such heat exchanger 204 is connected to a heat exchange fluid inflow lumen 208 which terminates proximally at a heat exchange fluid inflow connector 207 and a heat exchange fluid outflow lumen 210 which terminates proximally at a heat exchange fluid outflow connector 209. The first conduit 14 of the closed loop heat exchange fluid circulation system 10 is connected to the heat exchange fluid inflow connector 207 and the second conduit 16 of the closed loop heat exchange fluid circulation system 10 is connected to the heat exchange fluid outflow connector 209. During operation, the container 12 is inserted to its operating position within the heater-cooler unit 20 as described above (not shown in Figure 7) and the pump apparatus 18 circulates warmed or cooled heat exchange fluid from the container 12, through first conduit 14, through heat exchange fluid inflow connector 207, through the heat exchange inflow lumen 208, through endovascular heat exchanger 204, through heat exchange fluid outflow lumen 210 through heat exchange fluid outflow connector 209, through second conduit 16 and back into the container 12. In this manner, the heat exchanger 204 will warm or cool blood flowing through the patient's vasculature as well as blood entering the blood withdrawal cannula 202.

**[0059]** In any embodiment of the heat exchange fluid circulation system 10, all or part(s) of the system 10 may be constructed and designed for disposal after a single use. For example, all or part of the heat exchange fluid circulation system 10 may be formed of relatively inexpensive materials. In certain embodiments, all or part of the heat exchange fluid circulation system 10 may be difficult to clean, dry and/or sterilize between uses resulting in bacteria growth or other contamination of the system that would make the system unsuitable for reuse in a medical or patient treatment environment without cleaning.

**[0060]** In some embodiments, the entire extracorporeal blood heat exchanger HE, or at least blood contacting portions of the extracorporeal blood heat exchanger, may also be constructed and designed so as to be disposable after a single use. For example, in some embodiments a disposable extracorporeal blood heat exchanger HE or blood-contacting portion thereof may be pre-connected to the first and second conduits 14, 16 of a disposable heat exchange fluid circulation system 10 at the time of manufacture or at some other time prior to use and, and after a single use, that entire heat exchange fluid circulation system 10 along with the extracorporeal blood heat exchanger HE or blood contacting portion thereof may be disposed of, thereby eliminating any need for cleaning and sterilization between repeat uses.

**[0061]** In certain embodiments, no portion of the heat exchange fluid circulation system 10 or the heat exchange fluid that circulates therethrough comes in direct contact with blood, other body fluid or contaminated water from a reused water bath. Thus, after a single use, the first and second conduits 14, 16 may be detached from the blood heat exchanger HE and the entire heat exchange fluid circulation system 10 as well as the heat exchange fluid contained therein may be disposed of by placement in a standard non-hazardous waste or recycling receptacle. On the other hand, applicable law or regulation may require disposal of the blood heat exchanger HE and other blood-contacting disposable portions of the system (e.g., the blood-carrying tubing, oxygenator OX, filters, etc.) by way of a hazardous or biological waste process. Thus, use of a disposable heat exchange fluid circulation system 10 may not only reduce potential for transmission of pathogenic microbes, but also provides for economically advantageous disposal by way of a regular, non-hazardous waste disposal or recycling process.

**[0062]** The present disclosure also includes methods for using the devices and systems described above. In one embodiment, the present disclosure includes a method as set forth in the flow diagram of Figure 8. In this method, a patient (i.e., patient A) is connected to an extracorporeal system EC which has a heat exchanger HE that comprises a blood flow path and a heat exchange fluid flow path so that blood from patient A circulates through the extracorporeal system EC including through the blood flow path of the heat exchanger HE. Such extracorporeal system may comprise any extracorporeal system or circuit, including but not limited to an ECMO system, CPB system, blood cleansing system, blood warming or cooling system, autotransfusion system, hemofiltration system, hemodialysis system, aphresis system, plasmapheresis system, etc. A user may obtain or provides a heat exchange fluid circulation 10, 10a, 10b or 10c (e.g., system A) which comprises a container 12, 12a, 12b, (e.g., container A), a supply conduit 14, 14d (e.g., supply conduit A) which is connected to container A, and a return conduit 16, 16d (e.g., return conduit A) which is also connected to container A. Supply conduit A and return conduit A are connected to the heat exchange fluid flow path of the heat exchanger HE, thereby establishing a closed circulation loop (e.g., circulation loop A) through which heat exchange fluid may circulate from container A, through supply conduit A, through the heat exchange fluid flow path of the heat exchanger, through return conduit A and back into heat exchange fluid container A. Heat exchange fluid container A is positioned in thermal contact with warmable or coolable fluid or surface 26 and blood is caused to circulate from a subject patient (e.g., patient A), though the extracorporeal system EC, including through the blood flow path of the heat exchanger HE, and back into the vasculature of patient A. Heat exchange fluid (e.g., sterile water or sterile saline solution) is circulated through closed circulation loop A and the warmable or coolable fluid or surface 25 is warmed or cooled. This causes warming or cooling of the heat exchange fluid as it circulates through heat exchange fluid container A which in turn results in exchange of heat in the heat exchanger HE between the warmed or cooled heat exchange fluid and the blood of patient A.

**[0063]** After treatment of patient A is complete (or in some cases while treatment of patient A is still ongoing) the circulation of heat exchange fluid through closed circulation loop A may be stopped and the heat exchange fluid circulation system A may be removed and replaced. If heat exchange fluid circulation system A is disposable, it may be disconnected from the heat exchanger HE and disposed of in a suitable manner. As described above, in at least some instances, such disposal of heat exchange fluid circulation system A may be by placing it in a regular non-hazardous waste or recycling container. The heat exchanger HE and other blood-contacting parts of the extracorporeal system may be separately disposed of as hazardous waste.

**[0064]** The extracorporeal system EC may then be reused to treat a different patient (e.g., patient B). Any disposable portions of the extracorporeal system EC may be replaced and the system EC may be connected to patient B. Blood from patent B will be circulated through the extracorporeal system EC including through the blood flow path of a heat exchanger HE. A user will obtain a fresh, previously unused heat exchange fluid circulation system 10, 10a, 10b or 10c (e.g., system B) which comprises heat exchange fluid container B, supply conduit B and return conduit B. Supply conduit B and return conduit B are connected to the heat exchange fluid flow path of the heat exchanger HE, thereby establishing a closed circulation loop B through which heat exchange fluid may circulate from container B, through supply conduit B, through the heat exchange fluid flow path of the heat exchanger, through return conduit B and back into heat exchange fluid container B. Heat exchange fluid container B is positioned in thermal contact with warmable or coolable fluid or surface. Blood is caused to circulate from Patient B, though the extracorporeal system EC, including through the blood flow path of the heat exchanger HE and back into the vasculature of patient B. Heat exchange fluid is caused to circulate through closed circulation loop B. The warmable or coolable fluid or surface is warmed or cooled, thereby warming or cooling of the heat exchange fluid as it circulates through heat exchange fluid container B and in turn resulting in exchange of heat in the heat exchanger HE between the warmed or cooled heat exchange fluid and the blood of patient B.

**[0065]** It is to be appreciated that, although the embodiments described above are used to warm or cool blood in an extracorporeal circuit, some or all of the disclosed systems may be used to warm or cool other materials (e.g., fluids, suspensions, powders, etc.) that flow through a conduit. For example, heat exchange fluid circulation systems 10, 10a, 10b or 10c as described herein may be used to warm or cool flowing materials by way of a heat exchanger located in a sanitary or sterile environment, such as in a clean room facility where pharmaceuticals, biologics, intravenous solutions and the like are manufactured or packaged. In such applications, a user may obtain a heat exchange fluid circulation system. A user may obtain or provide a heat exchange fluid circulation system 10, 10a, 10b or 10c which comprises a container 12, 12a or 12b, a supply conduit 14 or 14d connected to the container and a return conduit 16 or 16d which is also connected to the container 12, 2a or 12b. The supply conduit 14, 14d and return conduits 16, 16d are connected to the heat exchange fluid flow path of the heat exchanger HE located in the sanitary or sterile environment. This establishes a closed circulation loop through which heat exchange fluid may circulate from the container 12, 12a or 12b, through the supply conduit 14a, 4d, through the heat exchange fluid flow path of the heat exchanger, through return conduit 16, 16d and back into container 12, 12a or 12b. Heat exchange fluid is then caused to circulate through that closed circulation loop. The container 12, 12a or 12b is positioned in thermal contact with a warmable or coolable fluid or surface. The warmable or coolable fluid or surface may be located outside of the sanitary or sterile area. The warmable or coolable fluid or surface may then be warmed or cooled to thereby warm or cool the heat exchange fluid as it circulates through the heat exchange fluid container 12, 12a or 12b. In this manner, heat exchange occurs in the heat exchanger between the warmed or cooled heat exchange fluid and the flowing material without the heat exchange fluid or any non-sterile or non-sanitary components coming into contact with the air, objects or surfaces within the sanitary or sterile area where the heat exchanger is located.

**[0066]** It is to be appreciated that, although the invention has been described hereabove with reference to certain examples or embodiments of the invention, various additions, deletions, alterations and modifications may be made to those described examples and embodiments without departing from the intended spirit and scope of the invention. For example, any elements, steps, members, components, compositions, reactants, parts or portions of one embodiment or example may be incorporated into or used with another embodiment or example, unless otherwise specified or unless doing so would render that embodiment or example unsuitable for its intended use. Also, where the steps of a method or method have been described or listed in a particular order, the order of such steps may be changed unless otherwise specified or unless doing so would render the method or method unsuitable for its intended purpose. Additionally, the elements, steps, members, components, compositions, reactants, parts or portions of any invention or example described herein may optionally exist or be utilized in the absence or substantial absence of any other element, step, member, component, composition, reactant, part or portion unless otherwise noted. All reasonable additions, deletions, modifications and alterations are to be considered equivalents of the described examples and embodiments and are to be included within the scope of the following claims.

