United States Patent Application Publication	20250256021
Kind Code	A1
Publication Date	August 14, 2025
Inventor(s)	CULBERT; BRADLEY S. et al.

SYSTEMS AND METHODS FOR INJECTION AND ASPIRATION

Abstract

A system for catheter-based aspiration includes an aspiration catheter having a distal portion configured for insertion within a blood vessel of a subject, the aspiration catheter including an aspiration lumen having a distal opening at the distal portion of the aspiration catheter, an injection lumen having a distal end at the distal portion of the aspiration catheter, and an orifice located at or near the distal end of the injection lumen, the orifice configured to direct liquid into the aspiration lumen at or near the distal opening of the aspiration lumen; an injector configured to pressurize the liquid within the injection lumen, such that liquid exits the orifice and enters the aspiration lumen; and a mechanical oscillator coupled to the injector and configured to cause a pulsatile pressure of the liquid as it is injected through the injection lumen.

Inventors: **CULBERT; BRADLEY S. (Mission Viejo, CA), CARLSON; GARY D. (Aliso Viejo, CA)**

Applicant: **INCUVATE, LLC** (Irvine, CA)

Family ID: **1000008574257**

Appl. No.: **19/110009**

Filed (or PCT Filed): **August 28, 2024**

PCT No.: **PCT/US24/44219**

Related U.S. Application Data

parent US continuation-in-part 18755567 20240626 parent-grant-document US 12280222 child US 19110009
us-provisional-application US 63579255 20230828

Publication Classification

Int. Cl.: **A61M3/02** (20060101); **A61M1/00** (20060101)

U.S. Cl.:

CPC **A61M3/0283** (20130101); **A61M3/0275** (20130101); A61M1/77 (20210501); A61M1/79 (20210501); A61M2205/10 (20130101); A61M2205/15 (20130101); A61M2205/18 (20130101); A61M2205/3344 (20130101); A61M2205/581 (20130101); A61M2205/582 (20130101); A61M2205/583 (20130101); A61M2210/12 (20130101)

Background/Summary

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS [0001] This application is a Continuation-In-Part of U.S. patent application Ser. No. 18/755,567, filed on Jun. 26, 2024, which claims the benefit of priority to U.S. Provisional Patent Application No. 63/579,255, filed on Aug. 28, 2023, both of which are herein incorporated by reference in their entirety for all purposes. Priority is claimed pursuant to 35 U.S.C. § 120 and 35 U.S.C. § 119.

BACKGROUND OF THE INVENTION
Field of the Invention
[0002] The field of the invention generally relates to an aspiration system for removing, by aspiration, undesired matter such as a thrombus from a fluid carrying cavity, duct, sinus, or lumen of the body, such as a blood vessel, including a vessel in the brain, or in any space in the body, whether intended to carry fluid or not.
SUMMARY OF THE INVENTION
[0003] In one embodiment of the present disclosure, a system for catheter-based aspiration includes an aspiration catheter having a distal portion configured for insertion within a blood vessel of a subject, the aspiration catheter including an aspiration lumen having a distal opening at the distal portion of the aspiration catheter, an injection lumen having a distal end at the distal portion of the aspiration catheter, and an orifice located at or near the distal end of the injection lumen, the orifice configured to direct liquid into the aspiration lumen at or near the distal opening of the aspiration lumen; an injector configured to pressurize the liquid within the injection lumen, such that liquid exits the orifice and enters the aspiration lumen; and a mechanical oscillator coupled to the injector and configured to cause a pulsatile pressure of the liquid as it is injected through the injection lumen.
[0004] In another embodiment of the present disclosure, a method for catheter-based aspiration includes providing a catheter having a distal portion configured for insertion within a blood vessel of a subject, the catheter including a first lumen having a distal opening at the distal portion of the catheter, a second lumen having a distal end at the distal portion of the catheter, and an orifice located at or near the distal end of the second lumen, the orifice configured to direct liquid into the first lumen at or near the distal opening of the first lumen; and actuating an injector in a non-uniform manner to cause a pulsatile pressure of a liquid in the second lumen as the liquid is injected through the second lumen.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0005] FIG. **1** is a plan view of a system for aspiration according to an embodiment of the present disclosure.
[0006] FIG. **2**A is a view of an aspiration monitoring system according to a first embodiment of the

