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(71) Applicant: **ZOLL CIRCULATION, INC.** [US/US]; 2000 Ringwood Avenue, San Jose, California 95131 (US).

(72) Inventors: **MYRICK, Stephen**; 2000 Ringwood Avenue, San Jose, California 95131 (US). **CREECH, Jeffrey**; 2000 Ringwood Avenue, San Jose, California 95131 (US). **DABROWIAK, Jeremy**; 2000 Ringwood Avenue, San Jose, California 95131 (US). **BUCKLEY, John**; 2000 Ringwood Avenue, San Jose, California 95131 (US).

Ringwood Avenue, San Jose, California 95131 (US). **MAFI, Masoumeh**; 2000 Ringwood Avenue, San Jose, California 95131 (US).

(74) Agent: **WONG, Richard** et al.; Fish & Richardson P.C., P.O. Box 1022, Minneapolis, Minnesota 55440-1022 (US).

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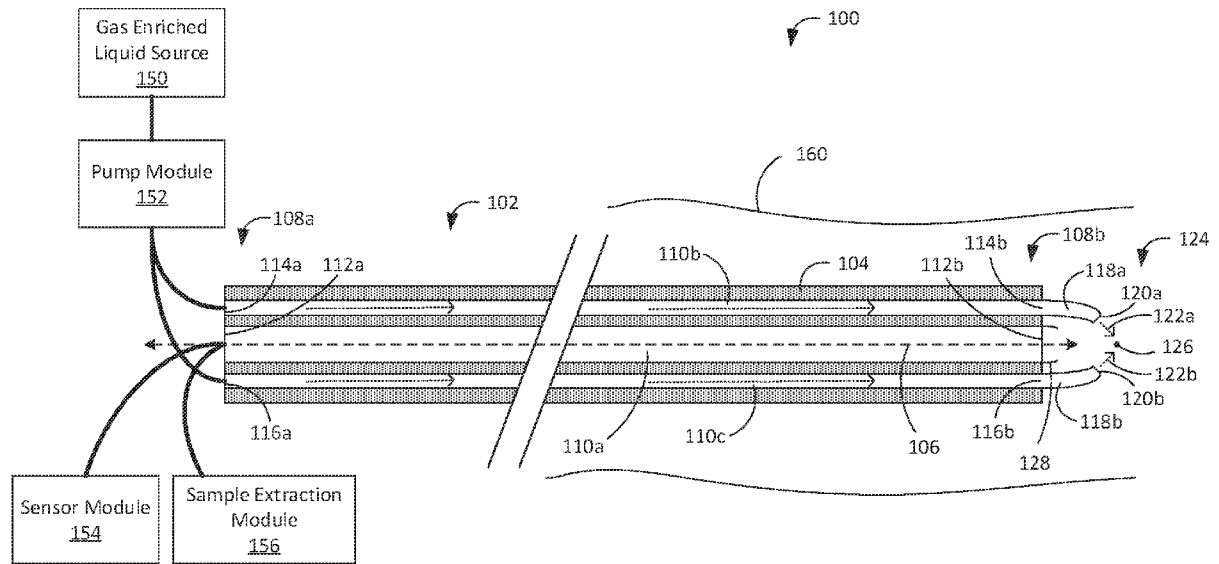


FIG. 1A

(57) Abstract: A catheter includes a catheter body, a first lumen extending through the catheter body, one or more second lumens extending through the catheter body, and two or more capillaries extending from the catheter body and coupled to the second lumens. The first lumen performs at least one of receiving a sample of the blood from a vasculature of the patient or measuring a parameter of the blood. The second lumens receive a gas enriched liquid from a gas enriched liquid source. The capillaries receive the gas enriched liquid from the one or more second lumens and to simultaneously dispense respective streams of the gas enriched liquid directly into the vasculature, such that the streams of the gas enriched liquid intersect and mix with the blood in a region beyond an end of the catheter body and beyond the first lumen.



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CATHETERS AND SYSTEMS FOR DIRECT INJECTION OF GAS-ENRICHED LIQUID INTO A PATIENT

CLAIM OF PRIORITY

[0001] This application claims priority under 35 U.S.C. §119(e) to U.S. provisional patent application serial no. 63/151,422, filed on February 19, 2021, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The disclosure relates to catheters and systems for injection of gas-enriched liquid into a patient.

BACKGROUND

[0003] Gas-enriched liquids are desirable in a wide variety of applications. However, at ambient pressure, the relatively low solubility of many gases, such as oxygen or nitrogen, within a liquid, such as water, produces a relatively low concentration of the dissolved gas in the liquid. One method of obtaining an increase in the gas concentration level without significant increase in liquid volume involves an injection and mixing of a gas-enriched liquid, such as a gas-supersaturated liquid, into a liquid of interest. A liquid can be gas enriched at high pressure.

[0004] Conventional methods for the delivery of oxygenated blood or oxygen-enriched liquids to tissues and bodily liquids involve the use of extracorporeal circuits for blood oxygenation. Extracorporeal circuits require withdrawing blood from a patient, circulating the blood through an oxygenator to increase blood oxygen concentration, and then delivering the blood back to the patient.

SUMMARY

[0005] In an aspect, a catheter is configured to be inserted into a vasculature of a patient. The catheter includes an elongated catheter body, a first lumen extending through the catheter body, one or more second lumens extending through the catheter body, and two or more capillaries extending from the catheter body and coupled to the one or more second

lumens. The first lumen may be configured to be in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient, and the first lumen may be configured to perform at least one of receiving a sample of the patient's blood from the vasculature of the patient or measuring a parameter of the patient's blood. The one or more second lumens may be configured to receive a gas enriched liquid from a gas enriched liquid source. Each of the two or more capillaries are in fluid communication with the one or more second lumens and are configured to be in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient. Each of the two or more capillaries may be configured to receive the gas enriched liquid from the one or more second lumens and may be configured to simultaneously dispense respective streams of the gas enriched liquid directly into the vasculature of the patient.

[0006] The catheter body may be configured to position the two or more capillaries at one or more predetermined angles relative to one another, such that the streams of the gas enriched liquid intersect and mix with the patient's blood in a region beyond an end of the catheter body and beyond the first lumen. The first lumen may be recessed relative to respective output ends of the two or more capillaries. The first lumen may be recessed in a longitudinal or axial direction of the catheter body relative to respective output ends of the two or more capillaries. A capillary may also be referred to as a capillary tube, or just a tube. The first lumen may co-extend with the one or more second lumens. The first lumen may be in fluid isolation from the one or more second lumens within the body of the catheter.

[0007] Implementations of this aspect can include one or more of the following features.

[0008] In some implementations, the gas enriched liquid can be a supersaturated oxygen enriched liquid.

[0009] In some implementations, the first lumen can be configured to receive a guide wire for positioning the catheter with respect to the vasculature of the patient.

[0010] In some implementations, the catheter can further include a pressure sensor disposed within the first lumen. The pressure sensor can be configured to obtain one or more pressure measurements.

[0011] In some implementations, the parameter of the patient's blood can be at least one of a partial pressure of oxygen of the patient's blood, SO_2 of the patient's blood, a pressure of the patient's blood, a flow rate of the of the patient's blood, or a temperature of the of the patient's blood.

[0012] In some implementations, the first lumen can have a diameter ranging from 0.020 inches (about 0.5 mm) to 0.045 inches (about 1.1 mm).

[0013] In some implementations, the catheter can include a third lumen extending through the catheter body. The third lumen can be configured to be in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient. The third lumen can be configured to perform at least one of: receiving an additional sample of the patient's blood from the vasculature of the patient and measuring an additional parameter of the patient's blood.

[0014] In some implementations, the catheter body can be configured to position the two or more capillaries such that the streams of the gas enriched liquid intersect a longitudinal axis extending through a center of the catheter.

[0015] The catheter body can be configured to position the two or more capillaries. The two or more capillaries may be configured such that the streams of the gas enriched liquid intersect.

[0016] In some implementations, the catheter body can be configured to position the two or more capillaries such that the streams of the gas enriched liquid do not intersect a longitudinal axis extending through a center of the catheter.

[0017] In some implementations, the catheter can further include one or more shields or guards positioned over a distal opening of the first lumen and configured to reduce nucleation along one or more surfaces of the catheter.

[0018] In some implementations, at least one of the predetermined angles can range from 10 to 80 degrees.

[0019] In some implementations, a diameter of at least one of the two or more capillaries and a diameter of at least another one of the two or more capillaries can be equal.

[0020] In some implementations, a diameter of at least one of the two or more capillaries can be different from a diameter of at least another one of the two or more capillaries.

[0021] In some implementations, at least one of the two or more capillaries can have an inner diameter that ranges from 40 microns to 100 microns.

[0022] In some implementations, at least one of the two or more capillaries can have an outer diameter that ranges from 140 microns to 400 microns.

[0023] In some implementations, the two or more capillaries can include one or more elongated tubes extending from the catheter body.

[0024] In some implementations, a distance between (i) an intersection of the streams of the gas enriched liquid and (ii) an end tip of the catheter or an output aperture of the first lumen can be greater than or equal to a diameter of the end tip of the catheter.

[0025] In some implementations, a distance between (i) the output ends of the two or more capillaries and (ii) an end tip of the catheter or an output aperture of the first lumen can be greater than or equal to a diameter of the end tip of the catheter.

[0026] In some implementations, the at least one capillary can include a fiducial marking.

[0027] In some implementations, the streams of the gas enriched liquid can intersect and mix with the patient's blood without the formation of bubbles.

[0028] In some implementations, the streams of the gas enriched liquid can intersect and mix with the patient's blood in a region beyond an end of the catheter body and beyond the first lumen to reduce bubble nucleation along one or more surfaces of the catheter or capillaries.

[0029] In some implementations, the catheter can further include one or more sensors. The one or more sensors can be configured such that the one or more sensors are in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient.

[0030] In some implementations, at least one of the one or more sensors can be an oxygen partial pressure (pO_2) sensor.

[0031] In some implementations, the catheter can further include a self-centering device configured to center the catheter body within the vasculature of the patient.

[0032] In some implementations, the self-centering device can include one or more mesh structures encircling the catheter body.

[0033] In another aspect, a system can include a catheter as described herein, and a fluid dispensing device in fluid communication with the one or more second lumens. The fluid

dispensing device can include one or more pumps configured to provide the gas enriched liquid to the one or more second lumens.

[0034] Implementations of this aspect can include one or more of the following features.

[0035] In some implementations, the system can include one or more connectors configured to couple the one or more second lumens to one or more respective dispensing ports of the fluid dispensing device.

[0036] In some implementations, at least one of the one or more connectors can be a high pressure Luer fitting.

[0037] In some implementations, the gas-enriched liquid can include one or more of oxygen, ozone, inert gas, nitrogen, nitrous oxide, carbon dioxide, or air.

[0038] In some implementations, the gas-enriched liquid can include a dissolved oxygen (O₂) concentration that ranges from 0.2 and 3 ml O₂/ml solvent.

[0039] In some implementations, the gas-enriched liquid can include a dissolved oxygen (O₂) concentration of 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP).

[0040] In another aspect, a system includes a catheter as described herein, and a blood sampling device in fluid communication with the first lumen. The blood sampling device can be configured to withdraw the sample of the patient's blood from the vasculature of the patient through the first lumen.

[0041] Implementations of this aspect can include one or more of the following features.

[0042] In some implementations, the two or more capillaries can be coated with a hydrophilic coating.

[0043] As another aspect, a catheter is configured to be inserted into a vasculature of a patient. The catheter includes an elongated catheter body having a coiled shape, a first lumen extending through the catheter body, where the first lumen is configured to receive a gas enriched liquid, and a plurality of apertures positioned along a length of the catheter body. The plurality of apertures are in fluid communication with the first lumen. The apertures are configured to dispense the gas enriched liquid directly into the vasculature of the patient.

[0044] Implementations of this aspect can include one or more of the following features.

[0045] In some implementations, the gas enriched liquid can be a supersaturated oxygen enriched liquid.

[0046] In some implementations, the catheter can include one or more periodically repeating curved sections.

[0047] In some implementations, a length of each of the periodically repeating curved sections can vary.

[0048] In some implementations, the catheter body can have an inner diameter that ranges from 0.020 inches (about 0.5 mm) to 0.045 inches (about 1.1 mm).

[0049] In some implementations, the catheter body can have an outer diameter that ranges from 4 F to 12 F (about 1.33 mm to 4 mm).

[0050] In some implementations, the catheter can be at least partially composed of a shape-memory material.

[0051] In some implementations, one or more surfaces of the catheter can be composed of at least one of polycarbonate, glass, ceramic, stainless steel, polyether ether ketone (PEEK), or polyimide.

[0052] In some implementations, the catheter body can extend along an axial direction. At least some of the apertures can face one or more radial directions orthogonal to the axial direction.

[0053] In some implementations, each of the apertures can be positioned at a different respective radial position about the catheter body.

[0054] In some implementations, the catheter body can extend along an axial direction. Each of the apertures can face one or more radial directions orthogonal to the axial direction.

[0055] In some implementations, each of the apertures can have a diameter that ranges from 40 microns to 100 microns.

[0056] In some implementations, each of the apertures can have a circular shape.

[0057] In some implementations, the catheter body can extend along a helical path.

[0058] In some implementations, the catheter body can extend along a spiral path having a variable diameter.

[0059] In some implementations, adjacent apertures can be offset from one another along the catheter body by a distance that ranges from 1 cm to 5 cm.

[0060] In some implementations, the catheter body can be configured to receive a guiding rod.

[0061] In some implementations, the catheter body can be configured such that, when the guiding rod is inserted into the catheter body, a curvature of at least a portion of the catheter body is reduced.

[0062] In some implementations, the catheter can further include one or more elongated tubes extending from the catheter body. The one or more elongated tubes can include one or more second lumens in fluid communication with the apertures. The one or more elongated tubes can be configured to receive the gas enriched liquid from the apertures and to dispense the gas enriched liquid directly into the vasculature of the patient.

[0063] In some implementations, at least one of the one or more elongated tubes can branch into one or more respective portions, each defining a respective third lumen in fluid communication with the first lumen.

[0064] In some implementations, the gas-enriched liquid can include one or more of oxygen, ozone, inert gas, nitrogen, nitrous oxide, carbon dioxide, or air.

[0065] In some implementations, the gas-enriched liquid can include a dissolved oxygen (O₂) concentration that ranges from 0.2 to 3 ml O₂/ml solvent.

[0066] In some implementations, the gas-enriched liquid can include a dissolved oxygen (O₂) concentration of 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP).