## Claims

What is claimed is:

1. A system comprising:

an extracorporeal blood circuit having an extracorporeal blood heat exchanger; and

a heat exchange fluid circulation apparatus useable to circulate a heat exchange fluid through the extracorporeal blood heat exchanger, said heat exchange fluid circulation apparatus comprising;

a first tube connectable to the extracorporeal blood heat exchanger,

a second tube connectable to the extracorporeal blood heat exchanger; and

a heat exchange fluid container that is configured to connect to the first and second tubes, said container configured to be positioned in thermal contact with warmable or coolable fluid or surface such that heat exchange fluid circulating through the container will be warmed or cooled by said warmable or coolable fluid or surface;

a pumping apparatus

wherein connection of the first and second tubes to the extracorporeal blood heat exchanger and to the container establishes a closed loop heat exchange fluid flow path through which the pumping apparatus will cause the heat exchange fluid to circulate from the container, through the first tube, through the extracorporeal blood heat exchanger, through the second tube and back into the container.

2. A system according to claim 1 wherein the warmable or coolable fluid or surface comprises a plurality of warmable or coolable members and said heat exchange fluid container is positioned between a warmable or coolable member.

3. A system according to claim 1 wherein the warmable or coolable fluid or surface comprises a warmable or coolable fluid in which the heat exchange fluid container is fully or partially submersed.

4. A system according to claim 1 further comprising a filling port through which the closed heat exchange fluid flow path may be filled with a heat exchange fluid.

5. A system according to claim 1 further comprising a sensor positioned to monitor patient temperature or blood temperature and a controller configured to control the patient temperature or blood temperature based on patient temperature or blood temperature feedback from the sensor.

6. A system according to claim 1 wherein the pumping apparatus comprises a peristaltic pump tube configured to undergo repetitive peristaltic compression by a roller or other peristaltic compressor.

7. A system according to claim 1 wherein said heat exchange fluid container is positioned within a container receiving space of a heater/cooler device.

8. A system according to claim 7 wherein said receiving space is between thermal exchange plates which comprise warmable or coolable surfaces such that a heat exchange fluid circulating through the heat exchange fluid container will be warmed or cooled by said warmable or coolable surfaces.

9. A system according to claim 1 wherein said heat exchange fluid container is positioned within a container receiving space of a heater/cooler device that is configured to alternatively receive a different container configured for circulating heat exchange fluid through an endovascular heat exchange catheter or body surface heat exchanger.

10. A system according to claim 1 wherein, when said heat exchange fluid container is fully or partially submersed in the warmable or coolable fluid such that a heat exchange fluid circulating through the container will be warmed or cooled by said warmable or coolable fluid.

11. A system according to claim 1 wherein the heat exchange fluid container comprises a housing having an internal heat exchange fluid flow path defined within the housing.

12. A system according to claim 11 wherein the internal heat exchange fluid flow path of the heat exchange fluid container is coiled, serpentine, or circuitous.

13. A system according to claim 1 wherein the heat exchange fluid container has an outer surface that is textured and/or configured to deter sticking of that outer surface to separate warmable or coolable surfaces.

14. A system according claim 1 wherein the apparatus useable to circulate a heat exchange fluid is configured to be disposable after a single use.

15. A system according to claim 14 wherein at least one of the first and second tubes is braided or otherwise constructed so as not to collapse or substantially flatten during up to thirty days of continuous use.

16. A system according to claim 1 wherein the extracorporeal blood circuit comprises a system selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems.

17. A system according to claim 1 wherein the heat exchange fluid circulation apparatus further comprises one or more sensors for providing feedback regarding one or more of:

heat exchange fluid temperature;

heat exchange fluid pressure;

heat exchange fluid flow;

whether the heat exchange fluid circulation apparatus is approved for use; and

whether the heat exchange fluid circulation apparatus has been previously used

18. A system according to claim 1 further in combination with a sterile heat exchange fluid within the closed heat exchange fluid flow path.

19. A system according to claim 1 wherein the closed heat exchange fluid flow path and pumping apparatus are configured to circulate heat exchange fluid at a flow rate of 5 ml/min to 30 ml/min.

20. A system according to claim 19 wherein the first and second tubes have inner diameters in the range of from 3/8 inch to 5/8 inch.

21. A system for warming or cooling blood flowing through an extracorporeal system, said system comprising:

an extracorporeal blood heat exchanger configured for connection to the extracorporeal system;

a heat exchange fluid supply tube configured for connection to the extracorporeal blood heat exchanger,

a heat exchange fluid return tube configured for connection to the extracorporeal blood heat exchanger; and

a heat exchange fluid container configured for connection to the supply and return tubes;

a pumping apparatus

wherein connection of the supply and return tubes to the extracorporeal blood heat exchanger and heat exchange fluid container establishes a closed loop heat exchange fluid flow path through which the pumping apparatus causes the heat exchange fluid to circulate from the container, through the supply tube, through the extracorporeal blood heat exchanger, through the return tube, and back into the container; and

wherein the heat exchange fluid container is configured to be positioned in thermal contact with warmable or coolable fluid or surface such that heat exchange fluid which circulates though the container will become warmed or cooled by the warmable or coolable fluid or surface without contacting the warmable or coolable fluid or surface and blood which circulates through the extracorporeal blood heat exchanger will become warmed or cooled by the circulating heat exchange fluid.

22. A system according to claim 21 wherein all components of the system, including the extracorporeal blood heat exchanger are constructed of materials suitable for disposal after a single use.

23. A system according to claim 21 wherein the extracorporeal system is selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems.

24. A system according to claim 21 wherein the container comprises one or more temperature, pressure and/or flow sensors for providing feedback regarding the temperature, pressure and/or flow of the heat exchange fluid to a controller coupled to said container.

25. A system according to claim 21 further comprising one or more sensors for providing feedback regarding one or more of:

heat exchange fluid temperature;

heat exchange fluid pressure;

heat exchange fluid flow;

whether the heat exchange fluid circulation apparatus is approved for use; and

whether the heat exchange fluid circulation apparatus has been previously used.

26. A system for circulating a heat exchange fluid through an extracorporeal blood heat exchanger, said system comprising:

a container;

a heat exchange fluid supply tube;

a heat exchange fluid return tube; and

a pumping apparatus;

the supply tube and return tube connectable to the container and the extracorporeal blood heat exchanger so as to establish a closed heat exchange fluid circulation path through which the pumping apparatus will cause heat exchange fluid to circulate from the container, through the supply tube, through the extracorporeal blood heat exchanger, through the return tube and back into the container;

the container being configured to be positioned in thermal contact with a warmable or coolable fluid or surface so that heat exchange fluid circulating through the container will become warmed or cooled without directly contacting the warmable or coolable fluid or surface; and

the pumping apparatus and the closed heat exchange fluid circulation path being configured to provide circulation of heat exchange fluid through the closed heat exchange fluid circulation path at a flow rate in the range of from 5 liters per minute to 30 liters per minute.

27. A system according to claim 26 wherein the supply tube and return tube have inner diameters in the range of from 3/8 inch to 5/8 inch.

28. A system according to claim 26 wherein all components of the system, including the extracorporeal blood heat exchanger are constructed of materials suitable for disposal after a single use.

29. A system according to claim 26 further comprising one or more sensors for providing feedback regarding one or more of:

heat exchange fluid temperature;

heat exchange fluid pressure;

heat exchange fluid flow;

whether the heat exchange fluid circulation apparatus is approved for use; and

whether the heat exchange fluid circulation apparatus has been previously used.

30. A system useable for extracorporeal treatment of a subject's blood, said system comprising:

an extracorporeal blood flow circuit having an inlet that is connectable to vasculature of the subject and an outlet that is connectable to vasculature of the subject,

a pump useable to pump blood from vasculature of the subject, through the inlet, through the extracorporeal blood flow circuit, through the outlet and into vasculature of the subject;

a blood treatment device useable for treating blood that flows through the extracorporeal circuit; and,

a port through which a heat exchange device may be inserted into the extracorporeal blood flow circuit so as to exchange heat with blood flowing through the extracorporeal blood flow circuit.

31. A system according to claim 30 further comprising a hemostatic valving apparatus associated with the port to deter leakage of blood from the port.

32. A system according to claim 30 wherein the inlet comprises a first tube that is connectable to a cannula or catheter that is insertable into the subject's vasculature.

33. A system according to claim 32 wherein the outlet comprises a second tube that is connectable to a cannula or catheter that is insertable into the subject's vasculature.

34. A system according to claim 30 wherein the blood treatment device comprises an oxygenator which oxygenates blood flowing through the extracorporeal blood flow circuit.

35. A system according to claim 30 wherein the port is located upstream of the blood treatment device.

36. A system according to claim 30 further comprising a reservoir or other air removing apparatus wherein any air bubbles within the blood are separated from the blood.

37. A system according to claim 36 wherein the port is located upstream of the reservoir or other air removing apparatus.

38. A system according to claim 30 further in combination with a heat exchange device insertable through the port and useable to exchange heat with blood flowing through the extracorporeal circuit.

39. A system according to claim 38 wherein the heat exchange device comprises a Peltier, resistance heater or other electrical device for warming or cooling the blood.

40. A system according to claim 38 wherein the heat exchange device comprises a heat exchanger which is insertable through the port and

through which a warmed or cooled heat exchange fluid circulates to cause warming or cooling of the blood.

41. A system according to claim 40 further comprising tubing and a heat exchange fluid container connected to the heat exchange device to form a closed heat exchange fluid recirculation loop wherein heat exchange fluid will circulate from the container, through a first tube, through the heat exchange device, through a second tube and back into the container.

42. A system according to claim 41 further comprising a device for warming or cooling heat exchange fluid as it circulates through the container.

43. A heat exchanging conduit located within an extracorporeal blood flow circuit, said heat exchanging conduit comprising a lumen through which blood flows and least one of a) at least one heat exchange fluid lumen, b) at least one warming device and c) at least one cooling device, for warming or cooling blood as it flows though said lumen.