present disclosure.
[0007] FIG. **2**B is a view of an aspiration monitoring system according to a second embodiment of the present disclosure.
[0008] FIG. **3** is a view of an aspiration monitoring system according to a third embodiment of the present disclosure.
[0009] FIG. **4**A is a sectional view of an aspiration catheter in a blood vessel prior to contact with a thrombus.
[0010] FIG. **4**B is a sectional view of an aspiration catheter in a blood vessel upon contact with a thrombus.
[0011] FIG. **4**C is a sectional view of an aspiration catheter during a loss of aspiration.
[0012] FIG. **4**D is a sectional view of thrombi being aspirated through an aspiration catheter.
[0013] FIG. **5**A is a graphic representation of pressure vs. time for the condition of FIG. **4**A.
[0014] FIG. **5**B is a graphic representation of pressure vs. time for the condition of FIG. **4**B.
[0015] FIG. **5**C is a graphic representation of pressure vs. time for the condition of FIG. **4**C.
[0016] FIG. **5**D is a graphic representation of pressure vs. time for the condition of FIG. **4**D.
[0017] FIG. **6** is a graphic representation of pressure and an output sound amplitude vs. time for an embodiment of an aspiration monitoring system.
[0018] FIG. **7** is a graphic representation of pressure and an output sound amplitude vs. time for an embodiment of an aspiration monitoring system.
[0019] FIG. **8** is a graphic representation of pressure and an output sound frequency vs. time for an embodiment of an aspiration monitoring system.
[0020] FIG. **9** is a graphic representation of pressure and an output of sound frequency vs. time for an embodiment of an aspiration monitoring system.
[0021] FIG. **10** is a plan view of a system for aspiration according to another embodiment of the present disclosure.
[0022] FIG. **11** is a plan view of a system for aspiration according to another embodiment of the present disclosure.
[0023] FIG. **12** is a detailed view of an aspiration monitoring system of the system for aspiration of FIG. **11**.
[0024] FIG. **13** is a plan view of a system for aspiration according to another embodiment of the present disclosure.
[0025] FIG. **14** is a detailed view of an aspiration monitoring system of the system for aspiration of FIG. **13**.
[0026] FIG. **15** is a diagrammatic view of a system for aspirating thrombus according to an embodiment of the present disclosure.
[0027] FIG. **16** is a diagrammatic view showing more detail of the proximal portion of the system for aspirating thrombus of FIG. **15**.
[0028] FIG. **17** is a diagrammatic view of the distal end portion of the system for aspirating thrombus of FIG. **15**.
[0029] FIG. **18** is a plan view of a portion of a multi-purpose system according to an embodiment of the present disclosure.
[0030] FIG. **19** is a perspective view of a proximal portion of the multi-purpose system of FIG. **18**.
[0031] FIG. **20** is a plan view of a portion of a multi-purpose system according to an embodiment of the present disclosure.
[0032] FIG. **21** is a detail view of the distal end of a multi-purpose catheter of the multi-purpose system of FIG. **20**.
[0033] FIG. **22** is a perspective view of a proximal portion of the multi-purpose system of FIG. **20**.
[0034] FIG. **23** is a plan view of a proximal portion of the multi-purpose system of FIG. **20**.
[0035] FIG. **24** is a perspective view of a portion of the multi-purpose system of FIG. **20**.
[0036] FIG. **25** is a plan view of an aspiration catheter according to an embodiment of the present

