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Blood Collection System with Automatic Pressure Management and Related Methods

Abstract

A blood collection system may include a needle assembly, which may include a needle configured to receive an evacuated blood collection tube. The blood collection system may include a tubing, which may include a distal end and a proximal end. The proximal end may be coupled to the needle assembly. The tubing may include a first flow channel and a second flow channel. The first flow channel may be configured to collapse at a lower pressure differential than the second flow channel.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 17/086,982, filed Nov. 2, 2020, and entitled “Blood Collection System with Automatic Pressure Management and Related Methods” which claims the benefit of U.S. Provisional Application No. 62/934,960, filed Nov. 13, 2019, and entitled “Blood Collection System with Automatic Pressure Management and Related Methods”, the disclosures of which are incorporated herein in their entirety.

BACKGROUND
[0002] Intravenous catheters are commonly used for a variety of infusion therapies. For example, intravenous catheters may be used for infusing fluids, such as normal saline solution, various medicaments, and total parenteral nutrition, into a patient. Intravenous catheters may also be used for withdrawing blood from the patient.
[0003] Common types of intravenous catheter are peripheral IV catheters (“PIVCs”), peripherally inserted central catheters (“PICCs”), and midline catheters. Intravenous catheters may include “over-the needle” catheters, which may be mounted over a needle having a sharp distal tip. The sharp distal tip may be used to pierce skin and the vasculature of the patient. Insertion of the intravenous catheter into the vasculature may follow the piercing of the vasculature by the needle. The needle and the intravenous catheter are generally inserted at a shallow angle through the skin into the vasculature of the patient with a bevel of the needle facing up and away from the skin of the patient.
[0004] In order to verify proper placement of the introducer needle and/or the intravenous catheter in the vasculature, a user generally confirms that there is flashback of blood, which may be visible to the user. In some instances, the introducer needle may include a notch disposed towards a distal end of the introducer needle, and in response to the distal tip of the introducer needle being positioned within the vasculature, blood may flow proximally through a needle lumen, exit the needle lumen through the notch, and then travel proximally between an outer surface of the introducer needle and an inner surface of the intravenous catheter.
[0005] Accordingly, where the intravenous catheter is at least partially transparent, the user may visualize a small amount of blood “flashback” and thereby confirm placement of the intravenous catheter within the vasculature. Presence of a vasculature entrance indicator, such as flashback, may facilitate successful placement of intravenous catheters. Once placement of the introducer needle within the vasculature has been confirmed, the user may temporarily occlude flow in the vasculature and withdraw the introducer needle, leaving the intravenous catheter in place for future blood withdrawal and/or fluid infusion.
[0006] For blood withdrawal, an evacuated blood collection tube may be used. An evacuated blood collection tube includes a test tube with a rubber stopper at one end. The evacuated blood collection tube has had all or a portion of air removed from the test tube so pressure within the evacuated blood collection tube is lower than ambient pressure. Such an evacuated blood collection tube is often referred to as an internal vacuum or a vacuum tube. A commonly used evacuated blood collection tube is a VACUTAINER® blood collection tube, available from Becton, Dickinson & Company.
[0007] To collect a blood sample from a patient, an adapter is coupled to the needle or the intravenous catheter. The adapter includes an additional needle that penetrates the rubber stopper of the evacuated blood collection tube. When the rubber stopper is penetrated, a pressure in the vein is higher than a pressure in the evacuated blood collection tube, which pushes blood into the

evacuated blood collection tube, thus filling the evacuated blood collection tube with blood. A vacuum within the evacuated blood collection tube decreases as the evacuated blood collection tube fills, until the pressure in the evacuated blood collection tube equalizes with the pressure in the vein, and the flow of blood stops.

[0008] Unfortunately, as blood is drawn into the evacuated blood collection tube, red blood cells are in a high shear stress state and susceptible to hemolysis due to a high initial pressure differential between the vein and the evacuated blood collection tube. Hemolysis may result in rejection and discard of a blood sample. The high initial pressure differential can also result in catheter tip collapse, vein collapse, or other complications that prevent or restrict blood from filling the evacuated blood collection tube.

[0009] The subject matter claimed herein is not limited to embodiments that solve any disadvantages or that operate only in environments such as those described above. Rather, this background is only provided to illustrate one example technology area where some implementations described herein may be practiced.

SUMMARY

[0010] The present disclosure generally relates to a blood collection system with automatic pressure management, as well as related devices and methods. In some embodiments, a blood collection system may provide a fluid pathway between a catheter and an evacuated blood collection tube that has an inner diameter that is responsive to a pressure differential between the evacuated blood collection tube and a vein of a patient. In some embodiments, in response to coupling of the evacuated blood collection tube to the blood collection system, a spike in the pressure differential may occur. In some embodiments, in response to the spike in the pressure differential, an inner diameter of a portion of the fluid pathway may decrease, which may increase a fluidic resistance of the fluid pathway and slow blood flow into the blood collection system. In some embodiments, the decreased blood flow may reduce a risk of hemolysis. In some embodiments, the decreased blood flow may also reduce a risk of collapse of the vein and/or the catheter.

[0011] In some embodiments, as the evacuated blood collection tube fills with blood, a vacuum within the evacuated blood collection tube may decrease, and the pressure differential between the evacuated blood collection tube and the vein may decrease. In some embodiments, the decreased pressure differential may result in the inner diameter of the portion of the fluid pathway increasing, which may reduce the fluidic resistance and increase a flow rate of blood into the blood collection system. Thus, despite the decrease in the pressure differential, the evacuated blood collection tube may still fill quickly.