[0067]

[0068] In another aspect, a system includes a catheter as described herein, and a fluid dispensing device in fluid communication with the first lumen. The fluid dispensing device includes one or more pumps configured to provide the gas enriched liquid to the first lumen.

[0069] Implementations of this aspect can include one or more of the following features.

[0070] In some implementations, the catheter can include a connector configured to couple the first lumen to a dispensing port of the fluid dispensing device.

[0071] In some implementations, the connector can be a Luer fitting.

[0072] In another aspect, a catheter is configured to be inserted into a vasculature of a patient. The catheter includes an elongated catheter body, a first lumen extending through the catheter body, where the first lumen is configured to receive a gas enriched liquid, and a plurality of elongated tubes extending along the catheter body. Adjacent elongated tubes can be offset from one another along the catheter body. Each of the elongated tubes includes a respective second lumen in fluid communication with the first lumen. The

elongate tubes are configured to receive the gas enriched liquid from the first lumen and dispense the gas enriched liquid directly into the vasculature of the patient.

[0073] Implementations of this aspect can include one or more of the following features.

[0074] In some implementations, the gas enriched liquid can be a supersaturated oxygen enriched liquid.

[0075] In some implementations, at least one of the elongated tubes can branch into one or more respective portions.

[0076] In some implementations, each of the portions can be in fluid communication with the first lumen.

[0077] In some implementations, each of the portions can include a respective output end. Each of the output ends can be positioned at a different respective radial position about the catheter body.

[0078] In some implementations, the catheter body can have an inner diameter that ranges from 0.020 inches (about 0.5 mm) to 0.045 inches (about 1.1 mm).

[0079] In some implementations, the catheter body can have an outer diameter that ranges from 4 F to 12 F (about 1.33 mm to 4 mm).

[0080] In some implementations, at least one of the elongated tubes can have an inner diameter that ranges from 40 microns to 100 microns.

[0081] In some implementations, at least one of the elongated tubes can have an outer diameter that ranges from 140 microns to 400 microns.

[0082] In some implementations, at least one of the elongated tubes can have a circular cross-section.

[0083] In some implementations, the adjacent elongated tubes can vary in length from one another by a length that ranges from 1 cm to 5 cm.

[0084] In some implementations, the adjacent elongated tubes can be offset from one another along the catheter body by a distance that ranges from 1 cm to 5 cm.

[0085] In some implementations, the gas-enriched liquid can include one or more of oxygen, ozone, inert gas, nitrogen, nitrous oxide, carbon dioxide, or air.

[0086] In some implementations, the gas-enriched liquid can include a dissolved oxygen (O_2) concentration that ranges from 0.2 to 3 ml O_2 /ml solvent.

[0087] In some implementations, the gas-enriched liquid can include a dissolved oxygen (O₂) concentration of 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP).

[0088] In some implementations, the at least one capillary can include a fiducial marking.

[0089] In some implementations, the catheter can be sufficiently flexible to be guided through a catheter delivery system.

[0090] In another aspect, a system includes a catheter as described above, and a fluid dispensing device in fluid communication with the first lumen. The fluid dispensing device can include one or more pumps configured to provide the gas enriched liquid to the first lumen.

[0091] In some implementations, the catheter can include a connector configured to couple the first lumen to a dispensing port of the fluid dispensing device.

[0092] In some implementations, the connector can be a Luer fitting.

[0093] In general, an implementation described with respect to one aspect may be provided in combination with another aspect. The details of one or more embodiments are set forth in the accompanying drawings and the description. Other features and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0094] FIGS. 1A and 1B are diagrams of an example system for enriching a bodily liquid with a gas-enriched liquid inside of an enclosed area of a body.

[0095] FIGS. 2A and 2B are diagrams of an example catheter.

[0096] FIGS. 3A and 3B are diagrams of another example catheter.

[0097] FIGS. 4A and 4B are diagrams of another example catheter.

[0098] FIG. 5A is a diagram of an example catheter including an inflatable balloon structure.

[0099] FIG. 5B is a diagram of an example catheter including an expandable mesh structure.

[0100] FIGS. 6A-6C are diagrams showing example configurations of the capillaries of a catheter.

[0101] FIGS. 7A-7C are diagrams of another example system for enriching a bodily liquid with a gas-enriched liquid inside of an enclosed area of a body.

[00102] FIGS. 8A and 8B are diagrams showing an insertion of a guiding rod into an example catheter.

[00103] FIG. 9A is a diagram of an example catheter having tubular branching structures.

[00104] FIG. 9B is a diagram of an example catheter having tubular structures.

DETAILED DESCRIPTION

[00105] FIG. 1A shows an example system 100 for enriching a bodily liquid with a dissolved gas or gas enriched liquid inside of an enclosed area of a body. As an example, the system 100 can be used to enrich a patient's blood with supersaturated oxygen enriched liquid or supersaturated liquid within the vasculature of the patient thereby delivering supersaturated oxygen (SSO₂) therapy to a patient, increasing oxygen in the blood and diffusion of oxygen into tissue. In certain implementations, oxygen enriched liquid or solution, e.g., supersaturated oxygen enriched liquid or solution, may include liquid having a dissolved O₂ concentration of 0.1 ml O₂/ml liquid (STP) or greater or 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP) (e.g., without clinically significant gas emboli).

[00106] As shown in FIG. 1A, the system 100 includes a catheter 102, a gas enriched liquid source 150, a pump 152, a sensor 154, and a sample extraction device 156. The catheter 102 is configured to be inserted into the vasculature of a patient, to facilitate the delivery of a gas enriched liquid (e.g., from the gas enriched liquid source 150) into the vasculature of the patient via the pump 152. Further, the catheter 102 is configured to facilitate the measurement of one or more properties of the patient's blood within the patient's vasculature (e.g., by providing the sensor 154 access to the patient's vasculature) and/or to facilitate the collection of blood samples from the patient's vasculature (e.g., by providing the sample extraction device 156 access to the patient's vasculature). For example, the sensor 154 may be positioned on the distal (or first) end 108a of the catheter 102 or in a communicating lumen of the catheter 102. The sensor 154 can detect various blood parameters (e.g., partial pressure of oxygen in the patient's blood (pO₂), the oxygen saturation of the patient's blood (SO₂), the flow rate of the patient's blood, a temperature of the patient's blood), during treatment or after treatment is paused or completed.

[00107] The catheter 102 includes an elongated catheter body 104 (e.g., extending along a longitudinal axis 106 through the center of the catheter body 104) having a proximal (or second) end 108b opposing the distal end 108a. In some implementations, the catheter can have a circular, elliptical, or ovular cross-section along a portion of or an entirety of its length. In some implementations, the catheter body 104 can be flexible (e.g., such that it can be bent or curved at one or more locations along its length). In some implementations, at least a portion of the catheter 102 and/or the catheter body 104 can be composed of polycarbonate, glass, ceramic, stainless steel, polyether ether ketone (PEEK), polyether block amide (PEBA) (e.g., PEBAX produced by Akrema S.A., Colombes, France), acrylonitrile butadiene styrene (ABS), polyimide, and/or other suitable materials. In some implementations, the catheter body 104 can have an outer diameter ranging from 4 F to 12 F, or for example, 4 F to 6 F (according to the French scale - about 1.33 mm to 4 mm or about 1.33 mm to 2 mm).

[00108] Further, the catheter 102 includes multiple lumens extending through the catheter body 104. In this example, the catheter 102 includes one or more communicating lumens 110a extending through a center of the catheter body 104 (e.g., along the longitudinal axis 106). At least two additional lumens 110b and 110c may extend through opposing sides of the catheter body 104 (e.g., parallel to the communicating lumen 110a). Each of the lumens 110a-110c can have a circular, elliptical, or ovular cross-section along a portion of or an entirety of its length. In some implementations, the communicating lumen 110a can have an inner diameter ranging from 0.020 inches to 0.045 inches (about 0.5 mm to about 1.1 mm).

[00109] Each of the lumens 110a-110c includes a respective input aperture and a respective output aperture. For example, the communicating lumen 110a includes an input aperture 112a on the first (or distal) end 108a of the catheter body 104 and an output aperture 112b on the second (or proximal) end 108b of the catheter body 104. As another example, the lumen 110b includes an input aperture 114a on the first end 108a of the catheter body 104 and an output aperture 114b on the second end 108b of the catheter body 104. As another example, the lumen 110c includes an input aperture 116a on the first end 108a of the catheter body 104 and an output aperture 116b on the second end 108b of the catheter body 104.

[00110] Further, the catheter 102 includes a capillary 118a extending from and in fluid communication with the output aperture 114b of the lumen 110b (e.g., such that fluid can flow from the lumen 110b into the capillary 118a. The capillary 118a terminates at an output aperture 120a. In some implementations, the capillary 118a can have an inner diameter between 40 microns and 100 microns. In some implementations, the capillary 118a can have an outer diameter between 140 microns and 160 microns. In some implementations, the capillary 118a can have a length ranging from 5 cm to 10 cm or be a length “l” which is substantially equal to the diameter of the catheter tip or distal end.

[00111] The catheter 102 also includes a capillary 118b extending from and in fluid communication with the output aperture 116b of the lumen 110c (e.g., such that fluid can flow from the lumen 110c into the capillary 118b. The capillary 118b terminates at an output aperture 120b. In some implementations, the capillary 118b can have an inner diameter from 40 microns to 100 microns. In some implementations, the capillary 118b can have an outer diameter from 140 microns to 400 microns. In some implementations, the capillary 118b can have a length ranging from 5 cm to 10 cm or be a length “l” which is substantially equal to the diameter of the catheter tip or distal end.

[00112] In some implementations, the capillaries 118a and 118b may have identical or different sized inner and/or outer diameters. In some implementations, the capillaries 118a and 118b may have identical or different sized lengths.

[00113] During an example usage of the system 100, the gas enriched liquid source 150 and the pump 152 are coupled to the catheter 102, such that the gas enriched liquid source 150 and the pump 152 are in fluid communication with the input apertures 114a and 116a of the lumens 110b and 110c, respectively. As an example, one or more fluid-tight tubes can be used to convey gas enriched liquid from the gas enriched liquid source 150 to the pump 152, and from the pump 152 to the input apertures 114a and 116b. In some implementations, one or more fluid-tight tubes can be used to convey gas enriched liquid from the gas enriched liquid source 150 to the input apertures 114a and 116b, where at least a portion of the one or more fluid-tight tubes are coupled to a peristaltic pump or form part of the peristaltic pump, which urges fluid from the gas enriched liquid source to the input apertures 114a and 116b. In some implementations, the tubes can be secured to the

input apertures 114a and 116b using a fitting or connector, such as a high-pressure Luer fitting.

[00114] In some implementations, the gas enriched liquid source 150 can include one or more storage tanks for storing the gas enriched liquid. In some implementations, the gas enriched liquid can be a supersaturated oxygen enriched liquid or supersaturated liquid, such as a liquid having a dissolved oxygen (O₂) concentration between 0.2 and 3 ml O₂/ml solvent (which is the concentration equivalent of 100 psi to 1500 psi). In some implementations, the gas enriched liquid can include liquid enriched with oxygen, ozone, inert gas, nitrogen, nitrous oxide, carbon dioxide, and/or air. In some implementations, the gas enriched liquid source 150 may include an oxygenation device, which is operated by a console or hardware component that controls operation of the oxygenation device, as described in US Patent No. 9919276, the entire disclosure of such patent being expressly incorporated herein by reference in its entirety. The console or hardware component may include a controller, processor, memory and associated circuitry. The oxygenation device may include a fluid supply chamber for receiving a physiologic liquid e.g., saline from an IV bag, and an atomization chamber for receiving a suitable gas, e.g., oxygen from an oxygen tank. The saline is pumped into the oxygen-pressurized atomization chamber and atomized to create gas-enriched or supersaturated liquid, e.g., supersaturated oxygen-enriched saline or supersaturated saline. In certain implementations, the gas-enriched liquid can be oxygen enriched liquid or solution, e.g., supersaturated oxygen enriched liquid or solution, may include liquid having a dissolved O₂ concentration of 0.1 ml O₂/ml liquid (STP) or greater or 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP) (e.g., without clinically significant gas emboli). In some implementations, the gas enriched liquid can be a supersaturated oxygen enriched liquid or solution (e.g., saline with a dissolved O₂ concentration in saline of 0.1 ml O₂/ml saline (STP) or greater or 0.1 – 6 ml O₂/ml saline (STP) or 0.2 – 3 ml O₂/ml saline (STP) (e.g., without clinically significant gas emboli).

[00115] Further, a portion of the catheter 102 is inserted into a patient, such as the second end 108b of the catheter body 104 is positioned within a vasculature of a patient (e.g., a blood vessel 160, such as a vein or artery). After the catheter 102 has been inserted into the patient, the pump 152 is activated, such that it draws the gas enriched liquid from

the gas enriched liquid source 150, and pumps the gas enriched liquid, e.g., supersaturated liquid, into each of the lumens 110b and 110c. The gas enriched liquid flows through the lumens 110b and 110c and into the capillaries 118a and 118b and is expelled from the output apertures 120a and 120b as two respective streams 122a and 122b.

[00116] In some implementations, the system 100 can be configured to expel streams according to different flow rates and/or pressures. For example, the system 100 can be configured to expel streams between 1 mL/minute (e.g., at a pressure of 100 psi, about 690 kPa) to 3 mL/minute (e.g., at a pressure of 300 psi, about 2 MPa).

[00117] The capillaries 118a and 118b are configured such that the streams 122a and 122b intersect with one another and mix in a mixing region 124 within the vasculature of the patient. For example, the capillaries 118a and 118b can define respective paths that are angled relative to the longitudinal axis 106, such that the streams 122a and 122b are expelled from the output apertures 120a and 120b at respective angles relative to the longitudinal axis 106. In some implementations, the capillaries 120a and 120b can be configured such that the streams 122a and 122b intersect at a point 126 beyond the tip of the catheter 102 (e.g., where the point 126 is on or around the longitudinal axis 106). For example, the streams 122a and 122b may mix without bubble formation or without significant bubble formation in the mixing region 124 at a distance downstream from the output apertures of the capillaries 118a and 118b.

[00118] Further, the communicating lumen 110a provides access to the vasculature of the patient. For example, in some implementations, a sensor 154 can be at least partially inserted into the communicating lumen 110a, such that it is in fluid communication with the blood of the patient. In other implementations, the sensor may be located outside of the communicating lumen or on a catheter wall. The sensor 154 can obtain one or more sensor measurements regarding the blood and provide feedback regarding measured parameters affected by the SSO₂ therapy in order to optimize the SSO₂ therapy. For example, the sensor 154 can measure a partial pressure of oxygen of the patient's blood, an oxygen concentration or SO₂ of the patient's blood, a pressure of the patient's blood, e.g., arterial blood pressure, a flow rate of the of the patient's blood, and/or a temperature of the of the patient's blood.