44. A heat exchanging conduit according to claim 43 having a plurality of heat exchange fluid lumens disposed at locations around said blood flow lumen.

45. A heat exchanging conduit according to claim 43 having at least one heat exchange lumen that is connected, by way of a first tube and a second tube, to a heat exchange fluid container so as to establish a closed heat exchange fluid flow path through which heat exchange fluid will circulate from the container, through the first tube, through said at least one heat exchange lumen, through the second tube and back into the container, said container being positionable at an operating location in or sufficiently near a warmable or coolable fluid or surface to cause heat exchange fluid circulating through the container to become warmed or cooled by the warmable or coolable fluid or surface.

46. A heat exchanging conduit according to claim 43 having at least one resistance heater on or in the heat exchanging conduit so as to warm blood flowing through the blood flow lumen.

47. A heat exchanging conduit according to claim 43 located within an extracorporeal system selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems.

48. A system for circulating heat exchange fluid through an extracorporeal blood heat exchanger that has a heat exchange fluid inflow port and a heat exchange fluid outflow port, said system comprising:

a first tube connectable to the heat exchange fluid outflow port of the extracorporeal blood heat exchanger,

a second tube connectable to the heat exchange fluid inflow port of the extracorporeal blood heat exchanger;

a disposable heat exchange fluid cassette that is connected or connectable to the first and second tubes, said cassette being positioned or positionable in contact with or proximity to a warmable or coolable surface so as to warm or cool a heat exchange fluid circulating through the cassette; and

a pumping apparatus;

wherein, when the first tube is connected to the heat exchange fluid outflow port of the extracorporeal blood heat exchanger and the second tube is connected to the heat exchange fluid inflow port of the extracorporeal blood heat exchanger, the pumping apparatus is useable to circulate a heat exchange fluid from the heat exchange fluid outflow port of the blood heat exchanger, through the first tube, through the cassette, through the second tube, through the inflow port and through the extracorporeal blood heat exchanger.

49. A system according to claim 48 wherein the heat exchange fluid is not exposed to room air or blood while circulating through the system.

50. A system according to claim 48 wherein the pumping apparatus is engageable with a pump drive apparatus so as to circulate the heat exchange fluid through the system without the heat exchange fluid contacting the pump drive apparatus.

51. A system according to claim 50 wherein the pumping apparatus comprises a peristaltic pump tube and the pump drive apparatus comprises a roller or other tube compressing apparatus that causes peristaltic compression of the peristaltic pump tube.

52. A system according to claim 48 further comprising a blood heat exchanger.

53. A system according to claim 52 wherein the blood heat exchanger is part of an extracorporeal system.

54. A system according to claim 53 wherein the extracorporeal system selected from: extracorporeal membrane oxygenation systems; cardiopulmonary bypass systems; extracorporeal blood cleansing systems; extracorporeal blood warming or cooling systems; autotransfusion systems, hemofiltration systems, hemodialysis systems, aphresis systems and plasmapheresis systems.

55. A system according to claim 48 further in combination with a device having a heater or cooler for heating or cooling heat exchange fluid circulating through the cassette.

56. A system according to claim 48 further in combination with a pump drive apparatus for driving the pumping apparatus.

57. A system according claim 48 wherein the cassette comprises one or more temperature, pressure and/or flow sensors for providing feedback

regarding temperature, pressure and/or flow of the heat exchange fluid to a controller coupled to the cassette.

58. A system according to claim 57 wherein the controller controls the operation of the pumping apparatus based on the feedback.

59. A system according to claim 48 further in combination with a heater and/or cooler device which comprises:

a housing having an opening through which the cassette is insertable to an inserted position;

a heater and/or cooler for heating and/or cooling fluid circulating through the cassette when in the inserted position; and,

a pump drive apparatus that engages and drives the pumping apparatus when the cassette is in the inserted position.

60. A system according to claim 59 wherein the heater and/or cooler device is alternately or concurrently useable with a different cassette for circulating heated and/or cooled heat exchange fluid through a heat exchange catheter or body surface heat exchanger.

61. A system according to claim 59 wherein the system is useable for at least thirty days.

62. A system according to claim 61 further in combination with a sterile heat exchange fluid within the system.

63. A system according to claim 61 wherein one or more portions of the system is/are coated with or comprise an antimicrobial or microbiostatic substance to deter microbial growth.

64. A system according to claim 61 wherein tubing of the system is constructed to remain patent for at least thirty days.

65. A cannula for use in a system for extracorporeal blood treatment, said cannula being insertable into a subject's vasculature and useable for either withdrawing blood from the subject's vasculature into the extracorporeal blood treatment system or for returning blood from the extracorporeal blood treatment system into the subject's vasculature, wherein said cannula comprises a heat exchanger which exchanges heat with blood flowing through said cannula and/or through the patient's vasculature.

66. A cannula according to claim 65 wherein the cannula is for use in withdrawing blood from the subject's vasculature into the extracorporeal blood treatment system and wherein the heat exchanger is located on the cannula upstream of a location where blood enters the cannula such that the heat exchanger warms blood being withdrawn through the cannula into the extracorporeal blood treatment system.

67. A system comprising a cannula according to claim 65 in combination with and connected to an extracorporeal blood treatment system.

68. A system according to claim 67 wherein the extracorporeal blood treatment system comprises an extracorporeal membrane oxygenation system and the cannula effects both a) heat exchange with a subject's blood and b) either i) withdrawal of blood from the subject's vasculature into the extracorporeal membrane oxygenation system or ii) return of blood from the extracorporeal membrane oxygenation system into the subject's vasculature.

69. A system according to any of claims 21, 26, 30, 43 and 48 further comprising a sensor positioned to monitor patient temperature or blood temperature and a controller configured to control the patient temperature or blood temperature based on patient temperature or blood temperature feedback from the sensor.

70. A method comprising:

connecting, to patient A, an extracorporeal system having a first heat exchanger which comprises a blood flow path and a heat exchange fluid flow path;

causing blood from patient A to circulate through the extracorporeal system including through the blood flow path of the heat exchanger;

obtaining a heat exchange fluid circulation system A which comprises a container A, a supply conduit A connected to container A, and a return conduit A connected to container A;

connecting supply conduit A and return conduit A to the heat exchange fluid flow path of the heat exchanger, thereby establishing a closed circulation loop A through which heat exchange fluid may circulate from container A, through supply conduit A, through the heat exchange fluid flow path of the heat exchanger, through return conduit A and back into heat exchange fluid container A;

causing heat exchange fluid container A to be positioned in thermal contact with warmable or coolable fluid or surface;

causing blood to circulate from Patient A, though the extracorporeal system, including through the blood flow path of the heat exchanger, and back into the vasculature of patient A;

causing a heat exchange fluid to circulate through closed circulation loop A; and

warming or cooling the warmable or coolable fluid or surface, thereby warming or cooling of the heat exchange fluid as it circulates through heat exchange fluid container A, thereby resulting in exchange of heat in the heat exchanger between the warmed or cooled heat exchange fluid and the blood of patient A.

71. A method according to claim 70 further comprising:

stopping the circulation of heat exchange fluid through closed circulation loop A; and

disconnecting and disposing of heat exchange fluid circulation system A after a single use.

72. A method according to claim 70 wherein the heat exchange fluid circulation system is disposed of as non-hazardous waste.

73. A method according to claim 70 further comprising:

disconnecting and disposing of the heat exchanger after a single use;

74. A method according to claim 73 wherein the heat exchanger is disposed of as hazardous waste.

75. A method according to claim 71 further comprising:

connecting to patient B the extracorporeal system, including a heat exchanger which comprises a blood flow path and a heat exchange fluid flow path;

causing blood from patient B to circulate through the extracorporeal system including through the blood flow path of the heat exchanger;

obtaining a heat exchange fluid circulation system B which comprises a container B, a supply conduit B connected to container B, and a return conduit B connected to Container B;

connecting supply conduit B and return conduit B to the heat exchange fluid flow path of the heat exchanger, thereby establishing a closed circulation loop B through which heat exchange fluid may circulate from container B, through supply conduit B, through the heat exchange fluid flow path of the heat exchanger, through return conduit B and back into heat exchange fluid container B;

causing heat exchange fluid container B to be positioned in thermal contact with warmable or coolable fluid or surface;

causing blood to circulate from Patient B, though the extracorporeal system, including through the blood flow path of the heat exchanger, and back into the vasculature of patient B;

causing a heat exchange fluid to circulate through closed circulation loop B; and

warming or cooling the warmable or coolable fluid or surface, thereby warming or cooling of the heat exchange fluid as it circulates through heat exchange fluid container B, thereby resulting in exchange of heat in the heat exchanger between the warmed or cooled heat exchange fluid and the blood of patient B.

76. A method for warming or cooling a material flowing through a heat exchanger located in a sterile or sanitary area, said method comprising:

obtaining a heat exchange fluid circulation system which comprises a container, a supply conduit connected to the container and a return conduit connected to the container;

connecting the supply conduit and return conduit to a fluid flow path of the heat exchanger thereby establishing a closed circulation loop through which heat exchange fluid may circulate from the container, through the supply conduit, through the heat exchange fluid flow path of the heat exchanger, through return conduit and back into container;

causing a heat exchange fluid to circulate through the closed circulation loop;

causing the container to be positioned in thermal contact with a warmable or coolable fluid or surface; and

warming or cooling the warmable or coolable fluid or surface, thereby warming or cooling the heat exchange fluid as it circulates through the heat exchange fluid container and resulting in exchange of heat in the heat exchanger between the warmed or cooled heat exchange fluid and the material.