[0012] In some embodiments, the blood collection system may include a needle assembly, which may include a needle configured to receive the evacuated blood collection tube. In some embodiments, the blood collection device may include a blood collection tube holder, which may be coupled to the needle assembly and surround the needle. In some embodiments, the blood collection system may include a tubing, which may include a distal end and a proximal end. In some embodiments, the proximal end may be coupled to the needle assembly. In some embodiments, the tubing may include a first flow channel and a second flow channel. In some embodiments, the fluid pathway of the blood collection system may include the first flow channel and the second flow channel.

[0013] In some embodiments, the first flow channel may be configured to collapse at a lower pressure differential than the second flow channel. In some embodiments, the first flow channel may collapse in response to the spike in the pressure differential between the evacuated blood collection tube and a vein of a patient. In some embodiments, the second flow channel may not collapse in response to the spike in the pressure differential. In some embodiments, because the second flow channel remains open but the first flow channel collapses, the inner diameter may decrease but the fluid pathway may remain open. In some embodiments, as the evacuated blood

collection tube fills with blood, the first flow channel may open, allowing a flow rate of blood to increase.

[0014] In some embodiments, a fluidic resistance of the first flow channel may be less than a fluidic resistance of the second flow channel. In these embodiments, the fluidic resistance of the first flow channel may be less than the fluidic resistance of the second flow channel because a size or diameter of the first flow channel may be greater than a size or diameter of the second flow channel. In some embodiments, the first flow channel may be formed by a first wall and a shared wall, which may be shared between the first flow channel and the second flow channel. In some embodiments, the second flow channel may be formed by a second wall and the shared wall. In some embodiments, the first wall may include a lower durometer than the second wall. In some embodiments, the second flow channel may include a bore hole. In some embodiments, the bore hole may extend from the distal end of the tubing to the proximal end of the tubing.

[0015] In some embodiments, the blood collection system may include a catheter assembly. In some embodiments, the catheter assembly may include a catheter adapter, which may include a distal end, a proximal end, and a lumen extending through the distal end of the catheter adapter and the proximal end of the catheter adapter. In some embodiments, the distal end of the tubing may be coupled to the catheter adapter. In some embodiments, the catheter assembly may include the catheter extending distally from the distal end of the catheter adapter. In some embodiments, the blood collection system may include a male luer adapter coupled to the distal end of the tubing, and a female luer adapter coupled to the proximal end of the tubing. In some embodiments, the catheter assembly may be replaced with a needle set, which may be coupled to the distal end of the tubing.

[0016] In some embodiments, the blood collection system may include an outer tubing and an inner tubing. In some embodiments, an inner diameter of the outer tubing may be greater than an outer diameter and an inner diameter of the inner tubing. In some embodiments, the blood collection system may include another first flow channel and another second flow channel. In some embodiments, the other first flow channel may extend between the outer tubing and the inner tubing. In some embodiments, the other second flow channel may extend through the inner tubing. In some embodiments, the other first flow channel may be configured to collapse at a different pressure differential than the other second flow channel.

[0017] In some embodiments, the outer tubing may include a lower durometer than the inner tubing. In some embodiments, the other first flow channel may be configured to collapse at a lower pressure differential than the other second flow channel. In some embodiments, at the lower pressure differential, the outer tubing may contact the inner tubing to close at least a portion of the other first flow channel.

[0018] In some embodiments, the outer tubing may have a greater durometer than the inner tubing. In these and other embodiments, the other second flow channel may be configured to collapse at a lower pressure differential than the other first flow channel. In some embodiments, a distal end of the inner tubing may include a duck bill valve.

[0019] In some embodiments, the blood collection system may include another tubing, which may include no more than one flow channel. In some embodiments, an inner surface of the other tubing may include one or more ribs or one or more slots. In some embodiments, in response to the spike in the pressure differential, the slots may close, and the flow channel may remain open. In some embodiments, the slots may be configured to close when the pressure differential reaches a predetermined level. In some embodiments, the ribs may extend along a length of the other tubing and may be generally evenly spaced about a circumference of the inner surface. In some embodiments, the slots may extend outwardly from a generally cylindrical portion of the fluid channel. In some embodiments, in response to the spike in the pressure differential and the pressure differential reaching the predetermined level, the generally cylindrical portion of the fluid channel may remain open.

[0020] It is to be understood that both the foregoing general description and the following detailed

description are examples and explanatory and are not restrictive of the invention, as claimed. It should be understood that the various embodiments are not limited to the arrangements and instrumentality shown in the drawings. It should also be understood that the embodiments may be combined, or that other embodiments may be utilized and that structural changes, unless so claimed, may be made without departing from the scope of the various embodiments of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0021] Example embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0022] FIG. **1**A is an upper perspective view of an example blood collection system, according to some embodiments;

[0023] FIG. **1**B is a cross-sectional view along the line **1**B-**1**B of FIG. **1**A, according to some embodiments;

[0024] FIG. **1**C is an enlarged cross-section of an example tubing, according to some embodiments;

[0025] FIG. **1**D is a cross-sectional view of the blood collection system of FIG. **1**A, according to some embodiments;

[0026] FIG. **2**A is another cross-sectional view along the line **1**B-**1**B of FIG. **1**A, according to some embodiments;