disclosure.
[0037] FIG. **26** is a plan view of a tubing set according to an embodiment of the present disclosure.
[0038] FIG. **27** is a plan view of a stopcock according to an embodiment of the present disclosure.
[0039] FIG. **28** is a plan view of a stopcock according to an embodiment of the present disclosure.
[0040] FIG. **29** is a plan view of a vacuum source according to an embodiment of the present disclosure.
[0041] FIG. **30** is a plan view of an aspiration system according to an embodiment of the present disclosure.
[0042] FIG. **31** is a plan view of an aspiration system according to an embodiment of the present disclosure.
[0043] FIG. **32** is a plan view of an aspiration system according to an embodiment of the present disclosure.
[0044] FIG. **33** is a plan view of an aspiration system according to an embodiment of the present disclosure.
[0045] FIG. **34** is a partial sectional view of an embodiment of a saline injection aspiration (thrombectomy) catheter according to an embodiment of the present disclosure, with a guidewire in place.
[0046] FIG. **35** is a plan view of the proximal end of a guiding catheter with an aspiration catheter placed therein.
[0047] FIG. **36** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0048] FIG. **37** is a perspective view of a subject being reinjected with blood, according to an embodiment of the present disclosure.
[0049] FIG. **38** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0050] FIG. **39** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0051] FIG. **40** is a perspective view of an ultrasonic sensor for use with an aspiration system, according to an embodiment of the present disclosure.
[0052] FIG. **41** is a plan view of an aspiration system comprising a y-connector having the ultrasonic sensor of FIG. **40** placed therein.
[0053] FIG. **42** is a perspective view of a console of the aspiration system of FIG. **41**.
[0054] FIG. **43** is a plan view of an aspiration system according to an embodiment of the present disclosure.
[0055] FIG. **44** is a detail view of the weight-based aspiration monitoring system of the system of FIG. **43**.
[0056] FIG. **45** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0057] FIG. **46** is a detail view of an alternative weight-based aspiration monitoring system of the system.
[0058] FIG. **47** is a plan view of an aspiration system according to an embodiment of the present disclosure.
[0059] FIG. **48** is a perspective view of an aspiration system, according to an embodiment of the present disclosure.
[0060] FIG. **49** is a sectional view of the distal end of an aspiration catheter, according to an embodiment of the present disclosure.
[0061] FIG. **50** is a sectional view of the distal end of an aspiration catheter, according to an embodiment of the present disclosure.
[0062] FIG. **51** is a sectional view of the distal end of an aspiration catheter, according to an embodiment of the present disclosure.