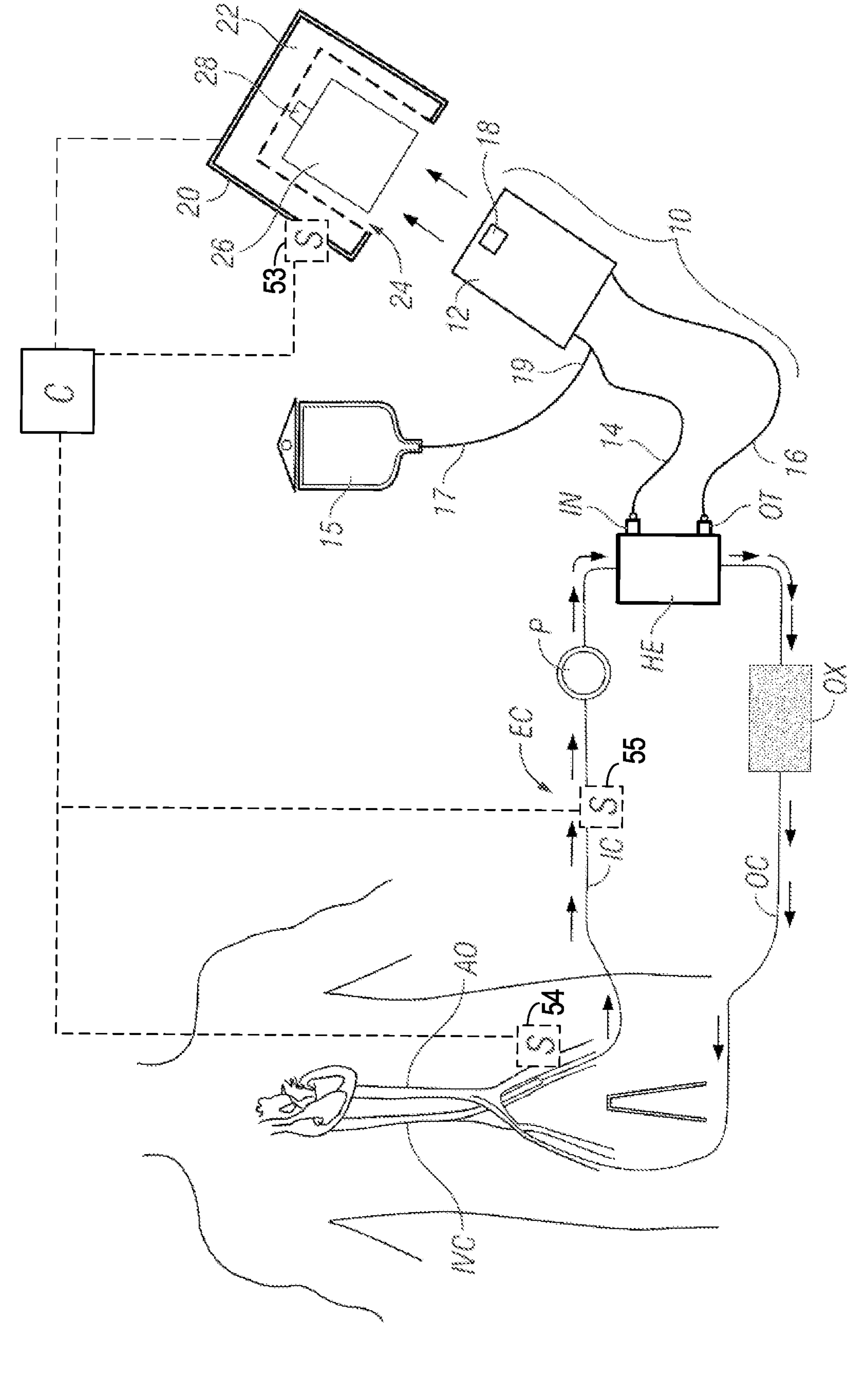

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FIG. 1

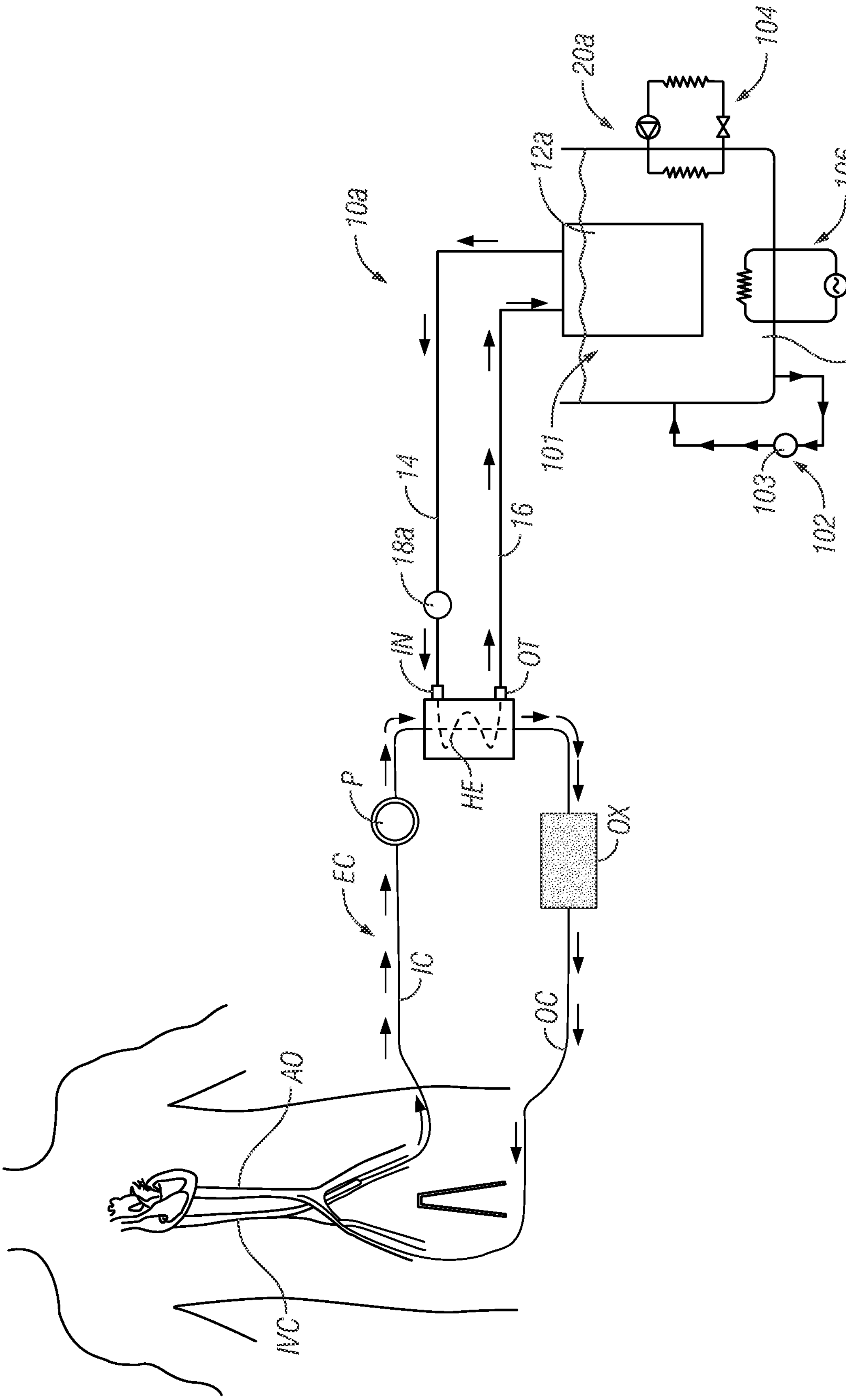
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FIG. 2

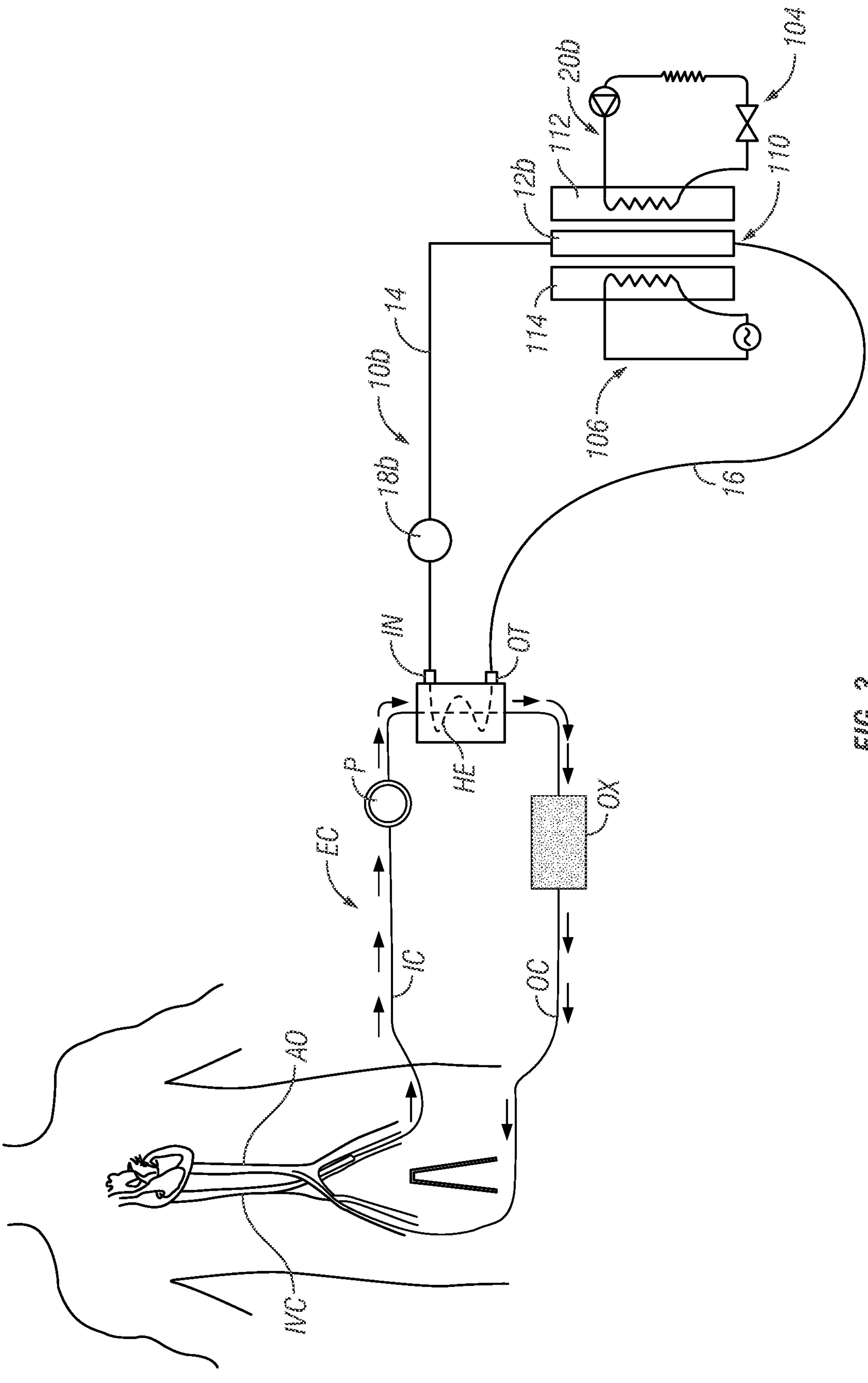
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FIG. 3