[0027] FIG. **2**B is an enlarged cross-section of another example tubing, according to some embodiments;

[0028] FIG. **2**C is another cross-sectional view of the blood collection system of FIG. **1**A, according to some embodiments;

[0029] FIG. **2**D is another cross-sectional view of the blood collection system of FIG. **1**A, illustrating an example flow channel with closed ends, according to some embodiments;

[0030] FIG. **3**A is another cross-sectional view along the line **1**B-**1**B of FIG. **1**A, according to some embodiments;

[0031] FIG. **3**B is an enlarged cross-section of another example tubing, according to some embodiments;

[0032] FIG. **3**C is another cross-sectional view of the blood collection system of FIG. **1**A, according to some embodiments;

[0033] FIG. **3**D is another cross-sectional view of the blood collection system of FIG. **1**A, illustrating an example evacuated blood collection tube coupled to the blood collection system, according to some embodiments;

[0034] FIG. **3**E is another cross-sectional view of the blood collection system of FIG. **1**A, according to some embodiments;

[0035] FIG. **4**A is another cross-sectional view along the line **1**B-**1**B of FIG. **1**A, according to some embodiments;

[0036] FIG. **4**B is an enlarged cross-section of another example tubing, according to some embodiments;

[0037] FIG. **4**C is another cross-sectional view of the blood collection system of FIG. **1**A, according to some embodiments;

[0038] FIG. **4**D is another cross-sectional view of the blood collection system of FIG. **1**A, illustrating the evacuated blood collection tube coupled to the blood collection system, according to some embodiments;

[0039] FIG. **5**A is another cross-sectional view along the line **1**B-**1**B of FIG. **1**A, according to some embodiments;

[0040] FIG. **5**B is another cross-sectional view of the blood collection system of FIG. **1**A, according to some embodiments;
[0041] FIG. **6**A is a cross-sectional view of another example tubing at a first pressure differential, according to some embodiments;
[0042] FIG. **6**B is a cross-sectional view of the tubing of FIG. **6**A at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0043] FIG. **7**A is a cross-sectional view of another example tubing at a first pressure differential, according to some embodiments;
[0044] FIG. **7**B is a cross-sectional view of the tubing of FIG. **7**A at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0045] FIG. **8**A is a cross-sectional view of another example tubing at a first pressure differential, according to some embodiments;
[0046] FIG. **8**B is a cross-sectional view of the tubing of FIG. **8**A at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0047] FIG. **9**A is a cross-sectional view of another example tubing at a first pressure differential, according to some embodiments;
[0048] FIG. **9**B is a cross-sectional view of the tubing of FIG. **9**A at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0049] FIG. **10**A is a cross-sectional view of another example tubing at a first pressure differential, according to some embodiments;
[0050] FIG. **10**B is a cross-sectional view of the tubing of FIG. **10**A at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0051] FIG. **11**A is a cross-sectional view of another example tubing at a first pressure differential, according to some embodiments;
[0052] FIG. **11**B is a cross-sectional view of the tubing of FIG. **11**A at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0053] FIG. **12**A is another cross-sectional view of the blood collection system of FIG. **1**A, according to some embodiments;
[0054] FIG. **12**B is another cross-sectional view of the blood collection system of FIG. **12**A, illustrating the evacuated blood collection tube coupled to the blood collection system, according to some embodiments;
[0055] FIG. **12**C is a cross-sectional view of another example tubing at a first pressure differential, according to some embodiments;
[0056] FIG. **12**D is a cross-sectional view of the tubing of FIG. **12**C at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0057] FIG. **13**A is a cross-sectional view of another blood collection system, according to some embodiments;
[0058] FIG. **13**B is another cross-sectional view of the blood collection system of FIG. **13**A, illustrating the evacuated blood collection tube coupled to the blood collection system, according to some embodiments;
[0059] FIG. **14** is a cross-sectional view of the blood collection system of FIG. **13**A, according to some embodiments;
[0060] FIG. **15**A is a cross-sectional view of the blood collection system of FIG. **13**A at a first pressure differential, according to some embodiments;
[0061] FIG. **15**B is a cross-sectional view of the blood collection system of FIG. **15**A at a second pressure differential higher than the first pressure differential, according to some embodiments;
[0062] FIG. **16**A is a cross-sectional view of the blood collection system of FIG. **13**A at a first pressure differential, according to some embodiments;
[0063] FIG. **16**B is a cross-sectional view of the blood collection system of FIG. **16**A at a second pressure differential higher than the first pressure differential, according to some embodiments; and

[0064] FIG. **17** is a cross-sectional view of the blood collection system of FIG. **13**A, according to some embodiments.

DESCRIPTION OF EMBODIMENTS

[0065] Referring now to FIGS. **1**A-**1**D, in some embodiments, a blood collection system **10** may provide a fluid pathway between a catheter **12** and an evacuated blood collection tube that has an inner diameter that is responsive to a pressure differential between the evacuated blood collection tube and a vein of a patient. In some embodiments, in response to coupling of the evacuated blood collection tube to the blood collection system **10**, a spike in the pressure differential may occur. In some embodiments, in response to the spike in the pressure differential, an inner diameter of a portion of the fluid pathway may decrease, which may increase a fluidic resistance of the fluid pathway and slow blood flow into the blood collection system **10**. In some embodiments, the decreased blood flow may reduce a risk of hemolysis. In some embodiments, the decreased blood flow may also reduce a risk of collapse of the vein and/or the catheter.