[00119] Examples of such sensors include the following:

[00120] One example of a sensor for measuring a partial pressure (pO_2) of oxygen or oxygen saturation SO_2 in the patient's blood is a pulse oximeter. A pulse oximeter may be used for estimating arterial pO_2 or SO_2 . Pulse oximetry estimates the percentage of oxygen bound to hemoglobin in the blood. A pulse oximeter uses light-emitting diodes and a light-sensitive sensor to measure the absorption of red and infrared light. In another example, a sensor for measuring partial pressure of oxygen comprises an electrode such as a Clark electrode for measuring pO_2 . A Clark electrode is an electrode that measures ambient oxygen concentration in a liquid using a catalytic platinum surface according to the net reaction $O_2 + 4 e^- + 4 H^+ \rightarrow 2 H_2O$. The various sensors may be coupled to a controller of the system via a cable or other wired connection or via a wireless connection.

[00121] The processor can receive the signals from these sensors, which signals correspond to the measured values of pO_2 . The processor compares the measured pO_2 to a target range of blood pO_2 , e.g., 760-1500 mmHg (about 100 kPa to 200 kPa). The target range may be calculated based on a blood flow rate of 50-150 ml/min, saline flow rate of 2-5 ml/min and dissolved O_2 concentration in saline of 0.2 – 3 ml O_2 /ml saline (STP). The controller can adjust the saline flow rate and/or dissolved O_2 concentration in saline based on the measured pO_2 in blood to achieve an arterial blood pO_2 within the target range. The processor may generate an alert, e.g., through a user interface, audible alarm and/or visual alarm that indicates the level of pO_2 . The measured pO_2 indicates the effectiveness of the supersaturated oxygen therapy, letting the caregiver know if the pO_2 in blood is within the target range for optimizing the delivery of oxygen to the patient's ischemic tissue. In certain implementations, the processor may control the delivery of supersaturated oxygen therapy by modifying one or more of the above referenced saline or oxygen parameters based on the signals received from the sensors.

[00122] Another example of a sensor is an O_2 fluorescence probe. The fluorescence probe may be coupled to a controller of the system via a cable or other wired or wireless connection. A light source of the O_2 fluorescence probe is illuminated. A fiber optic cable can be used to provide light to the light source in certain implementations, where the fiber optic cable is connected to the controller of the system. The fluorescence of a sensor molecule of the O_2 fluorescence probe is measured. The sensor molecule can include fluorophore. A signal is received by the processor from the O_2 fluorescence probe based

on the fluorescence measurement. Fluorescence is measured by measuring the lifetime or decay of the fluorescence intensity signal from the illuminated sensor molecule (e.g., fluorophore) on the fluorescence probe. The decay of this signal is caused by the quenching effect of oxygen molecules in the blood or in tissue on the fluorescence intensity signal of the sensor molecule. The processor can determine the oxygen concentration, SO_2 or pO_2 in blood or tissue based on the quenching effect of oxygen on the fluorescence intensity signal of the fluorescence probe. Changes in the amount of time that is required for the signal to decay due to oxygen quenching are indicative of the local oxygen concentration, SO_2 or pO_2 in blood or tissue. The processor generates an alert, e.g., through a user interface, audible alarm and/or visual alarm, based on the determined oxygen concentration, SO_2 or pO_2 in blood or tissue. The alert may indicate the effectiveness of the supersaturated oxygen therapy. The determined oxygen concentration, SO_2 or pO_2 indicates the effectiveness of the supersaturated oxygen therapy, letting the caregiver know if the oxygen concentration, SO_2 or pO_2 in blood is within a predefined target range (e.g., the expected range for a healthy individual) for optimizing the delivery of oxygen to the patient. In certain implementations, the processor may control the delivery of supersaturated oxygen therapy by modifying one or more of the saline or oxygen parameters, e.g., saline flow rate or dissolved O_2 concentration in saline, based on the determined oxygen concentration, SO_2 or pO_2 values.

[00123] Another example of a sensor is a temperature sensor located on or in the catheter. For example, a thermistor may be utilized to measure the blood temperature of the patient. The processor can receive signals from the thermistor, which signals correspond to the measured values of the blood temperature. The processor may generate an alert, e.g., through a user interface, audible alarm and/or visual alarm that indicates the blood temperature, which may alert the caregiver of a hypothermic or hyperthermic, e.g., febrile, state of the patient.

[00124] An example sensor for measuring an arterial pressure of the patient's blood would be a pressure sensor positioned in or coupled to the communicating lumen. The communicating lumen may be used for direct measurement of arterial pressure. The communicating lumen may be connected to a fluid-filled system, which is connected to an electronic pressure transducer. A change in detected blood pressure may be indicative of

improved perfusion and/or restored flow in ischemic tissue as a result of the SSO₂ therapy. The therapy may result in improved heart function. In certain implementations, the processor may control the delivery of supersaturated oxygen therapy based on the arterial pressure feedback.

[00125] An example sensor used to determine a blood flow rate includes a temperature sensor, e.g., a thermistor, thermocouple or thermal anemometer. A temperature sensor may be located on a catheter tip, capillary tip or in the communication lumen. The temperature sensor may be heated, such that the sensor temperature is raised. As blood flows past the temperature sensor, the degree to which the temperature sensor cools down is indicative of the flow rate past the temperature sensor. The determined blood flow rate may be fed back to the system and may be indicative of the efficacy of the SSO₂ therapy, which results in improved perfusion and/or restored flow in ischemic tissue. In certain implementations, the processor may control the delivery of supersaturated oxygen therapy based on the blood flow rate feedback.

[00126] If the sensor is a pressure sensor, the sensor may detect a pressure differential between ambient pressure and arterial pressure or an absolute value of arterial pressure. The pressure sensor may be placed anywhere in the communicating lumen but does not necessarily have to be positioned in the communicating lumen, and can be located outside of the lumen. One example of a pressure sensor is a strain gauge. In a catheter having multiple communicating lumens, a pressure sensor may be located in a first communicating lumen providing an uninterrupted pressure signal while blood sampling may be performed via a second communicating lumen simultaneously. In another example, two pressure sensors can be used, with one located in a first communicating lumen and one located in a second communicating lumen to provide redundancy of pressure readings.

[00127] As another example, in some implementations, a sample extraction device 156 can be used to obtain a sample of the patient's blood via the communicating lumen 110a. For example, the sample extraction device 156 can include one or more pumps or syringes to draw a sample of the patient's blood through the lumen 110a and out of the patient's body. The syringe may be coupled to a proximal end of the catheter for sampling.

A valve or stopcock may be included at the proximal end of one more lumen of the catheter to control sampling.

[00128] In some implementation, the communicating lumen 110a can also be used to guide the catheter 102 within the patient's body. For example, a guide wire can be inserted into the communicating lumen 110a, and manipulated to control the shape and/or position of the catheter 102 within the patient's body.

[00129] Further, the catheter 102 may be configured in such a way that eliminates or otherwise reduces the formation of bubbles within the vasculature of the patient. For example, the streams 122a and 122b mix in a mixing region 124 away from any surfaces of the catheter 102 or capillaries thereby reducing, preventing or reducing the likelihood of bubble formation through nucleation on the surfaces of the catheter 102 or capillaries.

[00130] Further, as shown in FIG. 1B, the output aperture 112b of the communicating lumen 110a is recessed from the output apertures 120a and 120b of the capillaries 118a and 118b (e.g., by a distance d along a direction of the longitudinal axis 106). Accordingly, the streams 122a and 122b are less likely to impinge on the surfaces of the lumen 110a, thereby further preventing or reducing the likelihood of bubble formation through nucleation. Further, the streams 122a and 122b are less likely to interfere with the obtaining of sensor measurements by the sensor 154. In some implementations, the distance d can be selected based on the dimensions of the tip of the catheter 102. For example, the distance d can be at least as long as the diameter of the tip or distal end of the catheter 102. In some implementations, the distance d can be 0.060 inches (about 1.5 mm) to 0.100 inches (about 2.5 mm). As shown in FIGS. 1A and 1B, in some implementations, the catheter 102 can also include one or more shields or guards 128 (e.g., protrusions, walls, bumps, etc.) positioned over the output aperture 112b to reduce nucleation along one or more surfaces of the catheter.

[00131] In certain examples, d is scaled to the diameter of the catheter. The diameter of the catheter tip or distal end will vary depending on factors such as artery size, blood flow rate, and blood back flow. The mixing region, where the streams intersect, may create a mixing zone away from the catheter distal end. Because the diameter of catheter tip will affect blood flow and turbulence in that mixing zone, it is important to ensure that the mixing zone is at least a distance d from the catheter tip and the output aperture of the

communicating lumen. In certain examples, a distance d that is substantially equal to the diameter of the catheter tip is the minimum distance that the mixing zone should be located from the catheter tip. This helps avoid the effects of the catheter tip diameter on mixing. A recessed output aperture of the communicating lumen also helps ensure the reliability of blood samples removed via the communicating lumen. It is desirable for the mixing zone to be at least a distance d away from the output aperture of the communicating lumen, to avoid sampling of unmixed SSO₂ solution. Also, when detecting pressure, a sufficiently recessed output aperture of a communicating lumen results a reduction in noise in the pressure measurement. In some implementations, the distance d can be 0.060 inches (about 1.5 mm) to 0.100 inches (about 2.5 mm).

[00132] Further, each of the surfaces of the catheter 102 (e.g., the interior surfaces of the lumens 110a-110c and the capillaries 118a and 118b, the exterior surfaces of the capillaries 118a and 118b, the exterior surfaces of the catheter body 104, etc.) can be smooth to prevent or further reduce the likelihood of bubble formation through nucleation. In some implementations, one or more of these surfaces can be coated or pre-wetted with liquids and/or hydrophilic agents or coatings (e.g., saline, ethanol, benzalkonium heparin, blood proteins, etc.) before use to further inhibit the formation of bubbles through nucleation.

[00133] In the example shown in FIGS. 1A and 1B, the lumen 110a extends along a longitudinal axis 106 through a center of the catheter body 104. However, this need not always be the case. For instance, FIGS. 2A and 2B show a perspective view and a head-on view, respectively, of another example catheter 102. In this example, the lumen 110a is positioned off-center along the catheter body 104, such that it extends parallel to the longitudinal axis (rather than along the longitudinal axis 106).

[00134] Further, in the example shown in FIGS. 1A and 1B, the catheter 102 includes two lumen 110b and 110c and two capillaries 118a and 118b for conveying a gas enriched liquid into the vasculature of a patient. However, this also need not always be the case. For instance, FIG. 3A and 3B show a perspective view and a head-on view, respectively, of another example catheter 102. In this example, the catheter 102 includes three lumen 110b-110d extending through the catheter body 104, each configured to convey a gas enriched liquid into the vasculature of a patient. Further, the catheter 102

includes three capillaries 118a-118c extending from and in fluid communication with the lumens 110b-110d, respectively. During an example usage of the system 100, the gas enriched liquid source 150 and the pump 152 are attached to the catheter 102, such that the gas enriched liquid source 150 and the pump 152 are in fluid communication with the input apertures of each of the lumens 110b-110d. Further, the pump 152 is activated, such that it draws a gas enriched liquid from the gas enriched liquid source 150, and pumps the gas enriched liquid into each of the lumens 110b-110d. The gas enriched liquid flows through the lumens 110b-110d and into the capillaries 118a-118c, and is expelled from the capillaries 118a-118c as three respective streams.

[00135] Further, the capillaries 118a-118c are configured such that the streams mix in a mixing region within the vasculature of the patient. For example, the capillaries 118a-118c can define respective paths that are angled relative to the longitudinal axis 106, such that the streams are expelled from the capillaries 118a-118c at respective angles relative to the longitudinal axis 106. In some implementations, the capillaries 118a-118c can be configured such that at least two of the streams intersect at a point some distance beyond the tip of the catheter 102. In some implementations, the capillaries 118a-118c can be configured such all of the streams intersect at a point some distance beyond the tip of the catheter 102 (e.g., a point on the longitudinal axis 106).

[00136] Although FIGS. 3A and 3B show an example catheter having three lumens and three capillaries for conveying a gas enriched liquid, this is merely an illustrative example. In practice, a catheter can have any number of lumen and capillaries for conveying a gas enriched liquid. As an example, a catheter can include one, two, three, four, or more lumens for conveying a gas enriched liquid. As another example, a catheter can include one, two, three, four, or more capillaries for conveying a gas enriched liquid.

[00137] In some implementations, a catheter may have a plurality of lumens coupled to a plurality of capillaries. For example, while not shown in the figures, the catheter may include a single capillary and a plurality of lumens, where certain of the plurality of lumens may converge and be coupled to the single capillary and other of the plurality of lumens may serve as communicating lumens for performing at least one of receiving a sample of a patient's blood from the vasculature of the patient or measuring a parameter of the patient's blood. The stream may exit the output aperture of the single capillary without

intersecting a vessel wall and mix with the blood without bubble formation at a distance downstream from the output aperture of the capillary. A single capillary catheter may also be utilized for indications where bubble formation is less of a concern, e.g., where blood flow is not going to the heart or brain, but instead is being pushed to a capillary bed or patient tissue, or when targeting venous blood flow.

[00138] Further, although the example catheters described above each have a single lumen for facilitating the measurement of one or more properties of the patient's blood within the patient's vasculature and/or facilitating the collection of blood samples from the patient's vasculature, this need not always be the case. In practice, a catheter can have any number of lumen for facilitating the measurement of one or more properties of the patient's blood within the patient's vasculature and/or facilitating the collection of blood samples from the patient's vasculature (e.g., one, two, three, four, or more).

[00139] As shown in FIGS. 3A-3C, the capillaries 118a-118c can be configured such that all or two or more of the streams expelled by the capillaries 118a-118c intersect at a point along the longitudinal axis 106, beyond the tip of the catheter 102. For example, as shown in FIG. 3B, in cross-section, each of the capillaries 118a-118c can extend radially from the longitudinal axis 106. However, this also need not always be the case. For instance, FIGS. 4A and 4B show a perspective view and a head-on view, respectively, of another example catheter 102. In this example, in cross-section, each of the capillaries 118a-118c does not extend radially from the longitudinal axis 106. Instead, in cross section, each of the capillaries 118a-118c is offset relative to a respective radius by a particular angle, such that the streams expelled by the capillaries 118a-118c interact at points that are not on the longitudinal axis 106. This can be beneficial, for example, in facilitating the mixing of the gas enriched liquid with the patient's blood in a spiral or vortex pattern, which may further suppress, reduce, or prevent the formation of bubbles. Having angled capillaries may create angular momentum, which causes rotational mixing. This may result in improved overall mixing. In certain examples, the capillaries may be offset or angled relative to each other at an angle ranging from greater than 0 degrees to 15 degrees. In general, reference to an axial direction of the catheter may be considered to be a longitudinal direction of the catheter. Further, reference to a radial direction of the catheter may be considered to be a lateral direction of the catheter.