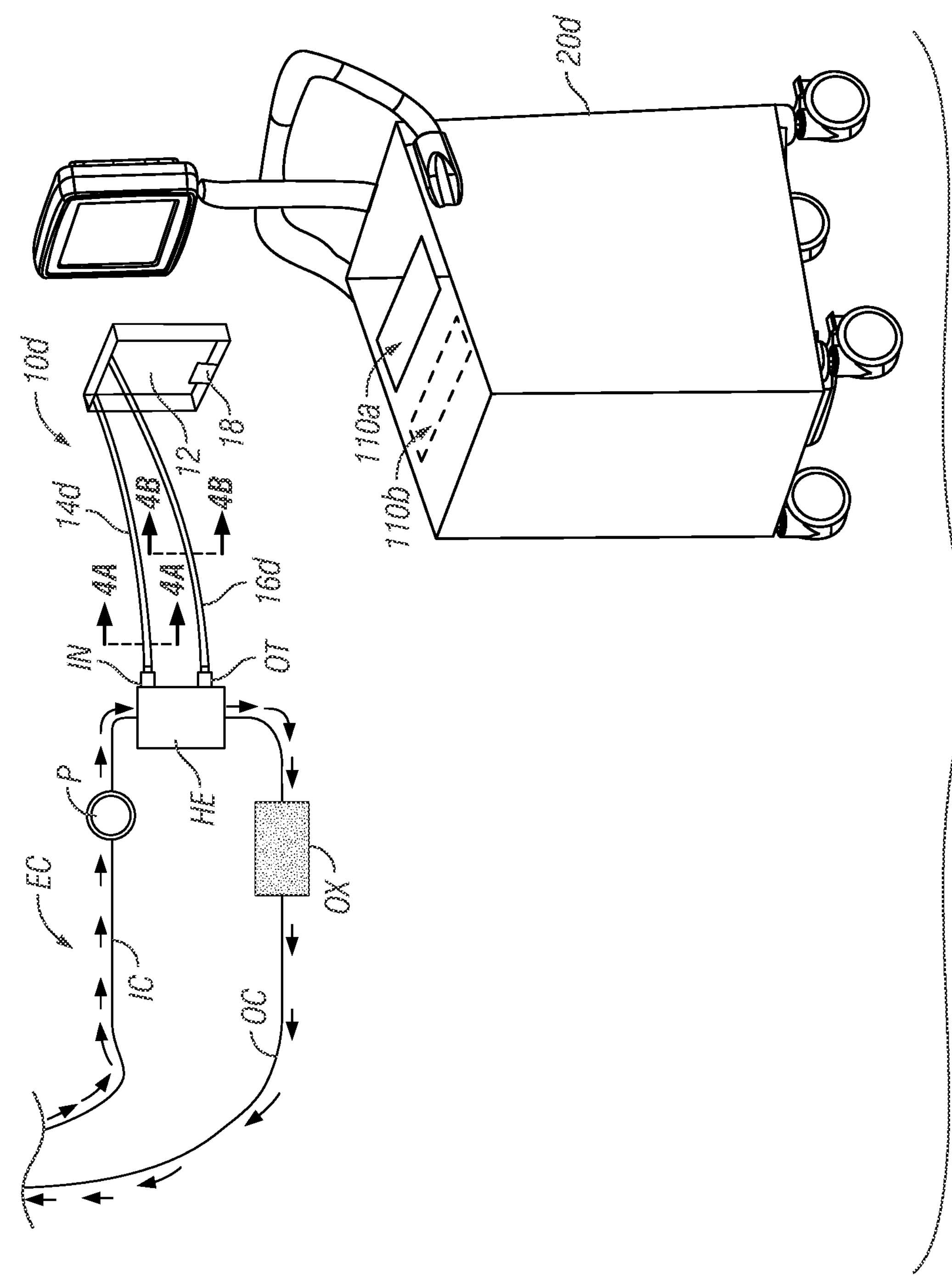



FIG. 4

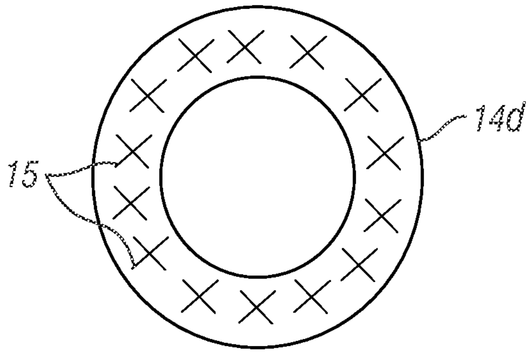



FIG. 4A

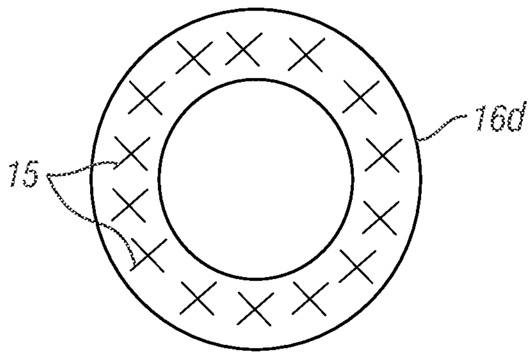



FIG. 4B

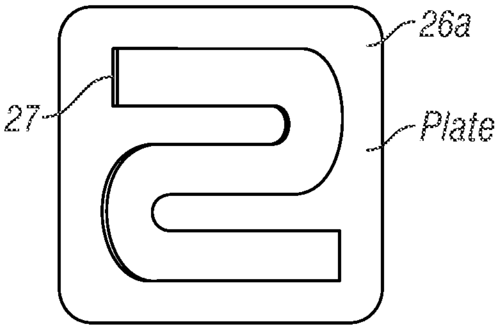



FIG. 4C

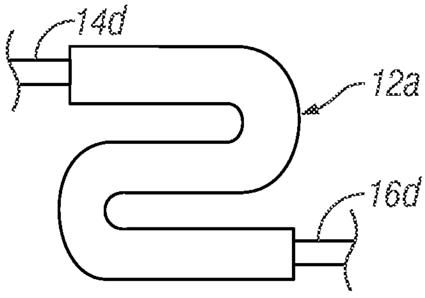
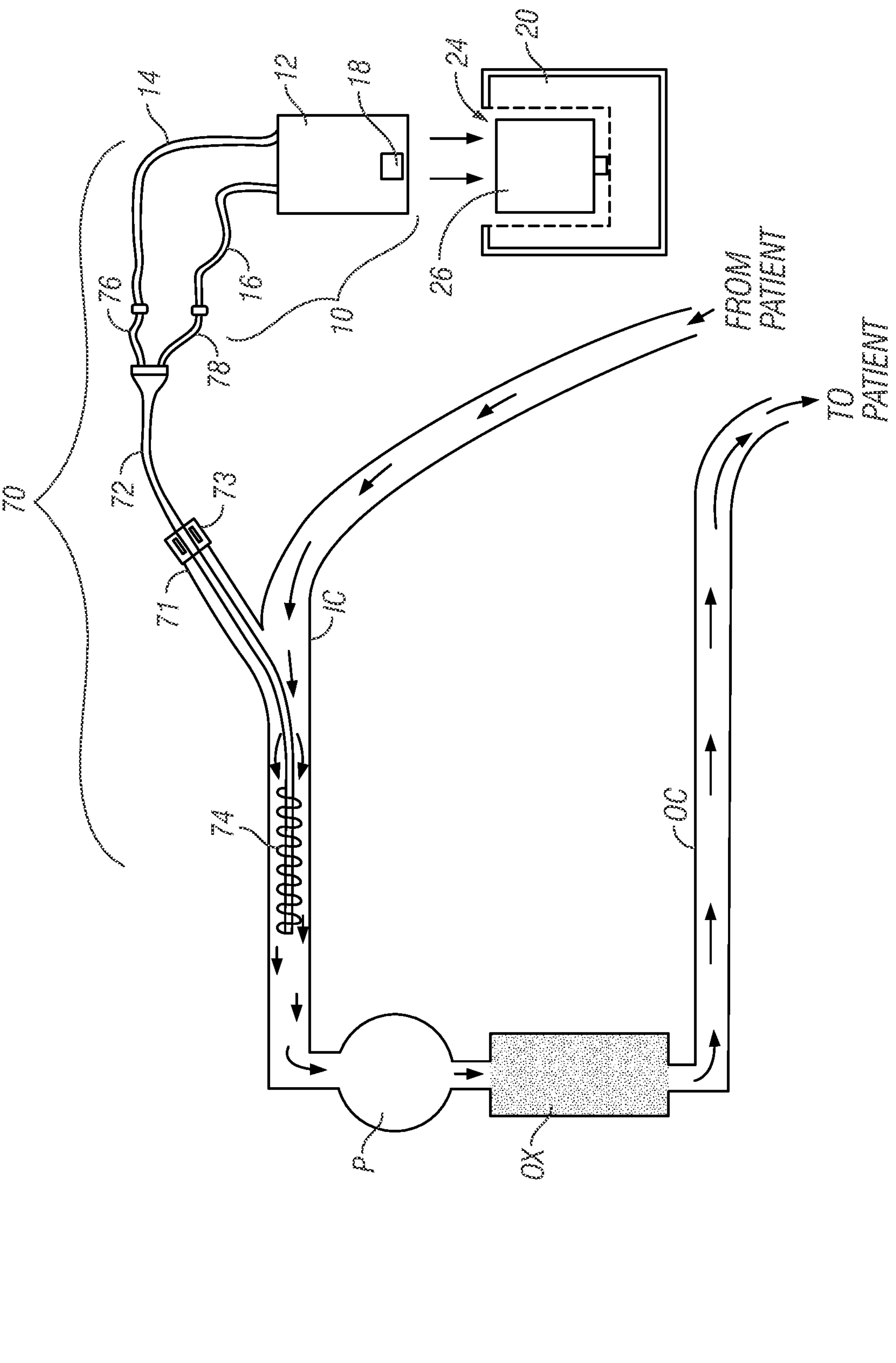