[0066] In some embodiments, the evacuated blood collection tube may be evacuated such that a pressure within the evacuated blood collection tube is lower than ambient or atmospheric pressure. In some embodiments, the evacuated blood collection tube may include any suitable evacuated blood collection tube. In some embodiments, as the evacuated blood collection tube fills with blood, a vacuum within the evacuated blood collection tube may decrease, and the pressure differential between the evacuated blood collection tube and the vein may decrease. In some embodiments, the decreased pressure differential may result in the inner diameter of the portion of the fluid pathway increasing, which may reduce the fluidic resistance and increase a flow rate of blood into the blood collection system **10**. Thus, despite the decrease in the pressure differential, the evacuated blood collection tube may still fill quickly.

[0067] In some embodiments, the blood collection system **10** may include a needle assembly **14**, which may include a needle **16** configured to receive the evacuated blood collection tube (see, e.g., FIG. **3**D). In some embodiments, the needle assembly **14** may include one or more threads, which may be configured to couple to a blood collection tube holder **18**, which may be generally cylindrical. In some embodiments, the blood collection tube holder **18** may surround the needle **16**. In some embodiments, the needle assembly **14** may include a luer lock access device, such as, for example, the VACUTAINER® LUER-LOK™ ACCESS DEVICE available from Becton, Dickinson & Company.

[0068] In some embodiments, the needle assembly **14** may include a luer adapter **20**, which may include a luer lock or luer slip connector. In some embodiments, the luer adapter **20** may include a male or female luer connector. In some embodiments, the needle **16** may extend proximally from the luer adapter **20**.

[0069] In some embodiments, the blood collection system **10** may include a tubing **22**, which may include a distal end **24** and a proximal end **26**. In some embodiments, the proximal end **26** may be coupled to the needle assembly **14**, such as, for example, the luer adapter **20** of the needle assembly **14**. In some embodiments, the tubing **22** may include a first flow channel **28** and a second flow channel **30**. In some embodiments, the fluid pathway of the blood collection system **10** may include the first flow channel **28** and the second flow channel **30**. In some embodiments, the tubing **22** may be constructed of urethane (including polyurethanes), rubber, polyvinyl chloride (PVC), silicone, polyethylene (low density and high density), nylon, fluropolymers, polypropylene, acrylonitrile-butadiene styrene (ABS), polycarbonate, acrylic, and/or the like.

[0070] In some embodiments, the first flow channel **28** may be configured to collapse at a lower pressure differential than the second flow channel **30**. In some embodiments, collapsing may include partial or complete blocking of a particular flow channel due to failing or caving in of a surrounding wall forming the particular flow channel. In some embodiments, the first flow channel **28** may collapse in response to the spike in the pressure differential between the evacuated blood collection tube and the vein of the patient. In some embodiments, when the first flow channel **28**

collapses, the first flow channel may be partially or completely blocked. In some embodiments, the second flow channel **30** may not collapse in response to the spike in the pressure differential and a diameter of the second flow channel **30** may remain the same. In other embodiments, the second flow channel **30** may partially collapse in response to the spike in the pressure differential. In other embodiments, the second flow channel **30** may collapse less than the first flow channel **28** in response to the spike in the pressure differential. In some embodiments, because the second flow channel **30** remains open but the first flow channel collapses, the inner diameter of the portion of the fluid pathway may decrease but the fluid pathway may remain open. In some embodiments, as the evacuated blood collection tube fills with blood and the pressure differential decreases, the first flow channel **28** may open, allowing a flow rate of blood to increase.

[0071] In some embodiments, a fluidic resistance of the first flow channel **28** may be less than a fluidic resistance of the second flow channel. In these embodiments, the fluidic resistance of the first flow channel **28** may be less than the fluidic resistance of the second flow channel **30** because a size or diameter of the first flow channel **28** may be greater than a size or diameter of the second flow channel **30**.

[0072] In some embodiments, the first flow channel **28** may be formed by a first wall **32** and a shared wall **34**, which may be shared between the first flow channel **28** and the second flow channel **30**. In some embodiments, the shared wall **34** may include any portion of the tubing **22** disposed between the first flow channel **28** and the second flow channel **30**. In some embodiments, the second flow channel **30** may be formed by a second wall **36** and the shared wall **34**. In some embodiments, the first wall **32** may include a lower durometer than the second wall **36** and/or the shared wall **34**.

[0073] In some embodiments, the second flow channel **30** may include a bore hole, as illustrated, for example in FIGS. **1**B-**1**D. In some embodiments, the bore hole may extend from the distal end **24** of the tubing **22** to the proximal end **26** of the tubing **22**. In some embodiments, the bore hole may extend along a majority of a length of the tubing **22** from the distal end **24** of the tubing **22** to the proximal end **26** of the tubing **22**. In some embodiments, the bore hole may extend along a portion of the length of the tubing **22** from the distal end **24** of the tubing **22** to the proximal end **26** of the tubing **22**. In some embodiments, the first flow channel **28** may include a shape that is generally circular with the shared wall **34** protruding inwardly towards a middle of the circle to form a general C-shape. In some embodiments, the shared wall **34** may be convex, extending towards a middle portion of the first flow channel **28**.