[0063] FIG. **52** is a sectional view of the distal end of an aspiration catheter, according to an embodiment of the present disclosure.
[0064] FIG. **53** is a plan view of a microcatheter being tracked over a guidewire, in a first step.
[0065] FIG. **54** is a plan view of the insertion of an insertable injection tube and cap being inserted into a microcatheter, in a second step according to an embodiment of the present disclosure.
[0066] FIG. **55** is a plan view of the insertable injection tube and cap being advanced through a lumen of the microcatheter, in a third step.
[0067] FIG. **56** is a plan view of the insertable injection tube and cap in a fully inserted position within the microcatheter, in a fourth step.
[0068] FIG. **57** is a perspective cut-away view of a distal end of an insertable injection tube and cap with a spline inserted within a microcatheter, according to an embodiment of the present disclosure.
[0069] FIG. **58** is a perspective view of the insertable injection tube and cap with spline of FIG. **57**.
[0070] FIG. **59** is a perspective cut-away view of a distal end of an insertable injection tube and cap with a spline inserted within a microcatheter, according to an embodiment of the present disclosure.
[0071] FIGS. **60-63** illustrate a method for treating a patient using an aspiration catheter and system, according to an embodiment of the present disclosure.
[0072] FIGS. **64-65** illustrate a method for treating a patient using an aspiration catheter and system, according to an embodiment of the present disclosure.
[0073] FIGS. **66-69** illustrate a method for treating a patient using an aspiration catheter and system, according to an embodiment of the present disclosure.
[0074] FIG. **70** is a sectional view of a translatable occluder of the aspiration system of FIGS. **66-69** in a first position, according to an embodiment of the present disclosure.
[0075] FIG. **71** is a sectional view of the translatable occluder of the aspiration system of FIGS. **66-69** in a second position.
[0076] FIG. **72** illustrates an optional blocking step in the method of FIGS. **66-69**, according to an embodiment of the present disclosure.
[0077] FIG. **73** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0078] FIG. **74** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0079] FIG. **75** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0080] FIG. **76** is a sectional view of an aspiration system according to an embodiment of the present disclosure.
[0081] FIGS. **77-78** illustrate a first embodiment of a flow oscillator of the system of FIG. **76**, according to an embodiment of the present disclosure.
[0082] FIGS. **79-81** illustrate a second embodiment of a flow oscillator of the system of FIG. **76**, according to an embodiment of the present disclosure.
[0083] FIG. **82** is an alternative block diagram, according to an embodiment of the present disclosure.
[0084] FIGS. **83-84** illustrate a third embodiment of a flow oscillator of the system of FIG. **76**, according to an embodiment of the present disclosure.
[0085] FIG. **85** is an alternative embodiment of the flow oscillator of FIGS. **79-81**.
[0086] FIG. **86** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0087] FIGS. **87-88** are elevation views of the aspiration system of FIG. **86**.
[0088] FIG. **89** is an exploded view of first and second disks of a flow oscillator of the aspiration system of FIG. **86**, according to a first embodiment of the present disclosure.
[0089] FIG. **90** is a perspective view of the first and second disks of the flow oscillator of FIG. **89** in a first relative rotational orientation.

[0090] FIG. **91** is a perspective view of the first and second disks of the flow oscillator of FIG. **89** in a second relative rotational orientation.
[0091] FIG. **92** is a side view of first and second disks of a flow oscillator of the aspiration system of FIG. **86**, according to an alternative embodiment of the present disclosure, with the first and second disks in a first relative rotational orientation.
[0092] FIG. **93** is a side view of the first and second disks of the flow oscillator of FIG. **92** in a second relative rotational orientation.
[0093] FIG. **94** is a graphic representation of pressure vs. time of an aspiration system having a flow oscillator, according to an embodiment of the present disclosure.
[0094] FIG. **95** is a sectional view of a hand switch of the aspiration system of FIG. **86**, according to an embodiment of the present disclosure.
[0095] FIG. **96** is a perspective view of an aspiration system according to an embodiment of the present disclosure.
[0096] FIG. **97** is an exploded view of the aspiration system of FIG. **96**.
[0097] FIGS. **98-99** are elevation views of an alternative aspiration system, according to an embodiment of the present disclosure.
[0098] FIG. **100** is a perspective view of a surgical aspiration probe, according to an embodiment of the present disclosure.
[0099] FIG. **101** is an exploded view of the surgical aspiration probe of FIG. **100**.
[0100] FIG. **102** is a perspective view of the surgical aspiration probe of FIG. **100** in use within the brain of a patient, according to an embodiment of the present disclosure.
[0101] FIGS. **103-104** are elevation views of an alternative aspiration system, according to an embodiment of the present disclosure.
[0102] FIG. **105**A is a first perspective view of a high-pressure pump, according to an embodiment of the present disclosure.
[0103] FIG. **105**B is a second perspective view of the high-pressure pump of FIG. **105**A, according to an embodiment of the present disclosure.
[0104] FIG. **106** is a first cut-away perspective view of the high-pressure pump of FIG. **105**A, according to an embodiment of the present disclosure.
[0105] FIG. **107** is a second cut-away perspective view of the high-pressure pump of FIG. **105**A, according to an embodiment of the present disclosure.
[0106] FIG. **108** is a cut-away detailed view of the high-pressure pump of FIG. **105**A.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0107] The present disclosure relates to aspiration catheter systems and monitoring, warning and communication systems for aspiration catheter systems, including aspiration systems for removing thrombus from the vasculature of patients. Such vasculature can include veins and arteries, including coronary arteries, carotid arteries, cerebral arteries, and other arteries of the head and neck. Clogging of aspiration catheters, for example by large pieces of thrombus, is a common concern for users. Techniques to avoid clogging/choking of material within the catheter often involve rapidly, aggressively advancing the aspiration catheter or gently plucking at edges of a thrombus to insure only small pieces or portions are introduced at a time, pieces which are small enough to not clog or occlude the aspiration lumen. When a device becomes clogged during use, the potential for inadvertent dislodgment of thrombus downstream increases; this is referred to as distal embolism. As aspiration procedures of this type are often used in highly technical emergent settings, early clog detection of the aspiration catheter for the user during aspiration can contribute to the success of the procedure and clinical outcome. Some sources have reported that up to 50% of aspiration catheters used get clogged during use.
[0108] The user may have difficulty determining whether there is a vacuum or negative pressure in the system or not. For example, the user may have difficulty determining whether the vacuum or negative pressure has been applied or not (e.g., the vacuum source has been turned on or off).