[00140] In some implementations, the system 100 can also include self-centering mechanisms for positioning the catheter 102 within the vasculature of the patient (e.g., such that the catheter body 104 capillaries and/or the streams expelled by the capillaries are positioned centrally in a vein or artery, away from the vessel walls to reduce or prevent nucleation or bubble formation by preventing the streams from hitting a vessel wall). For instance, FIG. 5A shows an example catheter 102 including an inflatable balloon structure 502. The balloon structure 502 encircles a portion of the catheter 104, and can be selectively inflated and deflated. For example, after a portion of the catheter 102 has been inserted into a vessel 160, the balloon structure 502 can be inflated such that it contacts the walls of the vessel 160. In this configuration, the catheter 104 body is positioned centrally within the vessel 160. Accordingly, the streams of gas enriched liquid expelled by the capillaries 118a and 118b mix in a mixing region away from the walls of the vessel 160. This can be beneficial, for example, in reducing mechanical stress on the walls of the vessel and in further suppressing, preventing, or reducing the formation of bubbles.

[00141] As another example, FIG. 5B shows an example catheter 102 including an expandable mesh structure 504. The mesh structure 504 encircles a portion of the catheter 104, and can be selectively expanded and collapsed. For example, after a portion of the catheter 102 has been inserted into a vessel 160, the mesh structure 504 can be expanded such that it contacts the walls of the vessel 160. In this configuration, the catheter 104 body is positioned centrally within the vessel 150. Accordingly, the streams of gas enriched liquid expelled by the capillaries 118a and 118b mix in a mixing region away from the walls of the vessel 160. As describe above, this can be beneficial, for example, in reducing mechanical stress on the walls of the vessel and in further suppressing preventing, or reducing the formation of bubbles.

[00142] As described above, the capillaries of a catheter can be configured such that the streams of gas enriched liquid expelled by the capillaries mix in a mixing region within the vasculature of the patient. For example, the capillaries can define respective paths that are angled relative to the longitudinal axis of the catheter, such that the streams are expelled from the capillaries at respective angles relative to the longitudinal axis 106. In some implementations, this angle can be from 10 degrees to 80 degrees or from 15 degrees to 75 degrees.

[00143] In some implementations, this angle can be selectively adjusted. For example, one or more of the capillaries can include a flexible portion or hinge that can be selectively bent or curved (e.g., to selectively increase or decrease the angle). This can be beneficial, for example, in enabling a user to adjust the distance between the mixing region and the end of the catheter.

[00144] For example, as shown in FIG. 6A, a catheter 102 can include two capillaries 118a and 118b (e.g., as described in connection with FIGS. 1A and 1B). Further, the capillaries 118a and 118b can define respective paths that are angled relative to the longitudinal axis 106 of the catheter 102 by a first angle 602a, such that the streams are expelled from the capillaries according to the first angle 602a relative to the longitudinal axis 106. For example, the capillaries 118a and 118b can define respective paths that are angled relative to the longitudinal axis 106 of the catheter 102 by a first angle 602a of about 45 degrees. In this configuration, the streams expelled by the capillaries 118a and 118b intersect at a first point 604a beyond the tip of the catheter 102.

[00145] Further, as shown in FIG. 6B, the capillaries 118a and 118b can be adjusted, such that they define respective paths that are angled relative to the longitudinal axis 106 of the catheter 102 by a second angle 602b, where the second angle 602b is greater than the first angle 602a. Accordingly, the streams are expelled from the capillaries according to the second angle 602b relative to the longitudinal axis 106. For example, the capillaries 118a and 118b can define respective paths that are angled relative to the longitudinal axis 106 of the catheter 102 by a second angle 602b of about 60 degrees. In this configuration, the streams expelled by the capillaries 118a and 118b intersect at a second point 604b beyond the tip of the catheter 102. As shown in FIG. 6B, the distance between the second point 604b and the tip of the catheter 102 is less than the distance between the first point 604a and the tip of the catheter 102.

[00146] Further, as shown in FIG. 6C, the capillaries 118a and 118b can be adjusted, such that they define respective paths that are angled relative to the longitudinal axis 106 of the catheter 102 by a third angle 602c, where the third angle 602c is less than the first angle 602a. Accordingly, the streams are expelled from the capillaries according to the third angle 602c relative to the longitudinal axis 106. For example, the capillaries 118a and 118b can define respective paths that are angled relative to the longitudinal axis 106

of the catheter 102 by a third angle 602c of about 30 degrees. In this configuration, the streams expelled by the capillaries 118a and 118b intersect at a third point 604c beyond the tip of the catheter 102. As shown in FIG. 6C, the distance between the third point 604c and the tip of the catheter 102 is greater than the distance between the first point 604a and the tip of the catheter 102.

[00147] In some implementations, the catheter 102 can include features that enable a user to determine the orientation of the capillaries when it is inside the patient's body. For example, the capillaries 118a and 118b can include fiducial markings or structures that allow for manipulation or movement of the capillaries. For example, the structures may include a wire or other mechanism coupled to the capillary through the catheter to allow for manipulation or bending of the capillary. The bendable capillary can allow a user to define or modify the angle of respective jet stream paths relative to the longitudinal axis 106 of the catheter 102. Further, the fiducial markings on the capillaries can be used for positioning or guiding the capillaries. The fiducial markings can be composed, at least in part, of a radiopaque material (e.g., a metal or metal alloy), such that the orientation of the fiducial markings can be determined using a medical imaging system (e.g., an X-ray imaging system). For example, the fiducial markings may include radiopaque markers 608a and 608b shown in FIG. 6A, positioned on the capillaries 118a and 118b, respectively.

[00148] FIG. 7A shows another example system 700 for enriching a bodily liquid with a gas-enriched liquid inside of an enclosed area of a body. As an example, the system 100 can be used to enrich a patient's blood with supersaturated oxygen enriched liquid within the vasculature of the patient.

[00149] As shown in FIG. 7A, the system 700 includes a catheter 702, a gas enriched liquid source 150, and a pump 152. The catheter 702 is configured to be inserted into the vasculature of a patient, and is configured to facilitate the delivery of a gas enriched liquid (e.g., from the gas enriched liquid source 150) into the vasculature of the patient via the pump 152.

[00150] The catheter 102 includes an elongated tubular catheter body 704 having a coiled portion 706 (shown in greater detail in FIG. 7B). Further, the coiled portion 706 defines multiple output apertures 708 along at least a portion of its length. In some implementations, at least a portion of the catheter 702 and/or the catheter body 704 can be

composed of polycarbonate, glass, ceramic, stainless steel, PEEK, and/or polyimide. In some implementations, the catheter body 174 can have an outer diameter ranging from 4 F to 12 F, or for example, 4 F to 5 F (according to the French scale). In some implementations, the catheter body 174 can have an inner diameter ranging from 0.020 inches to 0.045 inches (about 0.5 mm to about 1.1 mm).

[00151] FIG. 7C shows a cross-sectional view of the coiled portion 706. As shown in FIG. 7C, the catheter body 704 includes a tubular wall 710 (e.g., having a circular, elliptical, or ovular cross section) that defines a lumen 712. Further, each of the output apertures 708 extends through the wall 710, such that a fluid path extends from the lumen 712 into the surrounding environment. In some implementations, the catheter 702 can extend in an axial direction, and at least some of the output apertures 708 can fan one or more radial directions orthogonal to the axial direction (e.g., such that streams of the gas enriched liquid are expelled from the catheter 702 in a direction orthogonal to a flow of blood in the patient's vasculature).

[00152] During an example usage of the system 700, the gas enriched liquid source 150 and the pump 152 are attached to the catheter 702, such that the gas enriched liquid source 150 and the pump 152 are in fluid communication with the lumen 712. As an example, one or more fluid-tight tubes can be used to convey gas enriched liquid from the gas enriched liquid source 150 to the pump 152, and from the pump 152 to an input aperture 714 of the catheter 702. In some implementations, the tubes can be secured to the input aperture 714 using a fitting or connector, such as a high-pressure Luer fitting.

[00153] Further, a portion of the catheter 702 is inserted into a patient, such as the coiled portion 706 of the catheter body 704 is positioned within a vasculature of a patient (e.g., a blood vessel 160, such as a vein or artery). After the catheter 702 has been inserted into the patient, the pump 152 is activated, such that it draws a gas enriched liquid from the gas enriched liquid source 150, and pumps the gas enriched liquid into the lumen 712. The gas enriched liquid flows through the lumen 712 and is expelled from the output apertures 708 and into the vessel 160 as respective streams 716, whereby it mixes with the blood in the vessel 160. This configuration can be beneficial, for example, in providing the gas enriched liquid into the blood of the patient in a diffuse manner, thereby eliminating or otherwise reducing the formation of bubbles within the vasculature of the patient.

[00154] Although FIGS. 7A and 7B show an example configuration of the coiled portion 706 having four coils, this is merely an illustrative example. In practice, the coiled portion 706 can have any number of coils (e.g., one, two, three, four, five, or more). Further, the coiled portion 706 can include any number of output apertures 708 (e.g., one, two, three, four, five, or more).

[00155] In some implementations, one or more of the coils in the coiled portion 706 can have a helical shape or a spiral shape (e.g., having a variable diameter). In some implementations, the coils in the coiled portion 706 can repeat according to a periodic pattern. In some implementations, the elongated tubular catheter body can be substantially straight, without a coiled or helical portion.

[00156] In some implementations, at least some of the output apertures 708 can be distributed periodically along at least a portion of the catheter body 704. In some implementations, adjacent output apertures 708 can be separated from one another by at least a particular minimum distance. The minimal distance can depend on the jet penetration of each of the streams expelled from the output apertures 708 (e.g., which can depend on the flow rate of the gas enriched liquid and/or the diameter of the output apertures 708). The output apertures may be spaced or distanced such that the jet penetration dissipates before reaching an adjacent output aperture or output aperture branch to prevent or reduce nucleation or bubble formation. For example, if the jet penetration is higher, the minimum spacing may be longer. As another example, if the jet penetration is lower, the minimum spacing may be shorter. This can be beneficial, for example, in further preventing or reducing the likelihood of the formation of bubbles due to nucleation. Example ranges for minimum spacing distance between output apertures include: 1 cm to 5 cm from aperture center to aperture center, either around the circumference of a catheter or along the longitudinal axis. In some implementations, adjacent apertures 708 can be offset or spaced from one another along the catheter body 704 by a distance that ranges from 1 cm to 5 cm.

[00157] In some implementations, at least a portion of the catheter 702 can be flexible. This can be beneficial, for example, in facilitating the insertion and positioning of the catheter 702 within the body of the patient. As an example, as shown in FIG. 8A, a guiding rod 718 can be inserted into the lumen 712 of the catheter 702, and pushed towards

the coiled portion 706. As shown in FIG. 8B, the guiding rod 718 can be pushed through at least a portion of the coiled portion 706, such that the coiled portion 706 is at least partially straightened. In this configuration, the catheter 702 can be inserted more easily into the vessel of the patient. Upon insertion of the catheter 702 into the vessel of the patient, the guiding rod 718 can be withdrawn from the catheter 702. In some implementations, the catheter 702 can be composed, at least in part, of a shape memory material, such that the coiled portion 706 returns to its coiled shape upon the withdrawal of the guiding rod 718.

[00158] In the example shown in FIGS. 7A-7C, the catheter 702 includes multiple output apertures 708 in fluid communication with the lumen 712 of the catheter body 704 to the surrounding environment. However, in some implementations, the catheter 702 can further include one or more tubular structures to further increase the diffusivity by which the gas enriched liquid is expelled into the vasculature of the patient. For example, as shown in FIG. 9A, a catheter 702 can include one or more branching tubular structures 902, each configured to receive the gas enriched liquid from the lumen 712, and expel the gas enriched liquid into the vasculature of the patient as respective streams 904.

[00159] As another example, as shown in FIG. 9B, a catheter 702 can include one or more non-branching tubular structures 906, each configured to receive the gas enriched liquid from the lumen 712, and expel the gas enriched liquid into the vasculature of the patient as respective streams 908. In some implementations, a catheter can include both branching tubular structures and non-branching tubular structures. The tubular structures may be offset or spaced from one another along the longitudinal axis of the catheter to prevent a stream from a first tubular structure intersecting with a surface of a second tubular structure, to thereby reduce or prevent bubble formation or nucleation.

[00160] In general, the catheters 702 shown in FIGS. 9A and 9B can be similar to one or more of the other catheters described above (e.g., the catheters 702 described with reference to FIGS. 7A-7C). For example, the catheters 702 shown in FIGS. 9A and 9B can have an inner diameter that ranges from 0.020 inches to 0.045 inches (about 0.5 mm to about 1.1 mm), and/or an outer diameter that ranges from 4 F to 12 F (about 1.33 mm to 4 mm). Further, the catheters 702 shown in FIGS. 9A and 9B can include one or more fiducial markings. Further, one or more fluid-tight tubes can be used to convey gas

enriched liquid from a gas enriched liquid source (e.g., the gas enriched liquid source 150) to a pump (e.g., the pump 152), and from the pump to an input aperture of the catheter 702. In some implementations, the tubes can be secured to the input aperture using a fitting or connector, such as a high-pressure Luer fitting.

[00161] In some implementations, at least some of the tubular structures 902 and/or 906 can dimensions that are identical to those another tubular structure. In some implementations, at least some of the tubular structures 902 and/or 906 can dimensions that are different from those another tubular structure. In some implementations, at least some of the tubular structures 902 and/or 906 can have an inner diameter that ranges from 40 microns to 100 microns. Further, at least some of the tubular structures 902 and/or 906 can have an outer diameter that ranges from 140 microns to 400 microns. In some implementations, adjacent tubular structures 902 and/or 906 can vary in length from one another by a length that ranges from 1 cm to 5 cm. In some implementations, adjacent tubular structures can offset or spaced from one another along the catheter body by a distance that ranges from 1 cm to 5 cm.

[00162] While this specification contains many details, these should not be construed as limitations on the scope of what may be claimed, but rather as descriptions of features specific to particular examples. Certain features that are described in this specification in the context of separate implementations can also be combined. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple embodiments separately or in any suitable sub-combination.