FIG. 4D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FROM PATIENT
TO PATIENT

FIG. 5

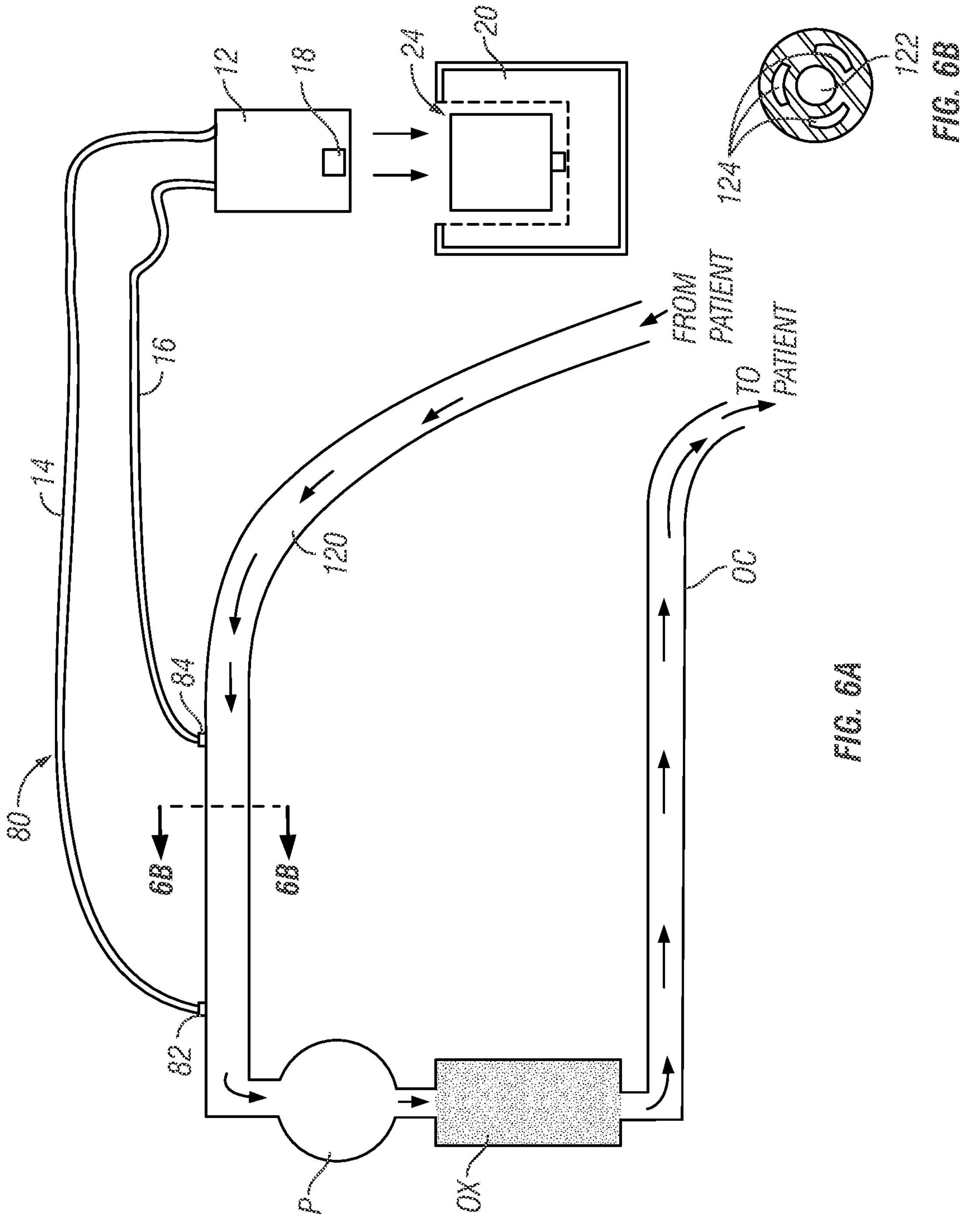
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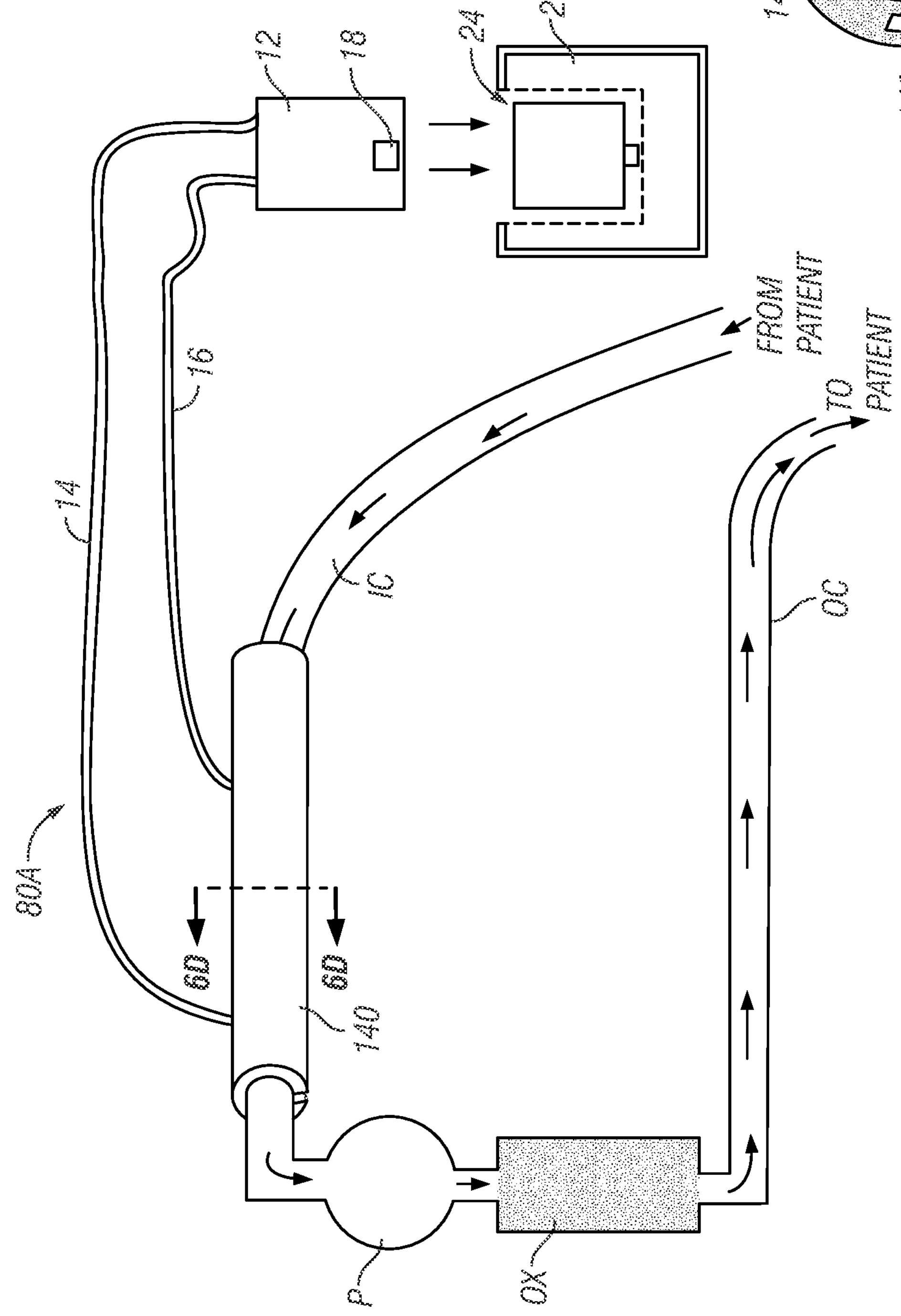
FIG. 6A

FIG. 6B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TO PATIENT
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6D
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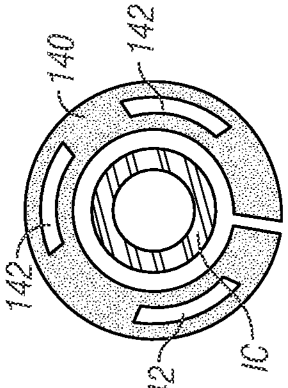
OX