Additionally, the user may have difficulty determining whether there has been a loss of vacuum in the system, for example because of the syringe (or other vacuum source) being full of fluid or because of a leak in the system. Blood is relatively opaque and can coat the wall of the syringe, thus making it difficult to determine when the syringe becomes full. This makes it difficult to determine whether sufficient vacuum or negative pressure is being applied to the aspiration catheter. The negative pressure gradient can change to an unacceptable level even before the syringe becomes full. Extension tubing or other tubing can also cause a loss in vacuum or negative pressure in the system. Certain tubing kinks can be difficult for a user to see or identify. It is also difficult to determine whether there is an air leak in the system, which can be another cause for a loss of vacuum or negative pressure even before the syringe becomes full of the aspirated fluid.

[0109] During the aspiration of thrombus with an aspiration catheter, it is difficult to identify when thrombus is actively being aspirated, or when only blood is being aspirated. Typically, it is desired to not aspirate sizable quantities of normal blood from blood vessels, because of the importance of maintaining normal blood volume and blood pressure. However, when tracking the tip of an aspiration catheter in proximity to a thrombus, it is difficult to know whether the aspiration catheter has actively engaged a thrombus, whether it has aspirated at least a portion of the thrombus, or whether it is not engaged with the thrombus, and is only aspirating blood. Though some aspiration catheters, such as those used in the peripheral blood vessels or in an arterio-venous fistula, can be around 50 cm or even less, the tip of an aspiration catheter can in same cases be more than 90 cm from the hands of the user, or as much as 135 cm from the hands of the user, or in some cases as much as 150 cm, and the particular status of aspiration capability at the tip of the catheter is often not known by the user. A user can thus be essentially plunging a catheter blindly without significant, usable sensory feedback. The catheter can have an outer diameter up to or even greater than 6 French, and can be as high as 10 French or greater. The increased catheter outer diameter can cause some concern of potential trauma inside a blood vessel. The use of aspiration catheters can therefore be inefficient, and cause more blood removal than desired, causing a user to minimize the length of the therapy and in severe cases necessitating blood transfusion. An increased volume of normal blood being aspirated also means that the vacuum source (e.g. syringe) will fill in a shorter amount of time, thus requiring more frequent replacement of the vacuum source. Distal embolism can occur if the negative pressure gradient is not sufficient, and yet the user is not aware.