[00163] A number of embodiments have been described. Nevertheless, various modifications can be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the claims.

WHAT IS CLAIMED IS:

1. A catheter configured to be inserted into a vasculature of a patient, wherein the catheter comprises:
 - an elongated catheter body,
 - a first lumen extending through the catheter body, wherein the first lumen is configured to be in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient, and the first lumen is configured to perform at least one of receiving a sample of blood from the vasculature of the patient or measuring a parameter of the patient's blood;
 - one or more second lumens extending through the catheter body, wherein the one or more second lumens are configured to receive a gas enriched liquid from a gas enriched liquid source; and
 - two or more capillaries extending from the catheter body and coupled to the one or more second lumens,
 - wherein each of the two or more capillaries are in fluid communication with the one or more second lumens and are in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient, and
 - wherein each of the two or more capillaries are configured to receive the gas enriched liquid from the one or more second lumens and to simultaneously dispense respective streams of the gas enriched liquid directly into the vasculature of the patient,
 - wherein the catheter body is configured to position the two or more capillaries at one or more predetermined angles relative to one another, such that the streams of the gas enriched liquid intersect and mix with the patient's blood in a region beyond an end of the catheter body and beyond the first lumen; and
 - wherein the first lumen is recessed relative to respective output ends of the two or more capillaries.

2. The catheter of claim 1, wherein the gas enriched liquid is a supersaturated oxygen enriched liquid.
3. The catheter of claim 1, wherein the first lumen is configured to receive a guide wire for positioning the catheter with respect to the vasculature of the patient.
4. The catheter of claim 1, further comprising a pressure sensor disposed within the first lumen, wherein the pressure sensor is configured to obtain one or more pressure measurements.
5. The catheter of claim 1, wherein the parameter of the patient's blood is at least one of:
 - a partial pressure of oxygen of the patient's blood,
 - SO₂ of the patient's blood,
 - a pressure of the patient's blood,
 - a flow rate of the of the patient's blood, or
 - a temperature of the of the patient's blood.
6. The catheter of claim 1, wherein the first lumen has a diameter ranging from 0.020 inches to 0.045 inches.
7. The catheter of claim 1, wherein the catheter comprises:
 - a third lumen extending through the catheter body, wherein the third lumen is configured to be in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient, and the third lumen is configured to perform at least one of receiving an additional sample of the patient's blood from the vasculature of the patient and or measuring an additional parameter of the patient's blood.
8. The catheter of claim 1, wherein the catheter body is configured to position the two or more capillaries such that the streams of the gas enriched liquid intersect a longitudinal axis extending through a center of the catheter.

9. The catheter of claim 1, wherein the catheter body is configured to position the two or more capillaries such that the streams of the gas enriched liquid do not intersect a longitudinal axis extending through a center of the catheter.

10. The catheter of claim 1, further comprising one or more shields or guards positioned over a distal opening of the first lumen and configured to reduce nucleation along one or more surfaces of the catheter.

11. The catheter of claim 1, wherein at least one of the predetermined angles ranges from 10 to 80 degrees.

12. The catheter of claim 1, wherein a diameter of at least one of the two or more capillaries and a diameter of at least another one of the two or more capillaries are equal.

13. The catheter of claim 1, wherein a diameter of at least one of the two or more capillaries is different from a diameter of at least another one of the two or more capillaries.

14. The catheter of claim 1, wherein at least one of the two or more capillaries has an inner diameter that ranges from 40 microns to 100 microns.

15. The catheter of claim 1, wherein at least one of the two or more capillaries has an outer diameter that ranges from 140 microns to 400 microns.

16. The catheter of claim 1, wherein the two or more capillaries comprise one or more elongated tubes extending from the catheter body.

17. The catheter of claim 1, wherein a distance between (i) an intersection of the streams of the gas enriched liquid and (ii) an end tip of the catheter or an output aperture of the first lumen is greater than or equal to a diameter of the end tip of the catheter.

18. The catheter of claim 1, wherein a distance between (i) the output ends of the two or more capillaries and (ii) an end tip of the catheter or an output aperture of the first lumen is greater than or equal to a diameter of the end tip of the catheter.

19. The catheter of claim 1, wherein at least one capillary comprises a fiducial marking.

20. The catheter of claim 1, wherein the streams of the gas enriched liquid intersect and mix with the patient's blood without formation of bubbles.

21. The catheter of claim 1, wherein the streams of the gas enriched liquid intersect and mix with the patient's blood in a region beyond an end of the catheter body and beyond the first lumen to reduce bubble nucleation along one or more surfaces of the catheter or capillaries.

22. The catheter of claim 1, further comprising one or more sensors, wherein the one or more sensors are configured such that the one or more sensors are in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient.

23. The catheter of claim 22, wherein at least one of the one or more sensors is an oxygen partial pressure (pO₂) sensor.

24. The catheter of claim 1, further comprising a self-centering device configured to center the catheter body within the vasculature of the patient.

25. The catheter of claim 24, wherein the self-centering device comprises one or more mesh structures encircling the catheter body.

26. A system comprising:

the catheter of claim 1, and a fluid dispensing device in fluid communication with the one or more second lumens, wherein the fluid dispensing device comprises one or more pumps configured to provide the gas enriched liquid to the one or more second lumens.

27. The system of claim 26, further comprising one or more connectors configured to couple the one or more second lumens to one or more respective dispensing ports of the fluid dispensing device.

28. The system of claim 27, wherein at least one of the one or more connectors is a high pressure Luer fitting.

29. The catheter of claim 1, wherein the gas enriched liquid comprises one or more of oxygen, ozone, inert gas, nitrogen, nitrous oxide, carbon dioxide, or air.

30. The catheter of claim 1, wherein the gas enriched liquid comprises a dissolved oxygen (O₂) concentration that ranges from 0.2 and 3 ml O₂/ml solvent.

31. A system comprising:
the catheter of claim 1, and a blood sampling device in fluid communication with the first lumen, wherein the blood sampling device is configured to withdraw the sample of the patient's blood from the vasculature of the patient through the first lumen.

32. A catheter of claim 1, wherein the two or more capillaries are coated with a hydrophilic coating.

33. A catheter configured to be inserted into a vasculature of a patient, the catheter comprising:

an elongated catheter body having a coiled shape;
a first lumen extending through the catheter body, wherein the first lumen is configured to receive a gas enriched liquid; and

a plurality of apertures positioned along a length of the catheter body, the plurality of apertures in fluid communication with the first lumen,

wherein the apertures are configured to dispense the gas enriched liquid directly into the vasculature of the patient.

34. The catheter of claim 33, wherein the gas enriched liquid is a supersaturated oxygen enriched liquid.

35. The catheter of claim 33, wherein the catheter comprises one or more periodically repeating curved sections.

36. The catheter of claim 35, wherein a length of each of the one or more periodically repeating curved sections varies.

37. The catheter of claim 33, wherein the catheter body has an inner diameter that ranges from 0.020 inches to 0.045 inches.

38. The catheter of claim 33, wherein the catheter body has an outer diameter that ranges from 4 F to 12 F.

39. The catheter of claim 33, wherein the catheter is at least partially composed of a shape-memory material.

40. The catheter of claim 33, wherein one or more surfaces of the catheter are composed of at least one of polycarbonate, glass, ceramic, stainless steel, PEEK, or polyimide.

41. The catheter of claim 33, wherein the catheter body extends along an axial direction, and wherein at least some of the one or more apertures face one or more radial directions orthogonal to the axial direction.

42. The catheter of claim 41, wherein each of the apertures is positioned at a different respective radial position about the catheter body.

43. The catheter of claim 33, wherein the catheter body extends along an axial direction, and wherein each of the apertures faces one or more radial directions orthogonal to the axial direction.

44. The catheter of claim 33, wherein each of the apertures has a diameter that ranges from 40 microns to 100 microns.

45. The catheter of claim 33, wherein each of the apertures has a circular shape.

46. The catheter of claim 33, wherein the catheter body extends along a helical path.

47. The catheter of claim 33, wherein the catheter body extends along a spiral path having a variable diameter.

48. The catheter of claim 33, wherein adjacent apertures are offset or spaced from one another along the catheter body by a distance that ranges from 1 cm to 5 cm.

49. The catheter of claim 33, wherein the catheter body is configured to receive a guiding rod.

50. The catheter of claim 49, wherein the catheter body is configured such that, when the guiding rod is inserted into the catheter body, a curvature of at least a portion of the catheter body is reduced.

51. The catheter of claim 33, further comprising one or more elongated tubes extending from the catheter body, wherein the one or more elongated tubes comprise one or more second lumens in fluid communication with the apertures, and wherein the one or more elongated tubes are configured to receive the gas enriched liquid from the

apertures and to dispense the gas enriched liquid directly into the vasculature of the patient.

52. The catheter of claim 51, wherein at least one of the one or more elongated tubes branches into one or more respective portions, each defining a respective third lumen in fluid communication with the first lumen.

53. The catheter of claim 33, wherein the gas enriched liquid comprises one or more of oxygen, ozone, inert gas, nitrogen, nitrous oxide, carbon dioxide, or air.

54. The catheter of claim 33, wherein the gas enriched liquid comprises a dissolved oxygen (O₂) concentration that ranges from 0.2 to 3 ml O₂/ml solvent.

55. A system comprising:
the catheter of claim 33; and
a fluid dispensing device in fluid communication with the first lumen, wherein the fluid dispensing device comprises one or more pumps configured to provide the gas enriched liquid to the first lumen.

56. The system of claim 55, wherein the catheter comprises a connector configured to couple the first lumen to a dispensing port of the fluid dispensing device.

57. The system of claim 56, wherein the connector is a Luer fitting.

58. A catheter configured to be inserted into a vasculature of a patient, the catheter comprising:
an elongated catheter body;
a first lumen extending through the catheter body, wherein the first lumen is configured to receive a gas enriched liquid; and
a plurality of elongated tubes extending along the catheter body, wherein adjacent elongated tubes are offset from one another along the catheter body, wherein each of the

elongated tubes comprises a respective second lumen in fluid communication with the first lumen, and

wherein the elongate tubes are configured to receive the gas enriched liquid from the first lumen and dispense the gas enriched liquid directly into the vasculature of the patient.

59. The catheter of claim 58, wherein the gas enriched liquid is a supersaturated oxygen enriched liquid.

60. The catheter of claim 58, wherein at least one of the elongated tubes branches into one or more respective portions.

61. The catheter of claim 60, wherein each of the portions is in fluid communication with the first lumen.

62. The catheter of claim 60, wherein each of the portions comprises a respective output end, and wherein each of the output ends is positioned at a different respective radial position about the catheter body.

63. The catheter of claim 58, wherein the catheter body has an inner diameter that ranges from 0.020 inches to 0.045 inches.

64. The catheter of claim 58, wherein the catheter body has an outer diameter that ranges from 4 F to 12 F.

65. The catheter of claim 58, wherein at least one of the elongated tubes has an inner diameter that ranges from 40 microns to 100 microns.

66. The catheter of claim 58, wherein at least one of the elongated tubes has an outer diameter that ranges from 140 microns to 400 microns.

67. The catheter of claim 58, wherein at least one of the elongated tubes has a circular cross-section.

68. The catheter of claim 58, wherein the adjacent elongated tubes vary in length from one another by a length that ranges from 1 cm to 5 cm.

69. The catheter of claim 58, wherein the adjacent elongated tubes are offset or spaced from one another along the catheter body by a distance that ranges from 1 cm to 5 cm.

70. The catheter of claim 58, wherein the gas enriched liquid comprises one or more of oxygen, ozone, inert gas, nitrogen, nitrous oxide, carbon dioxide, or air.

71. The catheter of claim 58, wherein the gas enriched liquid comprises a dissolved oxygen (O₂) concentration that ranges from 0.2 to 3 ml O₂/ml solvent.

72. The catheter of claim 58, wherein the at least one capillary comprises a fiducial marking.

73. The catheter of claim 58, wherein the catheter is sufficiently flexible to be guided through a catheter delivery system.

74. A system comprising:
the catheter of claim 58; and
a fluid dispensing device in fluid communication with the first lumen, wherein the fluid dispensing device comprises one or more pumps configured to provide the gas enriched liquid to the first lumen.

75. The system of claim 74, wherein the catheter comprises a connector configured to couple the first lumen to a dispensing port of the fluid dispensing device.

76. The system of claim 75, wherein the connector is a Luer fitting.
77. The catheter of claim 1, wherein the gas enriched liquid comprises a dissolved O₂ concentration of 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP).
78. The catheter of claim 33, wherein the gas enriched liquid comprises a dissolved O₂ concentration of 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP).
79. The catheter of claim 58, wherein the gas enriched liquid comprises a dissolved O₂ concentration of 0.1 – 6 ml O₂/ml liquid (STP) or 0.2 – 3 ml O₂/ml liquid (STP).