[0074] In some embodiments, the blood collection system **10** may include a catheter assembly **40**. In some embodiments, the catheter assembly **40** may include a catheter adapter **42**, which may include a distal end **44**, a proximal end **46**, and a lumen **48** extending through the distal end **44** of the catheter adapter **42** and the proximal end **46** of the catheter adapter **42**. In some embodiments, the distal end **24** of the tubing **22** may be coupled to the catheter adapter **42**. In some embodiments, the catheter assembly **40** may include the catheter **12** extending distally from the distal end **44** of the catheter adapter **42**. In some embodiments, the catheter assembly **40** may be replaced with a needle set, which may be coupled to the distal end **24** of the tubing **22**.

[0075] In some embodiments, the blood collection system **10** may include a luer adapter **50** coupled to the distal end **24** of the tubing **22** and/or a luer adapter **52** coupled to the proximal end **26** of the tubing **22**. In some embodiments, the luer adapter **50** and/or the luer adapter **52** may include a luer lock or luer slip connector. In some embodiments, the luer adapter **50** and/or the luer adapter **52** may include a male or female luer connector. In some embodiments, the proximal end **26** of the tubing **22** may be integrated with the luer adapter **20** and/or the needle assembly **14**.

[0076] In some embodiments, the catheter assembly **40** may include a PIVC, such as, for example, the BD NEXIVA™ Closed IV Catheter system, the BD CATHENA™ Catheter system, the BD VENFLON™ Pro Safely Shielded IV Catheter system, the BD NEOFLON™ IV Cannula system, the BD INSYTE™ AUTOGUARD™ BC Shielded IV Catheter system, or another suitable

peripheral intravenous catheter system. In some embodiments, the catheter assembly **40** may include a PICC or a midline catheter. In some embodiments, the luer adapter **50** may be coupled to the catheter adapter **42** in any number of suitable ways. For example, the luer adapter **50** may be coupled to the distal end **44** of the catheter adapter **42**. As another example, the luer adapter **50** may be coupled to an extension tube extending outwardly from the catheter adapter **42**.

[0077] In some embodiments, an elastomeric sheath **54** may be coupled to the needle assembly **14**. In some embodiments, a proximal end of the needle **16** may be enveloped within the elastomeric sheath **54**. In some embodiments, the elastomeric sheath **54** may include an open distal end **58** and a closed proximal end **56**. In some embodiments, in response to the evacuated blood collection tube pushing the elastomeric sheath **54** distally, the needle **16** may pierce the elastomeric sheath **54**, and the needle **16** may insert into a cavity of the evacuated blood collection tube.

[0078] Referring now to FIGS. **2**A-**2**D, in some embodiments, a shape of the first flow channel **28** and/or the second flow channel **30** may vary. In some embodiments, the first flow channel **28** may be formed by the first wall **32** and the shared wall **34**, as illustrated, for example, in FIG. **2**B. In some embodiments, the second flow channel **30** may be formed by the second wall **36** and the shared wall **34**, as illustrated, for example, in FIG. **2**B. In some embodiments, the first wall **32** may include a lower durometer than the second wall **36** and/or the shared wall. In some embodiments, the shared wall **34** may be convex with respect to the first flow channel **28**. In some embodiments, together the first flow channel **28** and the second flow channel **30** may form a generally circular shape. In some embodiments, one or more of the first wall **32**, the shared wall **34**, and the second wall **36** may be generally smooth.

[0079] In some embodiments, as illustrated in FIG. **2**D, the second flow channel **30** may be isolated from the fluid pathway of the blood collection system **10** and may contain air, which may facilitate collapse or reduction in size of the first flow channel **28** in response to the spike in the pressure differential. In these embodiments, ends of the second flow channel **30** may be closed or sealed.

[0080] Referring now to FIGS. **3**A-**4**D, in some embodiments, the blood collection system **10** may include an outer tubing **62** and an inner tubing **64**. In some embodiments, an inner diameter of the outer tubing **62** may be greater than an inner diameter and outer diameter of the inner tubing **64**. In some embodiments, the outer tubing **62** may include a first flow channel **66**, and the inner tubing **64** may include a second flow channel **68**. In some embodiments, the first flow channel **66** may extend between the outer tubing **62** and the inner tubing **64**. In some embodiments, the second flow channel **68** may extend through the inner tubing **64**, and the first flow channel **66** may extend through the outer tubing **62**. In some embodiments, the first flow channel **66** and the outer tubing **62** may be configured to collapse at a different pressure differential than the second flow channel **68** and the inner tubing **64**.

[0081] Referring now to FIGS. **3**A-**3**E, in some embodiments, the outer tubing **62** may include a lower durometer than the inner tubing **64**. In some embodiments, the first flow channel **66** and the outer tubing **62** may be configured to collapse at a lower pressure differential than the second flow channel **68** and the inner tubing **64**. In some embodiments, at the lower pressure differential, the outer tubing **62** may contact the inner tubing **64** to close at least a portion of the first flow channel **66**. In some embodiments, the first flow channel **66** and the outer tubing **62** may collapse in response to coupling the evacuated blood collection tube to the blood collection system **10**, as illustrated, for example, in FIG. **3**D.

[0082] In some embodiments, in response to the evacuated blood collection tube partially filling with blood, the first flow channel **66** may open. In some embodiments, the diameter of the second flow channel **68** may remain the same or substantially the same prior to and after coupling the evacuated blood collection tube to the blood collection system **10**. In some embodiments, the diameter of the second flow channel **68** may remain the same prior to and after coupling the evacuated blood collection tube partially filling with blood.