[0110] In some cases, a syringe that is completely or mostly full or blood and/or thrombus can continue to be used, though in this state, there is not sufficient pressure to effectively aspirate thrombus or unwanted material, thus causing inefficient use of time, and lengthening the procedure. In some cases, the user may not realize the plunger of the syringe has mistakenly not been pulled back (to evacuate the syringe). In some cases, the syringe itself can be defective, and a sufficient negative pressure may not be achieved, without the user being aware. In some cases, kinked tubing, lines, or catheters can go unnoticed, because of bad visibility in a procedural laboratory, or simply from the extent of concurrent activities being performed. In many cases, the user's eyes are oriented or focused on a monitor, for example a fluoroscopic monitor or other imaging monitor, or a monitor with patient vital data. Though the user may be able to view flow through transparent or partially transparent lumens (such as extension tubing), in dim lighting with intermittent viewing, it is difficult for the user's mind to process flow of an opaque liquid (such as blood/thrombus). Even in good lighting with a focused eye, the movement of fluid through extension tubing may not present an accurate picture of the aspiration status, as the visual flow effect can be delayed in relation to the applied vacuum or negative pressure. More than one medical device personnel can be sharing sensory information with each other to attempt to build a current status in each other's minds of the aspiration procedure. When a user relies on another's interpretation, especially when either are multitasking, a false sense of the status may occur. A syringe attached to the aspiration catheter can cause kinking, for example, if placed on an uneven surface. The distal opening in an aspiration lumen of an aspiration catheter can be prone to aspirating directly against the wall of a blood

vessel, thus being temporarily stuck against the vessel wall, and stopping flow throughout the aspiration lumen. In some cases, a negative pressure gradient that is too large can be accidentally or inappropriately applied to the aspiration lumen of the aspiration catheter, limiting effectiveness (for example, if it causes the walls surrounding the aspiration lumen to collapse and thus, cut off the significantly decrease the flow through the aspiration lumen). The syringes which are sometimes used as a vacuum source to connect to an aspiration lumen of an aspiration catheter can malfunction, and not be fully actuated/evacuated. But, even when the syringe is functioning correctly, it will tend to fill up at difficult to predict moments, and thus commonly have periods with no applied negative pressure gradient. In the cases wherein a portion of clot/thrombus is being aspirated through the aspiration lumen, a significant pressure drop can occur at the current position of the thrombus, and thus, a sufficient negative pressure can only exist from the proximal end of the aspiration lumen and distally up to the point of the thrombus. Thus, an insufficient negative pressure can exist, causing insufficient aspiration at the distal end of the aspiration lumen, e.g., at the distal end of the aspiration catheter. The same situation can occur if there is an actual clog at some intermediate point within the aspiration lumen. In either of these conditions, because of the insufficient aspiration at the distal end of the aspiration lumen, there can be a risk of thrombus or emboli being sent distally in the vasculature, which can cause occlusion, stroke, pulmonary embolism, or other disorders, depending upon the location of the intervention or procedure being performed. With current apparatus and techniques, these situations are very difficult to detect when they occur. It has been estimated that in as many as 50% of thrombus aspiration procedures, some sort of failure occurs.

[0111] An aspiration system **2** is illustrated in FIG. **1** and is configured to allow real time monitoring of catheter aspiration. The aspiration system **2** comprises an aspiration catheter **4**, a vacuum source **6**, a valve **8**, extension tubing **10**, and an aspiration monitoring system **48** including an in-line pressure transducer **12**. The aspiration catheter **4** has a proximal end **14** and a distal end **16** and an aspiration lumen **18** extending from the proximal end **14** to the distal end **16**. The aspiration lumen **18** can be sized for aspiration of thrombus, and in some embodiments can have an inner diameter of between about 0.38 millimeter (0.015 inches) and about 2.54 millimeters (0.100 inches). The aspiration catheter **4** includes a hub **20** at its proximal end which can include a female luer connector **22**. The aspiration lumen **18** at the distal end **16** of the aspiration catheter **4** can include an angled orifice **24**, which aids in the tracking through tortuous or occluded vasculature. In some embodiments, a guidewire lumen **26** is coupled to the distal end **16** of the aspiration catheter **4**, and is configured to track over a guidewire **28**. The vacuum source **6** can comprise a syringe, and can be sized between 5 ml and 100 ml, or between 20 ml and 60. The vacuum source **6** can comprise a VacLok® syringe, made by Merit Medical, South Jordan, Utah. The vacuum source **6** can include a barrel **30** and plunger **32**, with a lock **34** which is configured to retain the plunger **32** in position in relation to the barrel **30**, for example, when the plunger **32** is pulled back in direction D to create a negative pressure (vacuum) inside the barrel **30**. In some embodiments, the vacuum source **6** can comprise any other type of evacuable reservoir, or can comprise a vacuum pump. The vacuum source **6** is connected to the aspiration lumen **18** of the aspiration catheter **4** via the extension tubing **10** and the valve **8**. In some embodiments, the vacuum source **6** can be connected directly to the aspiration lumen **18** of the aspiration catheter **4**. Male luer connectors **36** and female luer connectors **38** are indicated in FIG. **1**. The valve **8** can be a standard two-way stopcock, as illustrated.