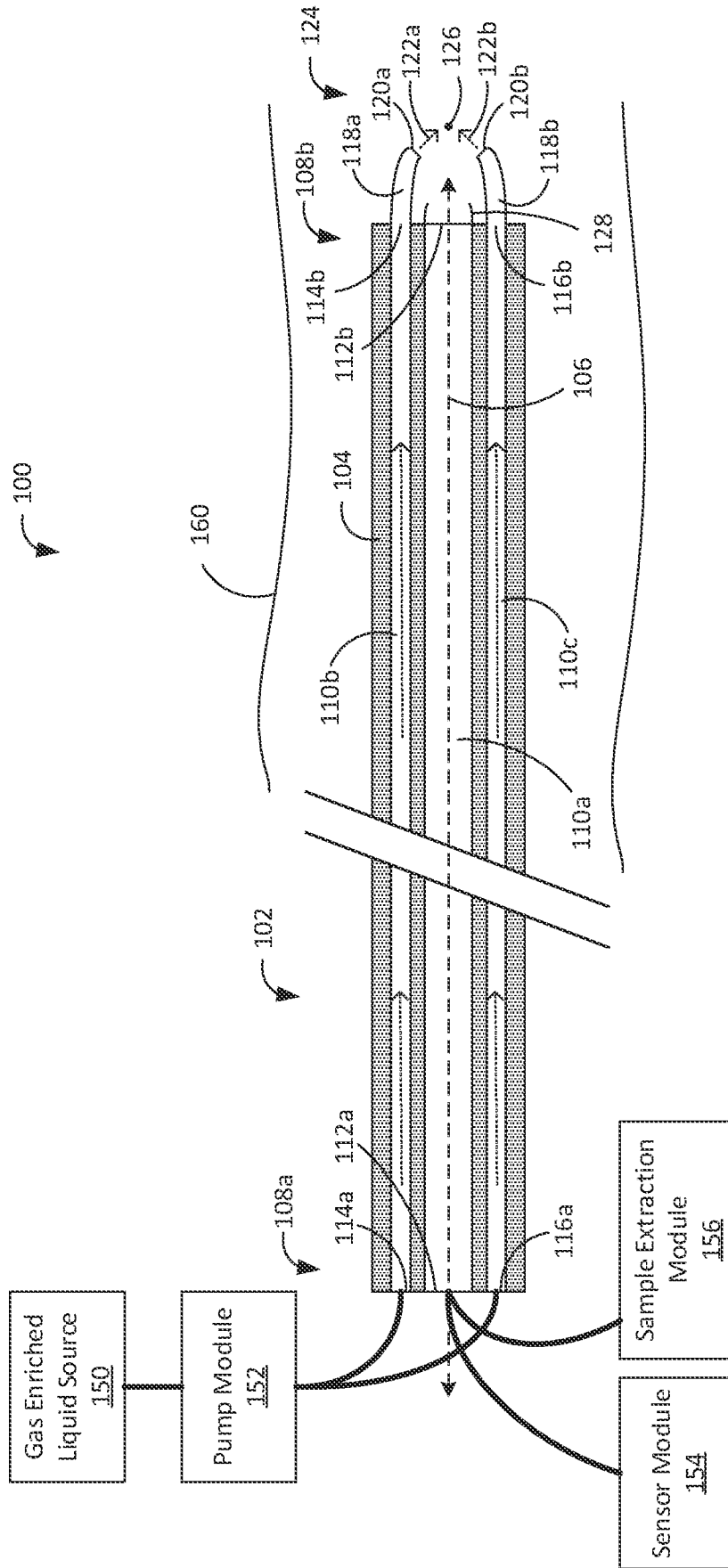


FIG. 1A

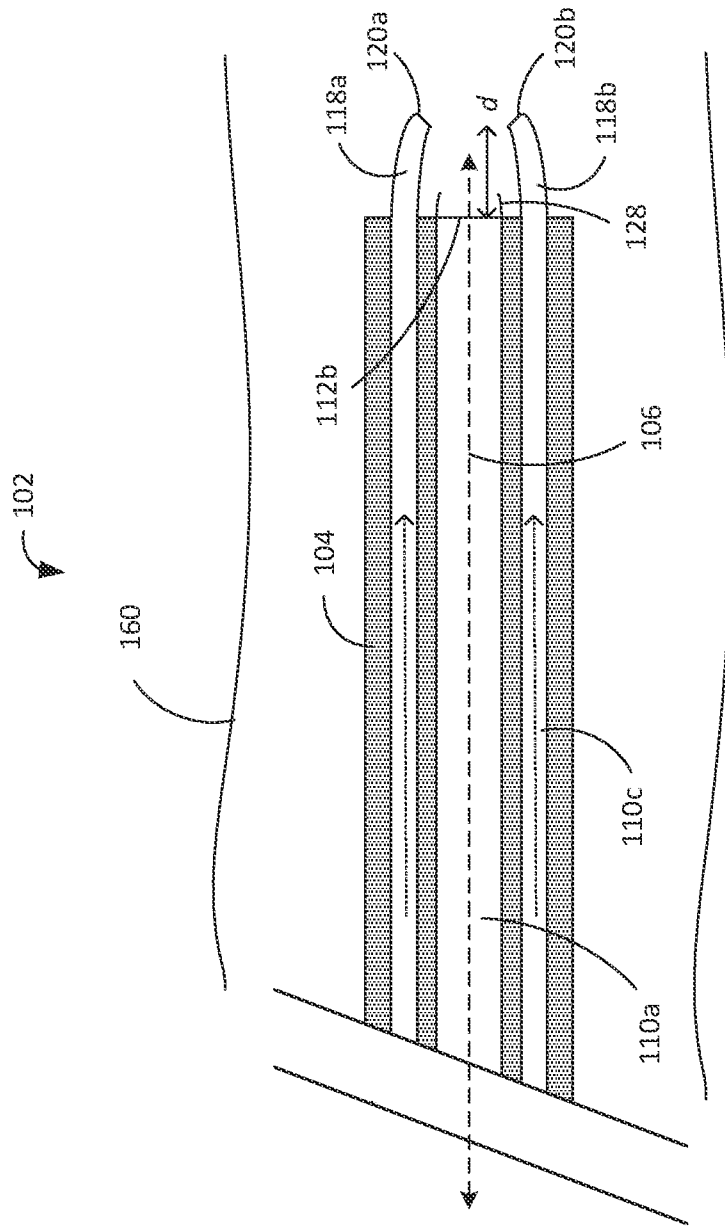


FIG. 1B

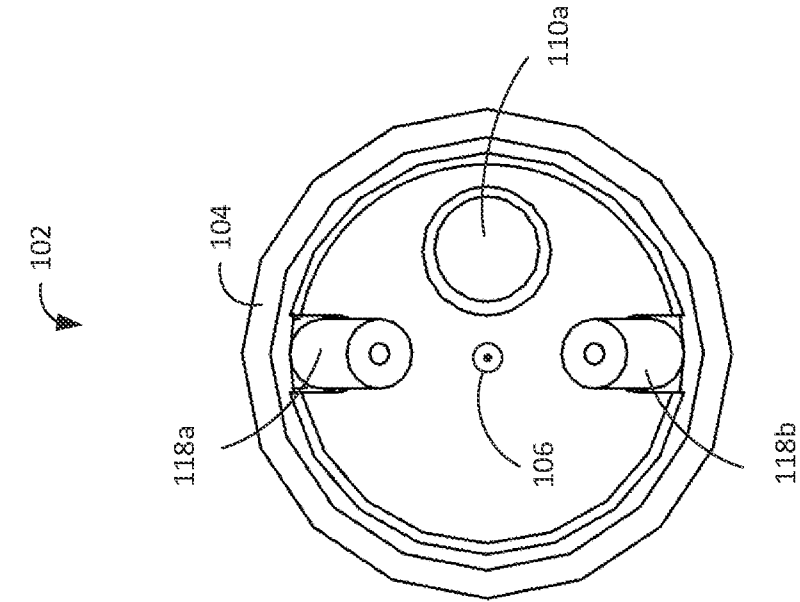


FIG. 2A

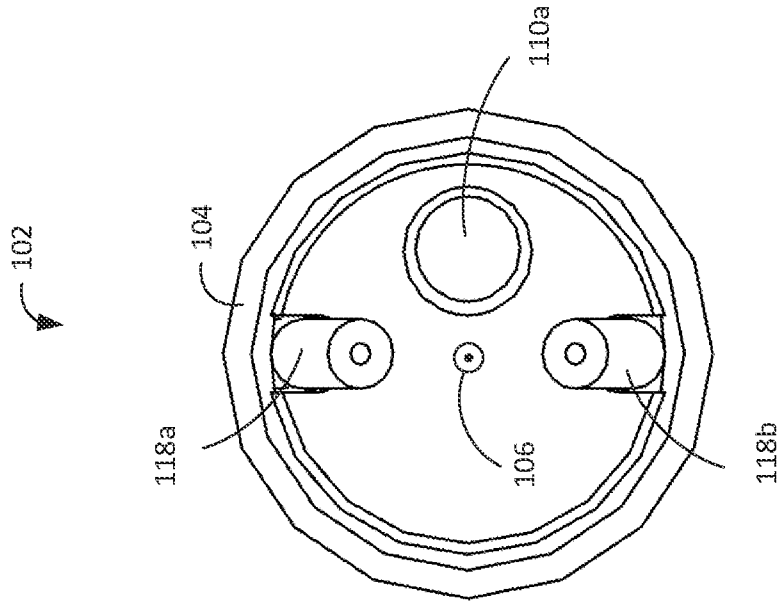


FIG. 2B

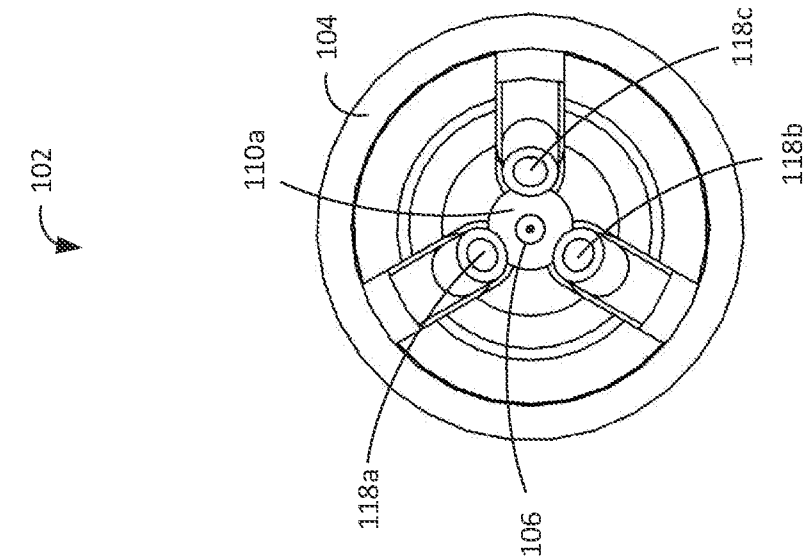


FIG. 3A

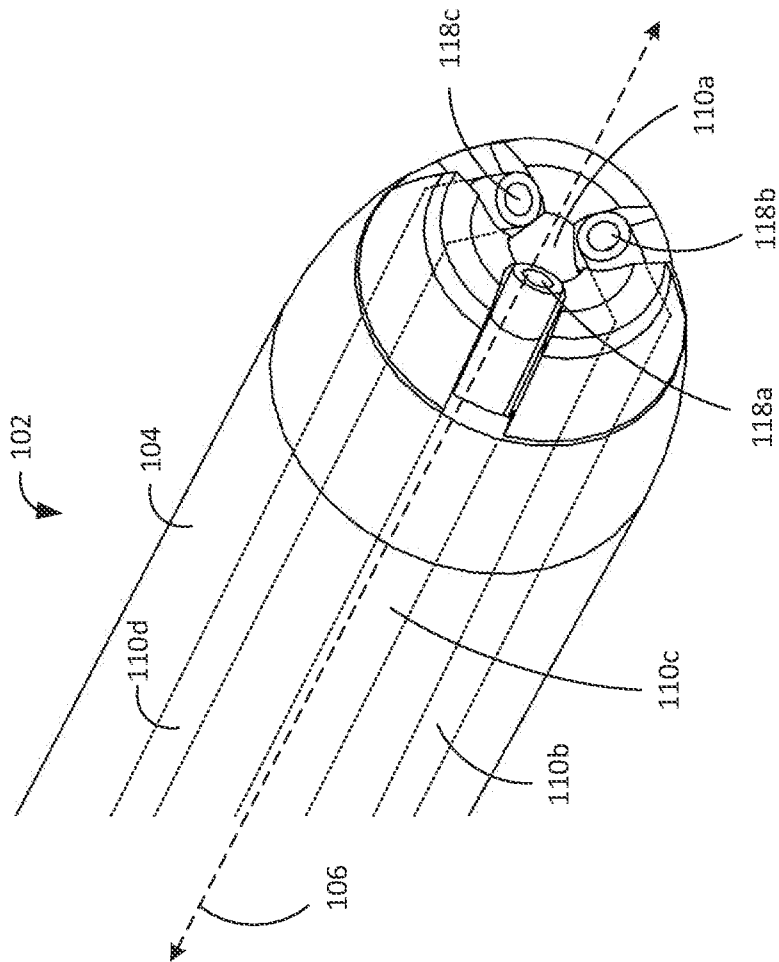


FIG. 3B

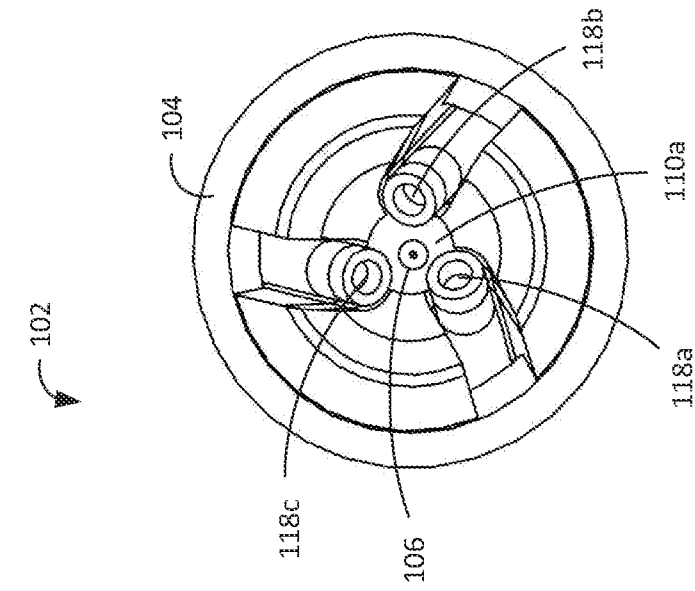


FIG. 4A

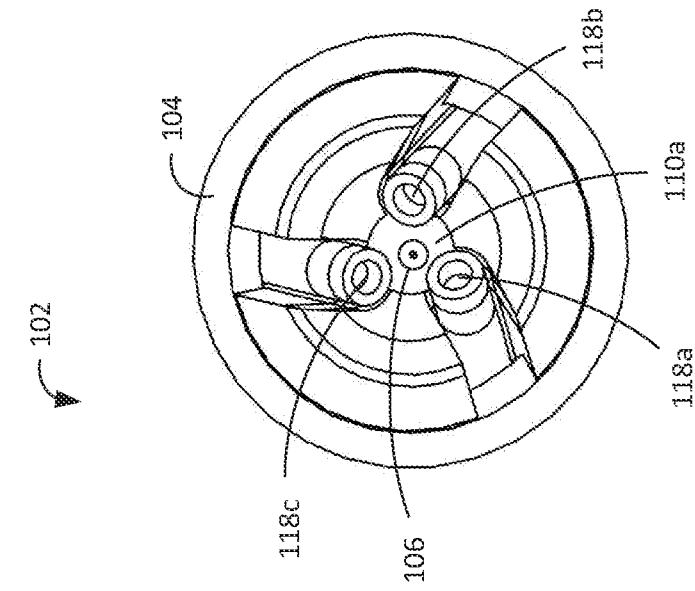


FIG. 4B

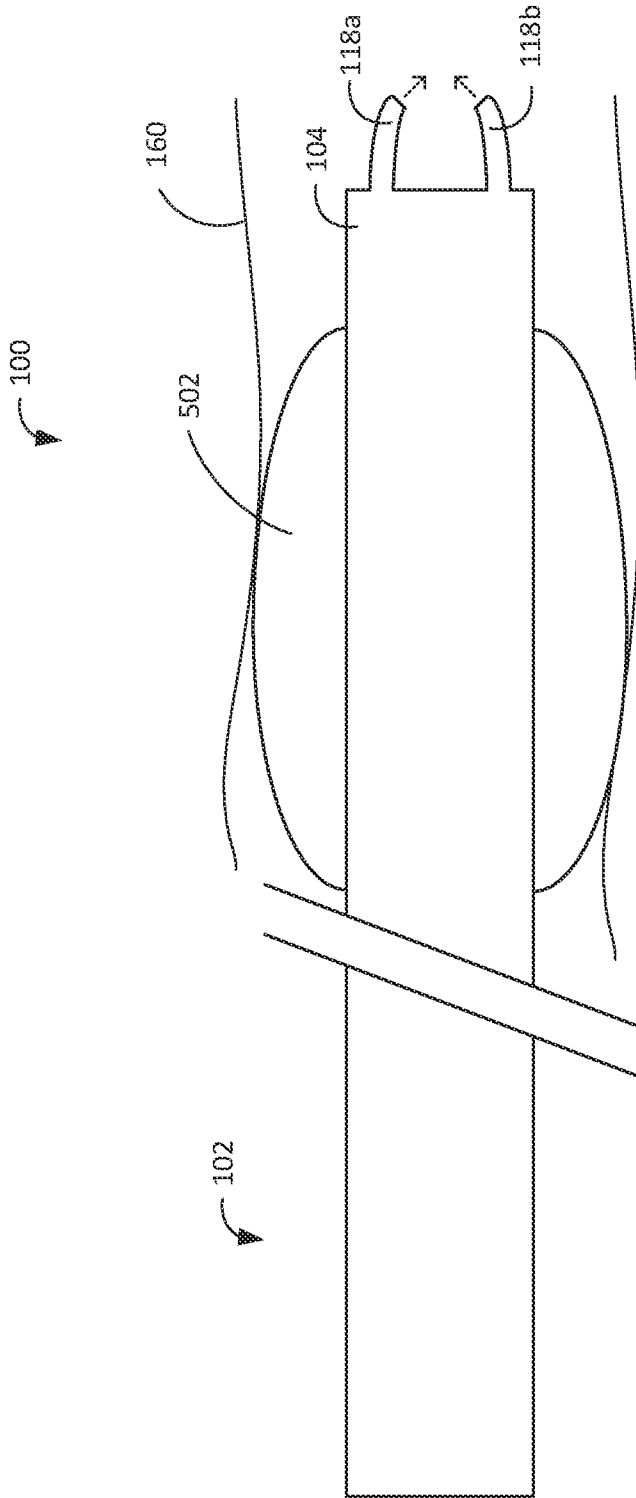


FIG. 5A

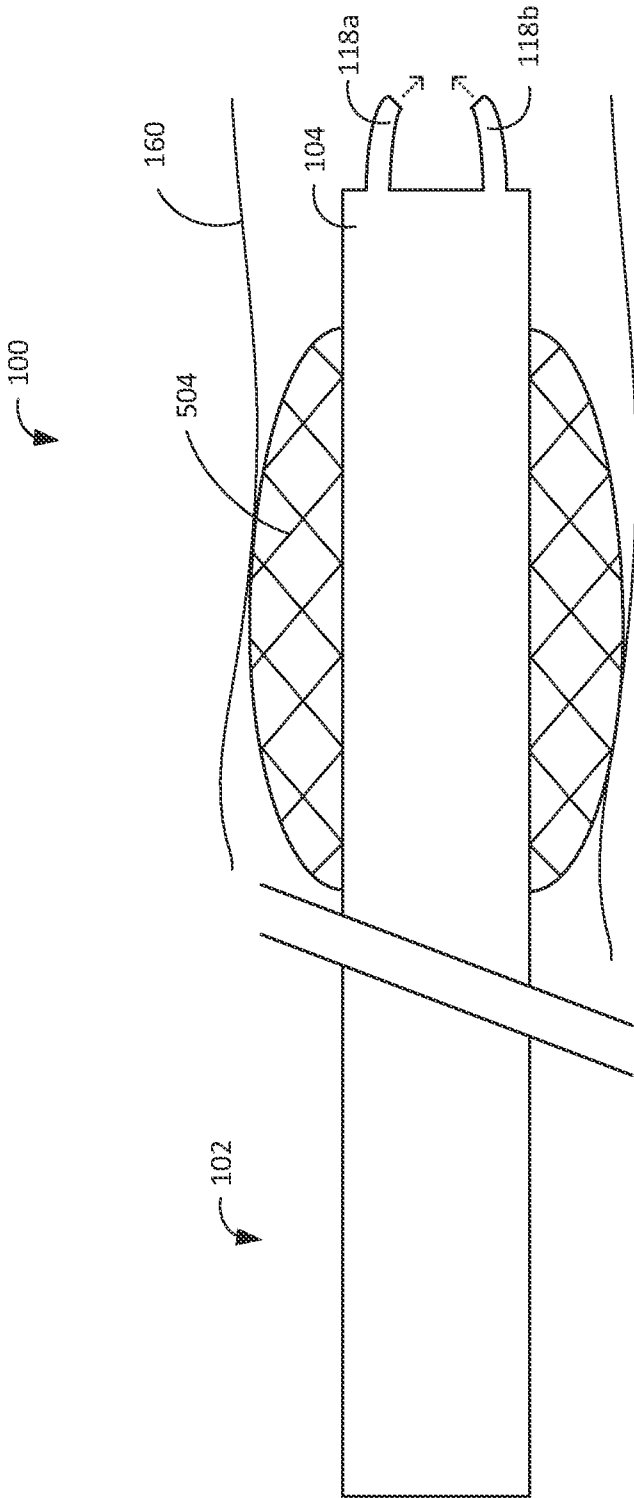


FIG. 5B

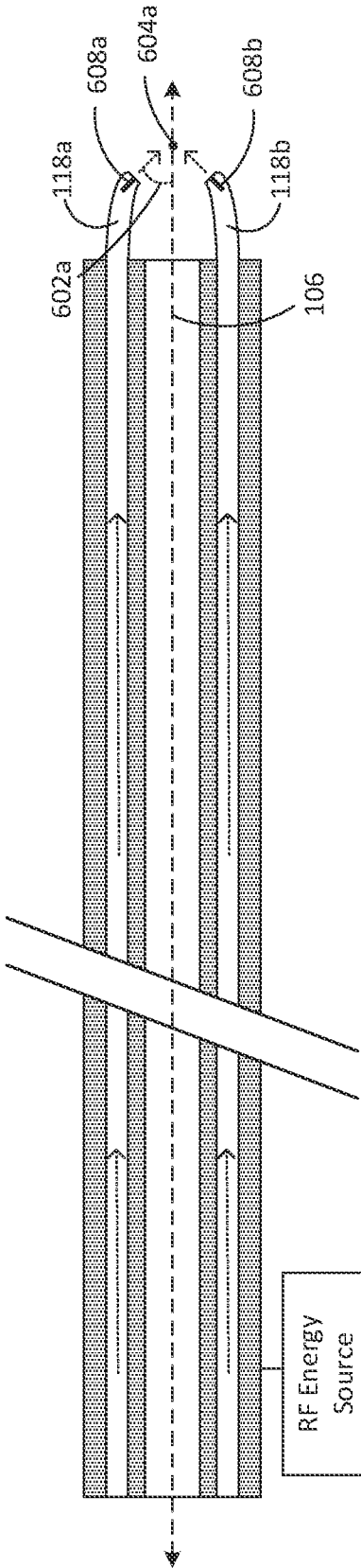


FIG. 6A

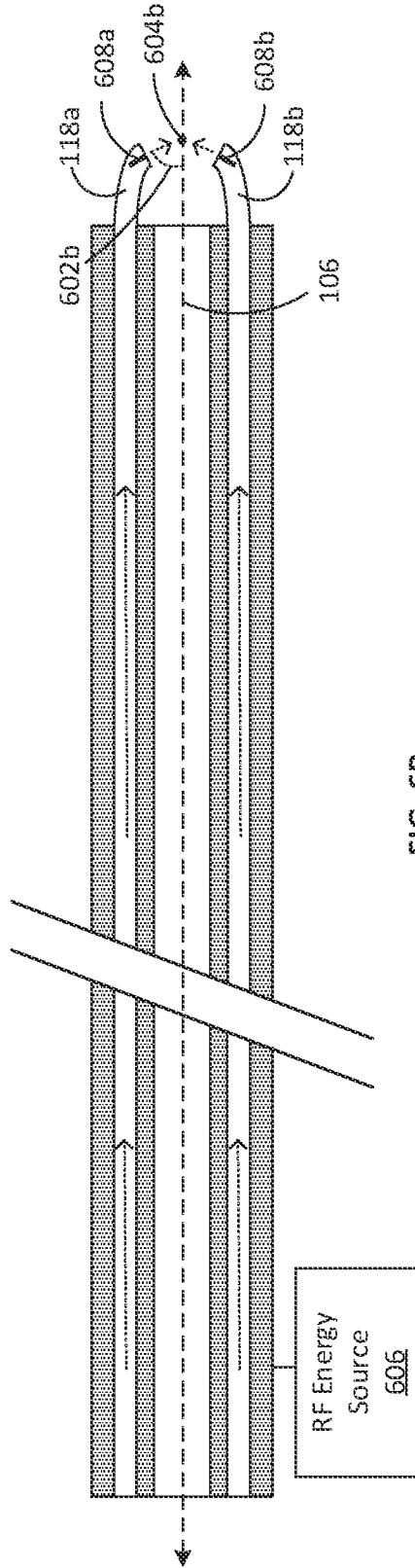


FIG. 6B

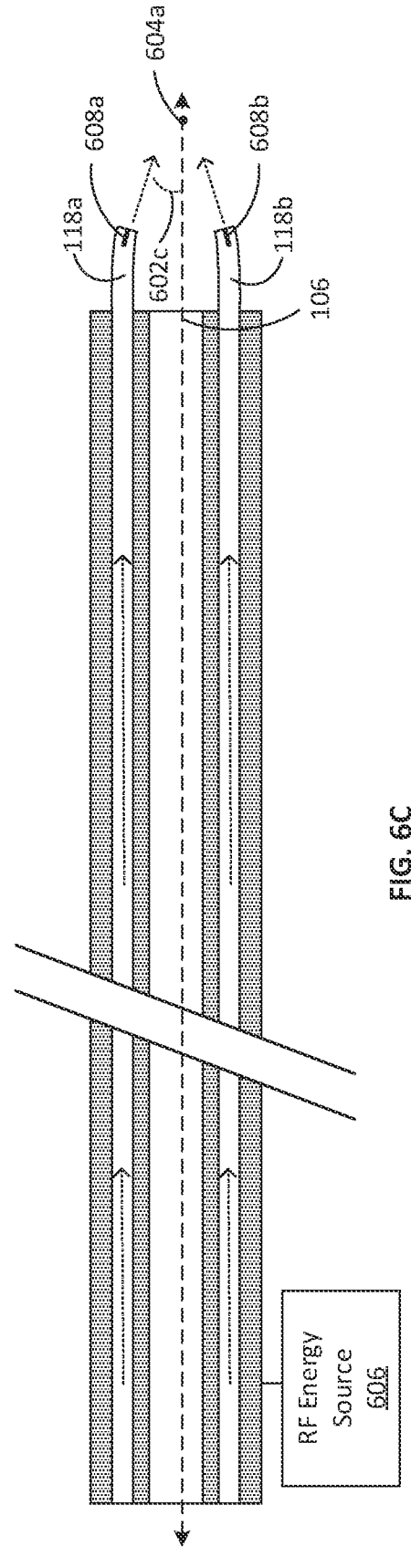


FIG. 6C

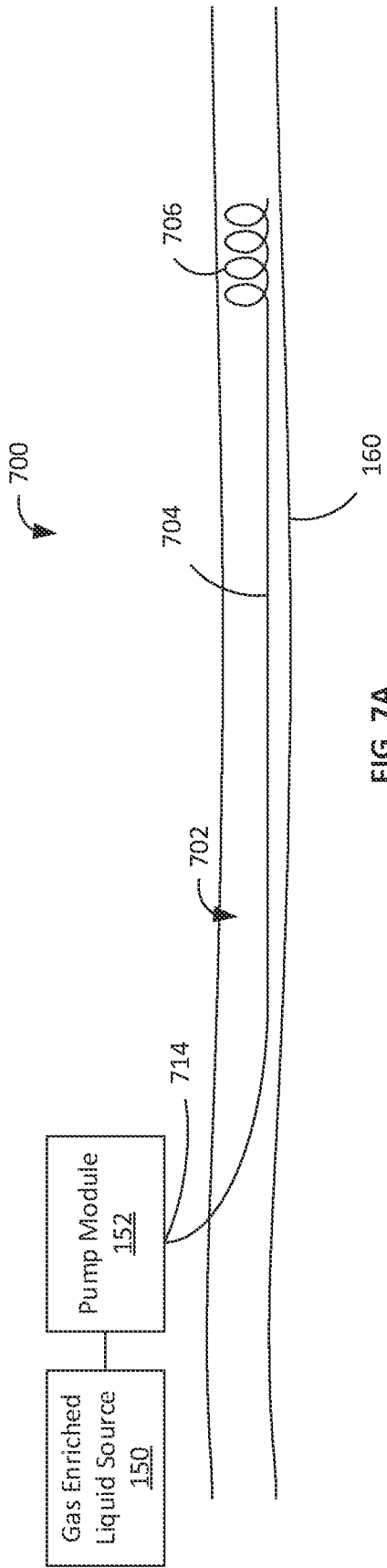


FIG. 7A

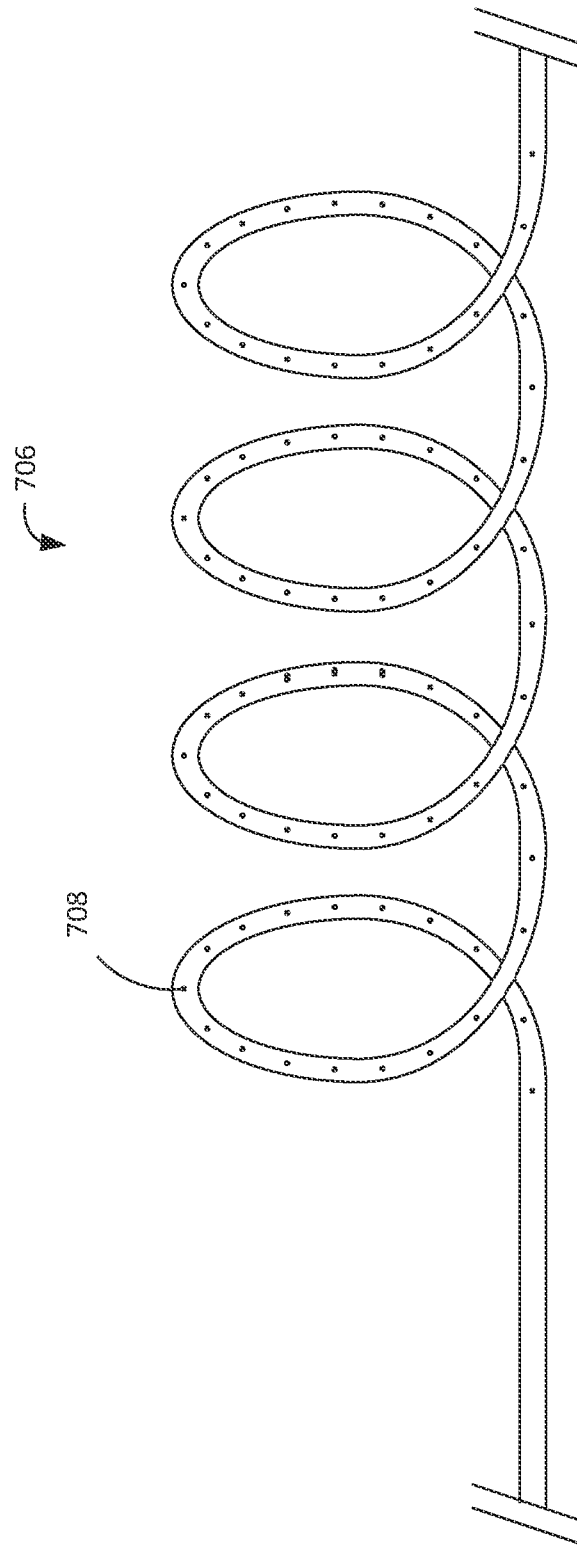


FIG. 7B

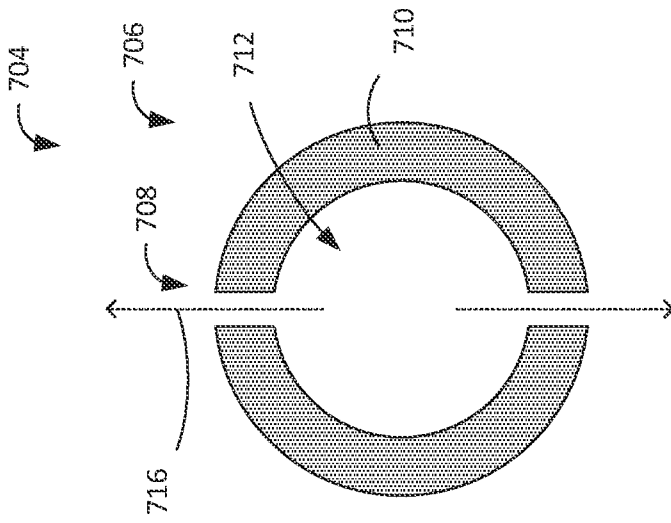


FIG. 7C

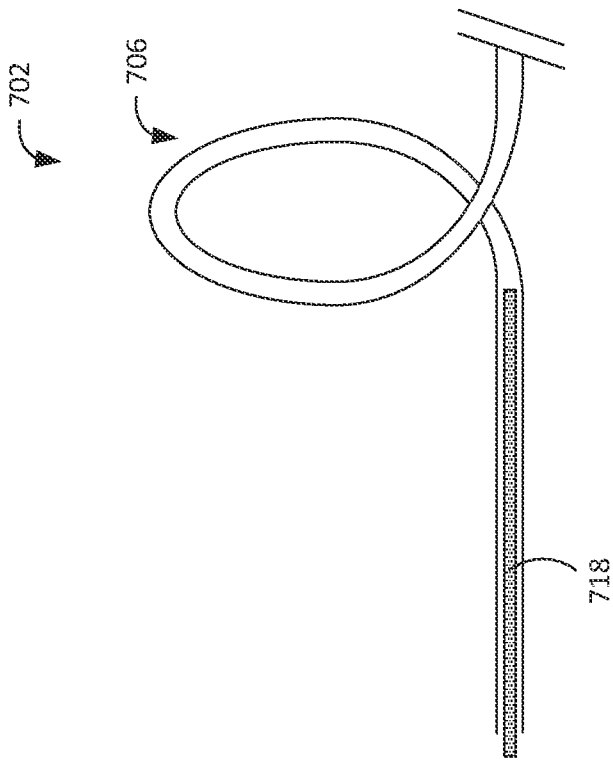


FIG. 8A

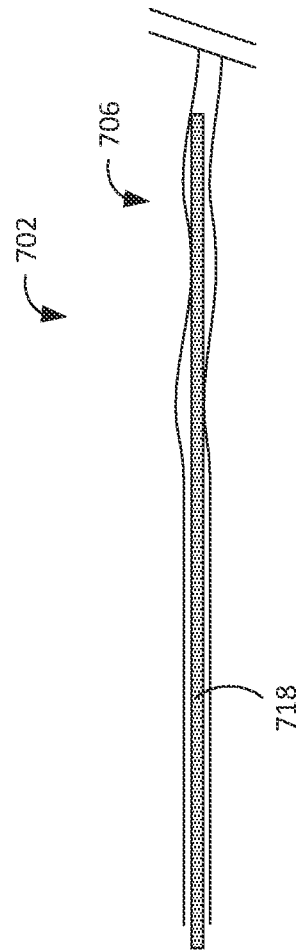


FIG. 8B

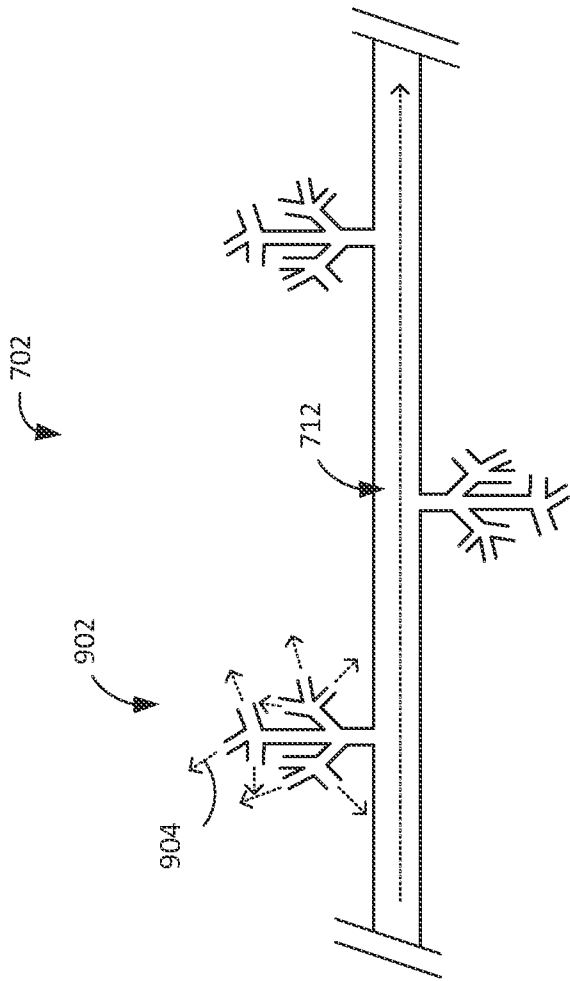


FIG. 9A

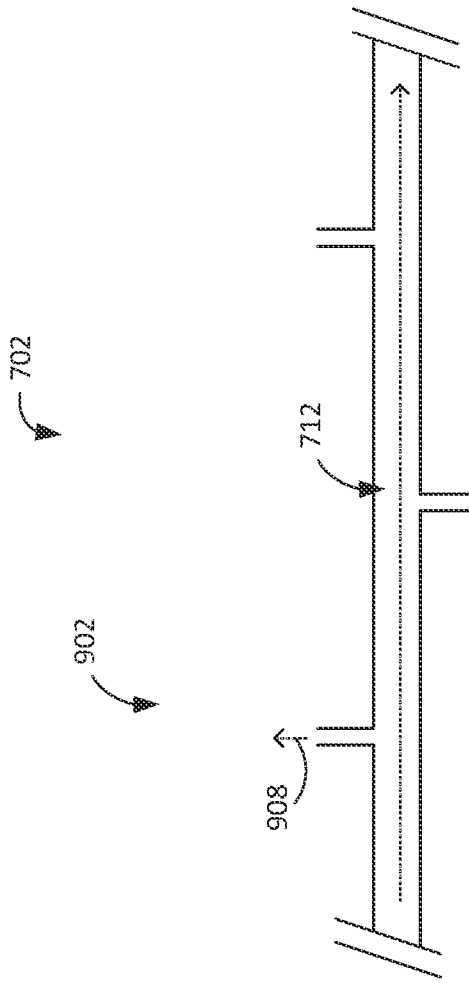


FIG. 9B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 22/16988

A. CLASSIFICATION OF SUBJECT MATTER IPC - A61M 25/00 (2022.01) CPC - A61M 25/0026		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) See Search History document		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched See Search History document		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) See Search History document		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y -- A	US 2012/0302995 A1 (HOCHAREON); 29 November 2012 (29.11.2012); entire document, especially Fig. 11A, para. [0062], [0087], [0094]-[0098].	1-8, 11-32, 77 ----- 9-10
Y, & ----- A	US 2018/0207592 A1 (THEROX, INC.); 26 July 2018 (26.07.2018); entire document, especially Fig. 5A-5C; Abstract, para. [0017]-[0018], [0031], [0038], [0043]-[0044], [0063]	1-8, 11-32, 77 ----- 9-10
Y	US 2013/0079859 A1 (ZOLL CIRCULATION, INC.); 28 March 2013 (28.03.2013); entire document, especially Abstract, Fig. 9, para. [0043]-[0044].	19
Y	US 5,423,320 A (SALZMAN et al.); 13 June 1995 (13.06.1995); entire document, especially Abstract.	23
Y	US 2006/0271093 A1 (HOLMAN et al.); 30 November 2006 (30.11.2006); entire document, especially Abstract, Fig. 1, para. [0050]-[0051].	25
A	US 2009/0107503 A1 (BARAN); 30 April 2009 (30.04.2009); entire document.	1-32, 77
<input type="checkbox"/> Further documents are listed in the continuation of Box C.		<input type="checkbox"/> See patent family annex.
* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family	
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)		
"O" document referring to an oral disclosure, use, exhibition or other means		