[0083] In some embodiments, the inner tubing **64** may not be coupled to the outer tubing **62**. In

some embodiments, the inner tubing **64** may be coupled to the outer tubing **62**. In some embodiments, a portion of the inner tubing **64** may be embedded in the outer tubing **62**. In some embodiments, the inner tubing **64** may be secured within the outer tubing **62** by a portion of a particular adapter, as illustrated, for example, in FIG. **3**E. In some embodiments, the second flow channel **68** may be isolated from the fluid pathway of the blood collection system **10** and may contain air, similar to, for example, FIG. **2**D. In some embodiments, a proximal end of the inner tubing **64** and/or the outer tubing **62** may be integrated with the luer adapter **20** and/or the needle assembly **14**.

[0084] Referring now to FIGS. **4**A-**4**D, in some embodiments, the outer tubing **62** may have a greater durometer than the inner tubing **64**. In some embodiments, the second flow channel **68** and the inner tubing **64** may be configured to collapse at a lower pressure differential than the first flow channel **66** and the outer tubing **62**. In some embodiments, the second flow channel **68** and the inner tubing **64** may collapse in response to coupling the evacuated blood collection tube to the blood collection system **10**, as illustrated, for example, in FIG. **4**D. In some embodiments, in response to the evacuated blood collection tube partially filling with blood, the second flow channel **68** may open. In some embodiments, the diameter of the first flow channel **66** may remain the same prior to and after coupling the evacuated blood collection tube to the blood collection system **10**. In some embodiments, the diameter of the first flow channel **66** may remain the same prior to and after coupling the evacuated blood collection tube partially filling with blood. In some embodiments, the second flow channel **68** may be isolated from the fluid pathway of the blood collection system **10** and may contain air, similar to, for example, FIG. **2**D.

[0085] Referring now to FIGS. **12**A-**12**B, in some embodiments, a distal end of the inner tubing **64** may include a duck bill valve **70**. In these and other embodiments, the outer tubing **62** may have a greater durometer than the inner tubing **64**. In some embodiments, the second flow channel **68** and the inner tubing **64** may collapse in response to coupling the evacuated blood collection tube to the blood collection system **10**, as illustrated, for example, in FIG. **12**B and **12**D. In some embodiments, in response to the second flow channel **68** and the inner tubing collapsing, the duck bill valve **70** may close. In some embodiments, in response to the evacuated blood collection tube partially filling with blood, the duck bill valve **70** and the second flow channel **68** may open, as illustrated, for example in FIG. **12**C.

[0086] Referring back to FIGS. **5**A-**5**B, in some embodiments, the tubing **22** may include no more than one flow channel **71** extending through the tubing **22**. In some embodiments, an inner surface of the tubing **22** may include one or more ribs **72**, as illustrated, for example, in FIGS. **5**A-**5**B. In some embodiments, the ribs **72** may extend along a length of the tubing **22** and/or may be generally evenly spaced about a circumference of the inner surface of the tubing **22**. In some embodiments, the ribs **72** may maintain a minimum flow rate through the tubing **22** even when the tubing **22** is collapsed. In some embodiments, the outer tubing **62** and/or the inner tubing **64** discussed with respect to FIGS. **3**A-**4**D and **12** may include the ribs **72**.

[0087] Referring now to FIGS. **6**A-**8**B, in some embodiments, the inner surface of the tubing **22** may include one or more slots **74**, as illustrated, for example, in FIGS. **6**A-**8**B. In some embodiments, the tubing **22** may include the one flow channel **71**. In some embodiments, the slots **74** may extend along a length of the tubing **22** and/or may be generally evenly spaced about a circumference of the inner surface of the tubing **22**. In some embodiments, the inner surface of the tubing **22** may include one slot, two slots, three slots, four slots, or more than four slots, depending on, for example, a desired change in flow rate.

[0088] In some embodiments, in response to the spike in the pressure differential, the tubing **22** may collapse such that the slots **74** close, and the flow channel **71** remains open. For example, in response to coupling the evacuated blood collection tube to the blood collection system **10**, the tubing **22** may collapse. In some embodiments, the slots **74** may extend outwardly from a generally cylindrical portion **76** of the flow channel **71**. In some embodiments, in response to the spike in the

pressure differential and the pressure differential reaching the predetermined level, the generally cylindrical portion **76** of the fluid channel may remain open. In some embodiments, in response to the evacuated blood collection tube partially filling with blood, the slots **74** may reopen.

[0089] Referring now to FIGS. **9**A-**9**B, the tubing **22** may include a generally hour-glass shape so that its medial portion has a smaller outer diameter and inner diameter than either side. In some embodiments, in response to the spike in the pressure differential and the pressure differential reaching the predetermined level, the tubing **22** may collapse such that the medial portion closes and two flow channels **78**, **80** are formed, as illustrated, for example, in FIG. **9**B. In some embodiments, in response to the evacuated blood collection tube partially filling with blood, the medial portion may reopen.

[0090] Referring now to FIGS. **10**A-**10**B, a cross-section of an inner lumen of the tubing **22** may include a generally hour-glass shape so that a medial portion of the inner lumen has a smaller diameter than either side of the inner lumen. In some embodiments, in response to the spike in the pressure differential and the pressure differential reaching the predetermined level, the tubing **22** may collapse such that the medial portion closes and one or more flow channels may be formed. For example, in response to the spike in the pressure differential and the pressure differential reaching the predetermined level, the tubing **22** may collapse such that the medial portion closes and the two flow channels **78**, **80** are formed, as illustrated, for example, in FIG. **10**B. In some embodiments, in response to the evacuated blood collection tube partially filling with blood, the medial portion may reopen.