FIG. 6C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IC

FIG. 6D

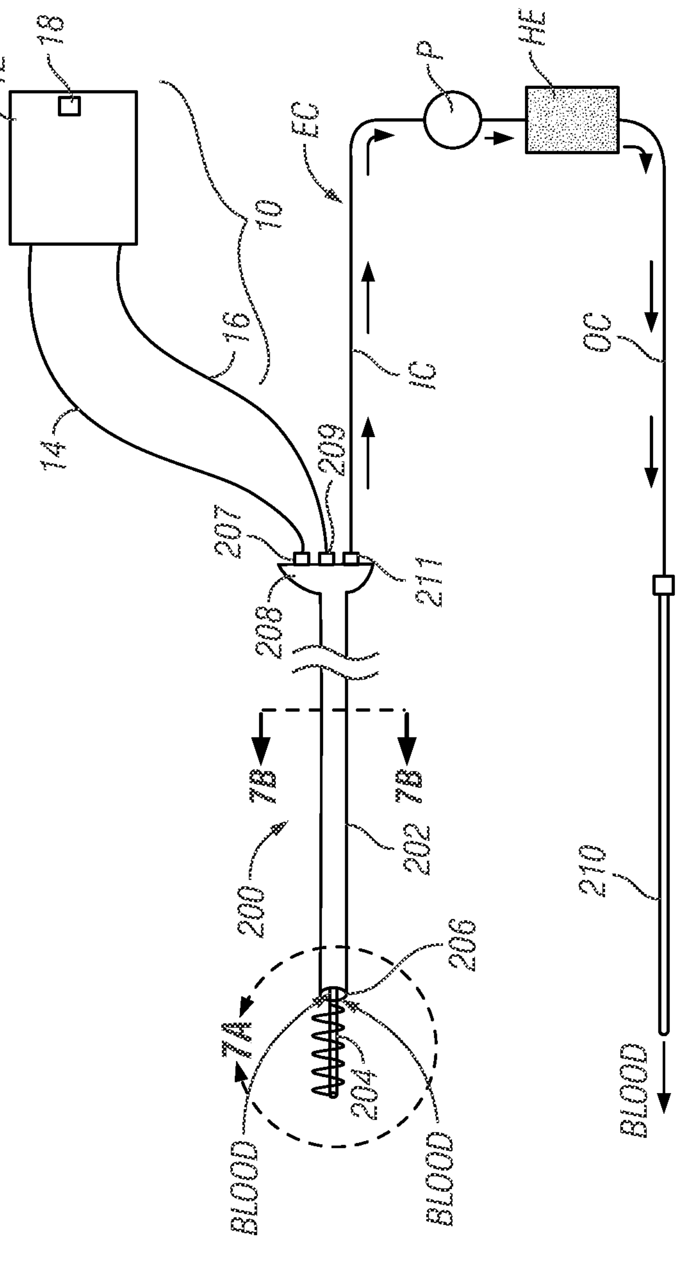


FIG. 7

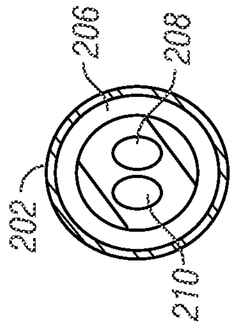


FIG. 7B

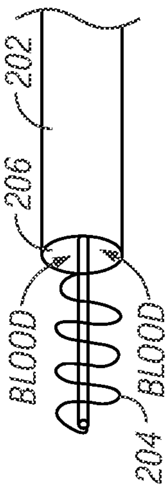


FIG. 7A

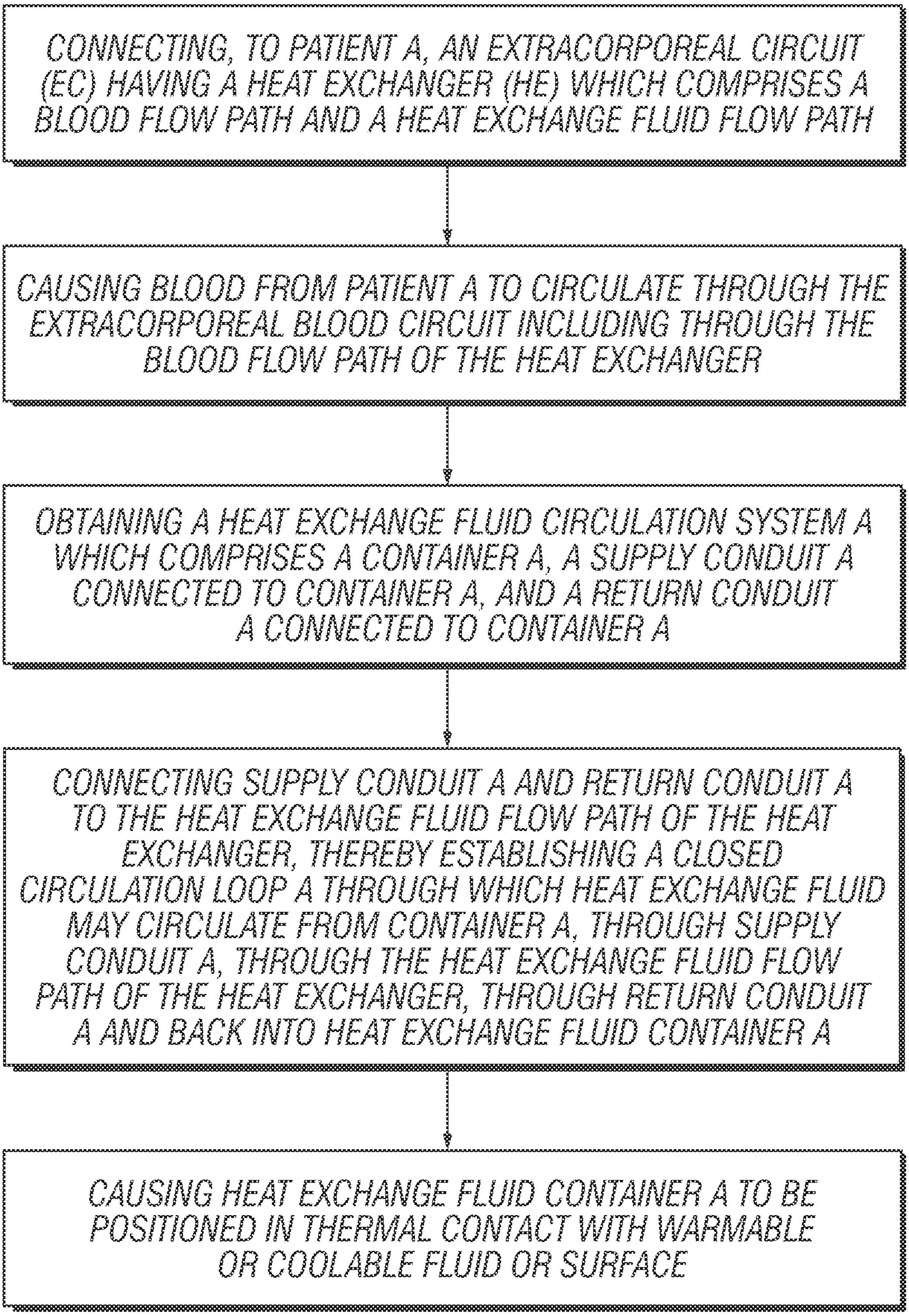
CONNECTING, TO PATIENT A, AN EXTRACORPOREAL CIRCUIT (EC) HAVING A HEAT EXCHANGER (HE) WHICH COMPRISES A BLOOD FLOW PATH AND A HEAT EXCHANGE FLUID FLOW PATH
CAUSING BLOOD FROM PATIENT A TO CIRCULATE THROUGH THE EXTRACORPOREAL BLOOD CIRCUIT INCLUDING THROUGH THE BLOOD FLOW PATH OF THE HEAT EXCHANGER
OBTAINING A HEAT EXCHANGE FLUID CIRCULATION SYSTEM A WHICH COMPRISES A CONTAINER A, A SUPPLY CONDUIT A CONNECTED TO CONTAINER A, AND A RETURN CONDUIT A CONNECTED TO CONTAINER A
CONNECTING SUPPLY CONDUIT A AND RETURN CONDUIT A TO THE HEAT EXCHANGE FLUID FLOW PATH OF THE HEAT EXCHANGER, THEREBY ESTABLISHING A CLOSED CIRCULATION LOOP A THROUGH WHICH HEAT EXCHANGE FLUID MAY CIRCULATE FROM CONTAINER A, THROUGH SUPPLY CONDUIT A, THROUGH THE HEAT EXCHANGE FLUID FLOW PATH OF THE HEAT EXCHANGER, THROUGH RETURN CONDUIT A AND BACK INTO HEAT EXCHANGE FLUID CONTAINER A
CAUSING HEAT EXCHANGE FLUID CONTAINER A TO BE POSITIONED IN THERMAL CONTACT WITH WARMABLE OR COOLABLE FLUID OR SURFACE