"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search 5 April 2022	Date of mailing of the international search report JUL 18 2022	
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Kari Rodriguez Telephone No. PCT Helpdesk: 571-272-4300	

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 22/16988

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

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

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

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

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-32 and 77 directed to a catheter comprising two or more capillaries.

Group II: Claims 33-57 and 78 directed to a catheter comprising a plurality of apertures.

Group III: Claims 58-76 and 79 directed to a catheter comprising a plurality of elongated tubes.

-*-Continued in extra sheet*-*

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-32 and 77

Remark on Protest

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

-Box No. III - Lack of unity-

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

SPECIAL TECHNICAL FEATURES

The invention of Group I includes the special technical features of [a first lumen extending through the catheter body], wherein [the first lumen] is configured to be in fluid communication with the vasculature of the patient when the catheter is inserted into the vasculature of the patient, and [the first lumen] is configured to perform at least one of receiving a sample of blood from [the vasculature of the patient] or measuring a parameter of the patient's blood; one or more second lumens extending through [the catheter body]; and two or more capillaries extending from [the catheter body] and coupled to the one or more second lumens, wherein each of the two or more capillaries are in fluid communication with the one or more second lumens and are in fluid communication with [the vasculature of the patient] when [the catheter] is inserted into [the vasculature of the patient], and wherein each of the two or more capillaries are configured to receive [the gas enriched liquid] from the one or more second lumens and to simultaneously dispense respective streams of [the gas enriched liquid] directly into [the vasculature of the patient], wherein [the catheter body] is configured to position the two or more capillaries at one or more predetermined angles relative to one another, such that the streams of [the gas enriched liquid] intersect and mix with the patient's blood in a region beyond an end of [the catheter body] and beyond [the first lumen]; and wherein [the first lumen] is recessed relative to respective output ends of the two or more capillaries., not required in Groups II-III.