[0091] Referring now to FIGS. **11**A-**11**B, the first flow channel **28** and the second flow channel **30** are illustrated, according to some embodiments. In some embodiments, the first flow channel **28** may be configured to collapse at a lower pressure differential than the second flow channel **30**. In some embodiments, the first flow channel **28** may collapse in response to the spike in the pressure differential between the evacuated blood collection tube and the vein of the patient. In some embodiments, when the first flow channel **28** collapses, the first flow channel may be partially or completely blocked. In some embodiments, the first flow channel **28** may be elongated and have a narrowed inner diameter along an entirety of its length compared to the second flow channel **30**, which may facilitate collapse of the first flow channel **28**. In some embodiments, the second flow channel **30** may be generally circular or another suitable shape.

[0092] Referring now to FIGS. **13**A-**13**B, in some embodiments, a blood collection system **82** may include a housing **84**. In some embodiments, the blood collection system **82** may be similar or identical to the blood collection system **10** discussed with respect to FIGS. **1**A-**12**D in terms of one or more included features and/or operation. In some embodiments, the housing **84** may include a distal end **86** and a proximal end **88**. In some embodiments, the housing **84** may correspond to a tubing. In some embodiments, the distal end **86** may include a luer adapter **87** and/or the proximal end **88** may include a luer adapter **89**. In some embodiments, the luer adapter **87** and/or the luer adapter **89** may include a luer lock or luer slip connector. In some embodiments, the luer adapter **87** and/or the luer adapter **89** may include a male or female luer connector. In some embodiments, the proximal end **88** may be integrated with the luer adapter **20** and/or the needle assembly **14**.

[0093] In some embodiments, the blood collection system **82** may include a tubing **90**, which may include a distal end **92** and a proximal end **94**. In some embodiments, the tubing **90** may be similar or identical to the tubing **22** discussed with respect to FIGS. **1**A-**2**C and **5**A-**11**B in terms of one or more included features and/or operation. In some embodiments, the distal end **92** and/or the proximal end **94** may be coupled to the housing **84**. In some embodiments, the housing **84** may include a higher durometer than the tubing **90**. In some embodiments, in response to the spike in the pressure differential and the pressure differential reaching the predetermined level, a flow channel **96** extending through the tubing **90** may collapse, as illustrated, for example, in FIG. **13**B. In some embodiments, the flow channel **96** may be closed or restricted in response to the tubing **90** collapsing. In some embodiments, in response to the evacuated blood collection tube partially

filling with blood, the flow channel **96** may reopen.
[0094] Referring now to FIG. **14**, in some embodiments, a septum **98** may be disposed within the housing **84**. In some embodiments, a flow channel or opening **100** may extend through the septum **98**. In some embodiments, the septum **98** may be annular. In some embodiments, a diameter of the opening **100** may be manually adjusted by a user. In some embodiments, the septum **98** may be coupled to a threaded nut, which may be threaded within the housing **84**. In some embodiments, the threaded nut may be rotated with respect to the housing **82** to increase or decrease a diameter of the opening **100** extending through the septum **98**.
[0095] Referring now to FIGS. **15**A-**16**B, in some embodiments, the septum **98** within the housing **84** may be partially pressurized with nitrogen or another gas that is compressible. In some embodiments, in response to the spike in the pressure differential, the opening **100** may narrow or close due to presence of nitrogen or the other gas and expansion of the septum **98**. In some embodiments, an inner surface of the septum **98** may include two opposing arc-shapes or another suitable shape. As illustrated in FIGS. **15**A-**15**B, in some embodiments, the septum **98** may not contact the housing **84** along an entirety of a length of the septum **98**. In some embodiments, the septum **98** may be coupled to the housing **84** at a first point and a second point, and a region between the first point and the second point may be spaced apart from the housing **84**. In some embodiments, the region may be arc-shaped or another suitable shape. As illustrated in FIGS. **16**A-**16**B, in some embodiments, the septum **98** may contact the housing **84** along an entirety of a length of the septum **98**.
[0096] Referring now to FIG. **17**, in some embodiments, in some embodiments, the tubing **90** may include a shape that facilitates a Coanda effect. In some embodiments, the tubing **90** may include a first branch **102**, which may be generally straight or parallel to a longitudinal axis of the blood collection system **82**. In some embodiments, blood within the first branch **102** may be configured to flow in a distal to proximal direction. In some embodiments, a second branch **104** may extend from the first branch **102**. In some embodiments, a portion of the second branch **104** proximate the first branch **102** may include a reverse branch, in which blood is configured to flow in a proximal to distal direction. In some embodiments, a distal end of the first branch **102** may extend through the distal end **86** of the housing **84** and/or be coupled with the luer adapter **87**. In some embodiments, a proximal end of the first branch **102** and/or a proximal end of the second branch **104** may be coupled to the proximal end **88** of the housing **84** and/or the luer adapter **89**.
[0097] In some embodiments, in response to a high pressure differential or the spike in the pressure differential, blood traveling through the tubing **90** from the catheter assembly **40** may largely bypass the second branch **104**. In some embodiments, in response to the high pressure differential or the spike in the pressure differential, a majority of blood traveling through the tubing **90** from the catheter assembly **40** may largely bypass the second branch **104** and may flow through the first branch **102**. In some embodiments, as the pressure differential decreases, more blood may flow through the second branch **104**, reducing an overall flow resistance.
[0098] All examples and conditional language recited herein are intended for pedagogical objects to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Although embodiments of the present inventions have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