FIG. 8

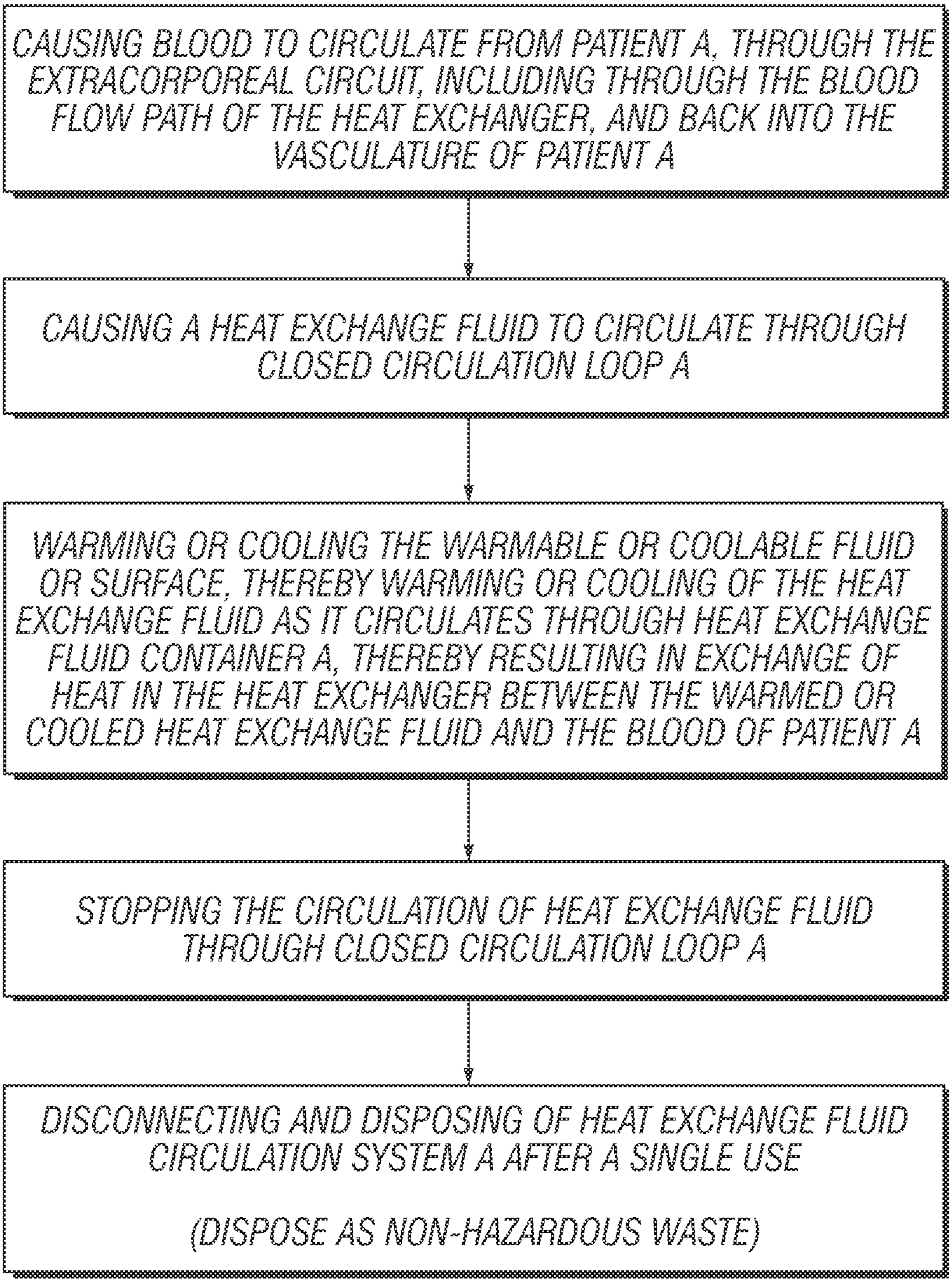
CAUSING BLOOD TO CIRCULATE FROM PATIENT A, THROUGH THE EXTRACORPOREAL CIRCUIT, INCLUDING THROUGH THE BLOOD FLOW PATH OF THE HEAT EXCHANGER, AND BACK INTO THE VASCULATURE OF PATIENT A
CAUSING A HEAT EXCHANGE FLUID TO CIRCULATE THROUGH CLOSED CIRCULATION LOOP A
WARMING OR COOLING THE WARMABLE OR COOLABLE FLUID OR SURFACE, THEREBY WARMING OR COOLING OF THE HEAT EXCHANGE FLUID AS IT CIRCULATES THROUGH HEAT EXCHANGE FLUID CONTAINER A, THEREBY RESULTING IN EXCHANGE OF HEAT IN THE HEAT EXCHANGER BETWEEN THE WARMED OR COOLED HEAT EXCHANGE FLUID AND THE BLOOD OF PATIENT A
STOPPING THE CIRCULATION OF HEAT EXCHANGE FLUID THROUGH CLOSED CIRCULATION LOOP A
DISCONNECTING AND DISPOSING OF HEAT EXCHANGE FLUID CIRCULATION SYSTEM A AFTER A SINGLE USE
(DISPOSE AS NON-HAZARDOUS WASTE)

FIG. 8
(Cont'd)

CONNECTING TO PATIENT B THE EXTRACORPOREAL SYSTEM, INCLUDING A HEAT EXCHANGER WHICH COMPRISES A BLOOD FLOW PATH AND A HEAT EXCHANGE FLUID FLOW PATH

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CAUSING BLOOD FROM PATIENT B TO CIRCULATE THROUGH THE EXTRACORPOREAL SYSTEM INCLUDING THROUGH THE BLOOD FLOW PATH OF THE HEAT EXCHANGER

↓

OBTAINING A HEAT EXCHANGE FLUID CIRCULATION SYSTEM B WHICH COMPRISES A CONTAINER B, A SUPPLY CONDUIT B CONNECTED TO CONTAINER B, AND A RETURN CONDUIT B CONNECTED TO CONTAINER B

↓

CONNECTING SUPPLY CONDUIT B AND RETURN CONDUIT B TO THE HEAT EXCHANGE FLUID FLOW PATH OF THE HEAT EXCHANGER, THEREBY ESTABLISHING A CLOSED CIRCULATION LOOP B THROUGH WHICH HEAT EXCHANGE FLUID MAY CIRCULATE FROM CONTAINER B, THROUGH SUPPLY CONDUIT B, THROUGH THE HEAT EXCHANGE FLUID FLOW PATH OF THE HEAT EXCHANGER, THROUGH RETURN CONDUIT B AND BACK INTO HEAT EXCHANGE FLUID CONTAINER B

FIG. 8
(Cont'd)

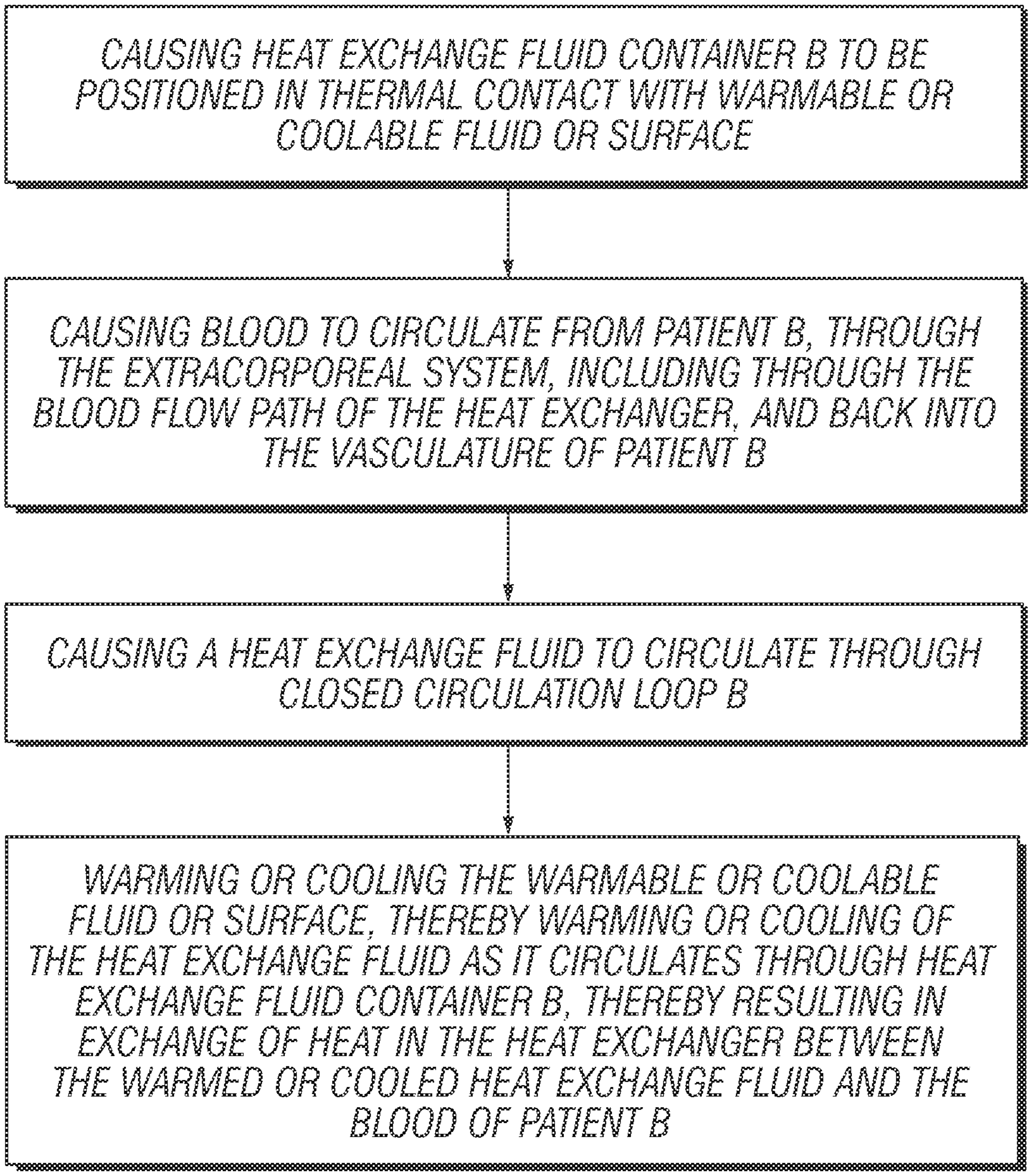
CAUSING HEAT EXCHANGE FLUID CONTAINER B TO BE POSITIONED IN THERMAL CONTACT WITH WARMABLE OR COOLABLE FLUID OR SURFACE
CAUSING BLOOD TO CIRCULATE FROM PATIENT B, THROUGH THE EXTRACORPOREAL SYSTEM, INCLUDING THROUGH THE BLOOD FLOW PATH OF THE HEAT EXCHANGER, AND BACK INTO THE VASCULATURE OF PATIENT B
CAUSING A HEAT EXCHANGE FLUID TO CIRCULATE THROUGH CLOSED CIRCULATION LOOP B
WARMING OR COOLING THE WARMABLE OR COOLABLE FLUID OR SURFACE, THEREBY WARMING OR COOLING OF THE HEAT EXCHANGE FLUID AS IT CIRCULATES THROUGH HEAT EXCHANGE FLUID CONTAINER B, THEREBY RESULTING IN EXCHANGE OF HEAT IN THE HEAT EXCHANGER BETWEEN THE WARMED OR COOLED HEAT EXCHANGE FLUID AND THE BLOOD OF PATIENT B

FIG. 8
(Cont'd)