The invention of Group II includes the special technical features of [an elongated catheter body] having a coiled shape, and a plurality of apertures positioned along a length of [the catheter body], the plurality of apertures in fluid communication with [the first lumen], wherein the apertures are configured to dispense [the gas enriched liquid] directly into [the vasculature of the patient], not required in Groups I and III.

The invention of Group III includes the special technical features of a plurality of elongated tubes extending along [the catheter body], wherein adjacent elongated tubes are offset from one another along [the catheter body], wherein each of the elongated tubes comprises a respective second lumen in fluid communication with [the first lumen], and wherein the elongated tubes are configured to receive [the gas enriched liquid] from [the first lumen] and dispense [the gas enriched liquid] directly into [the vasculature of the patient], not required in Groups I-II.

COMMON TECHNICAL FEATURES

The inventions of Groups I-III share the technical features of a catheter configured to be inserted into a vasculature of a patient, the catheter comprising:
an elongated catheter body; and
a first lumen extending through the catheter body, wherein the first lumen is configured to receive a gas enriched liquid, and further wherein the catheter is configured to dispense the gas enriched liquid directly into the vasculature of the patient. The common technical features are known in prior art as shown in US 2018/0207592 A1 to Therox, Inc. (hereinafter 'Therox'). Therefore, Groups I-III lack unity since the shared technical features do not represent a contribution over:

Therox teaches a catheter configured to be inserted into a vasculature of a patient (catheter 500, Fig. 5A, para. [0039]), the catheter comprising:
an elongated catheter body (elongated tube 40, Fig. 5A, para. [0044]); and
a first lumen extending through the catheter body (lumen of tube 40, Fig. 5A, 5B), wherein the first lumen is configured to receive a gas enriched liquid (oxygen-enriched saline is delivered from the fluid oxygenation device 54 to catheter 500 via the single lumen tube 40, para. [0044]), and further wherein the catheter is configured to dispense the gas enriched liquid directly into the vasculature of the patient (deliver oxygen enriched saline directly to the patient's coronary vasculature through the fluid delivery catheter, para. [0063]).

As the common features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups.

Therefore, Groups I-III lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.