Claims

1. A blood collection system, comprising: a needle assembly comprising a needle configured to receive an evacuated blood collection tube; and a tubing comprising: a distal end, a proximal end coupled to the needle assembly, and a first flow channel extending from the distal end to the

proximal end, and one or more ribs on an inner surface of the tubing, wherein the one or more ribs are configured to prevent the first flow channel from closing in response to a pressure differential between the proximal end and distal end.

2. The blood collection system of claim 1, wherein the one or more ribs extend along an entire length of the tubing.

3. The blood collection system of claim 1, wherein the one or more ribs are evenly spaced around a circumference of the inner surface of the tubing.

4. The blood collection system of claim 1, wherein the one or more ribs are configured to maintain a minimum fluid flow rate through the tubing in response to the pressure differential.

5. The blood collection system of claim 1, wherein the tubing further comprises a second flow channel, wherein the first flow channel is formed by a first wall and a shared wall, and wherein the second flow channel is formed by a second wall and the shared wall.

6. The blood collection system of claim 1, further comprising a blood collection tube holder coupled to the needle assembly, wherein the blood collection tube holder surrounds the needle.

7. The blood collection system of claim 1, further comprising a catheter assembly, wherein the catheter assembly comprises: a catheter adapter, comprising a distal end, a proximal end, and a lumen extending through the distal end of the catheter adapter and the proximal end of the catheter adapter, wherein the distal end of the tubing is coupled to the catheter adapter; and a catheter extending distally from the distal end of the catheter adapter.

8. A blood collection system, comprising: a needle assembly comprising a needle configured to receive an evacuated blood collection tube; and a tubing comprising: a distal end, a proximal end coupled to the needle assembly, and a first flow channel extending from the distal end to the proximal end, wherein the first flow channel includes a generally cylindrical portion and a plurality of slots extending outwardly from the generally cylindrical portion, and wherein the plurality of slots are configured to collapse in response to a pressure differential between the proximal end and distal end such that the generally cylindrical portion remains open.

9. The blood collection system of claim 8, wherein the plurality of slots extend along an entire length of the tubing.

10. The blood collection system of claim 8, wherein the plurality of slots are evenly spaced around a circumference of an inner surface of the tubing.

11. The blood collection system of claim 8, further comprising a blood collection tube holder coupled to the needle assembly, wherein the blood collection tube holder surrounds the needle.

12. The blood collection system of claim 8, further comprising a catheter assembly, wherein the catheter assembly comprises: a catheter adapter, comprising a distal end, a proximal end, and a lumen extending through the distal end of the catheter adapter and the proximal end of the catheter adapter, wherein the distal end of the tubing is coupled to the catheter adapter; and a catheter extending distally from the distal end of the catheter adapter.

13. A blood collection system, comprising: a needle assembly comprising a needle configured to receive an evacuated blood collection tube; and a tubing comprising: a distal end, a proximal end coupled to the needle assembly, and an inner lumen extending from the distal end to the proximal end, wherein a medial portion of the inner lumen has a smaller diameter than opposite side portions of the inner lumen, and wherein the medial portion is configured to collapse in response to a pressure differential between the proximal end and distal end such that one or more flow channels are formed in the side portions.

14. A blood collection system, comprising: a needle assembly comprising a needle configured to receive an evacuated blood collection tube; a housing comprising a distal end and a proximal end coupled to the needle assembly; a septum disposed within the housing; and a flow channel extending through the septum in fluid communication with the distal end and proximal end of the housing, wherein the flow channel is configured to narrow in response to a predetermined pressure differential.

15. The blood collection system of claim 14, wherein the septum is adjustable to increase or decrease a diameter of the flow channel.
16. The blood collection system of claim 15, wherein the septum is manually adjustable to increase or decrease a diameter of the flow channel.
17. The blood collection system of claim 16, further comprising a threaded nut rotatably attached to the housing, wherein the threaded nut is operable to increase or decrease the diameter of the flow channel.
18. The blood collection system of claim 14, wherein the septum is at least partially pressurized with a compressible gas.
19. The blood collection system of claim 14, wherein the septum is annular.
20. The blood collection system of claim 14, wherein the septum includes two opposing arc shapes.
21. The blood collection system of claim 14, wherein the septum is coupled to the housing at a first point and a second point, and a region of the septum between the first point and the second point is spaced apart from the housing.
22. The blood collection system of claim 21, wherein the region of the septum between the first point and the second point is arc-shaped.
23. The blood collection system of claim 14, wherein the septum contacts the housing along an entirety of a length of the septum.
24. The blood collection system of claim 14, further comprising a blood collection tube holder coupled to the needle assembly, wherein the blood collection tube holder surrounds the needle.
25. The blood collection system of claim 14, further comprising a catheter assembly, wherein the catheter assembly comprises: a catheter adapter comprising a distal end, a proximal end, and a lumen extending therethrough, wherein the distal end of the housing is coupled to the catheter adapter; and a catheter extending distally from the distal end of the catheter adapter.