[0112] The pressure transducer **12** of the aspiration monitoring system **48** is configured to be fluidly coupled between the vacuum source **6** and the aspiration catheter **4**. In FIG. **2**A, the aspiration monitoring system **48** is illustrated as a self-contained device of a first embodiment. The pressure transducer **12** comprises a housing **40** having a cavity **42** extending between a first port **44** and a second port **46**. In some embodiments, the first port **44** comprises a female luer and the second port **46** comprises a male luer. In some embodiments, the first port **44** comprises a female

luer lock and the second port **46** comprises a male luer lock, each of which is attachable to and detachable from a corresponding luer lock of the opposite gender. The first port **44** is configured to be coupled to the vacuum source **6**, either directly, or with the valve **8** and/or extension tubing **10** connected in between. The second port **46** is configured to be coupled to the aspiration lumen **18** of the aspiration catheter **4**, for example, by coupling the second port **46** directly or indirectly to the hub **20** of the aspiration catheter **4**. When the aspiration system **2** is used to aspirate body fluids and/or materials, for example blood and/or thrombus, the body fluids and/or materials are aspirated through the aspiration lumen **18** of the aspiration catheter from the angled orifice **24** at the distal end **16** to the female luer connector **22** at the proximal end **14**, then pass through the second port **46** of the pressure transducer **12** first, through the cavity **42**, and then through the first port **44**. Depending on the amount of vacuum or negative pressure applied by the vacuum source **6**, and the amount of flow resistance and resulting pressure drop along the aspiration system **2**, the pressure within the cavity **42** will vary. For example, a more viscous fluid like blood, or a fluid having solid, semi-solid, or gel-like particles or portions, will cause more flow resistance through the relatively small aspiration lumen **18** of the aspiration catheter **4** than would water or normal saline solution. Thus, the pressure within the cavity **42** of the pressure transducer **12** will decrease (the negative pressure gradient will increase) as the flow resistance in the aspiration lumen **18** increases.

[0113] For definition purposes, when speaking of the amount of "vacuum," a pressure of, for example, −15,000 pascal (−2.18 pounds per square inch, or psi) is a "larger vacuum" than −10,000 pascal (−1.45 psi). Actually, a true vacuum (−101,325 pascal or −14.7 psi at sea level), where no molecules are present within the volume is extremely difficult. Additionally, −15,000 pascal is a "lower pressure" than-10,000 pascal. Furthermore, −15,000 pascal has a larger "absolute vacuum pressure" than does −10,000 pascal, because the absolute value of −15,000 is larger than the absolute value of −10,000. In FIG. **2**A, a vacuum sensor **50** is disposed within the cavity **42** of the housing **40** and is in fluid communication with fluid that passes through the cavity **42**. The vacuum sensor **50** can be a standard pressure sensor or transducer, including a pressure sensor designed primarily for measuring positive pressure. It can use any type of pressure sensing technology known in the art, including MEMS Technology. In some embodiments, the vacuum sensor **50** is configured for highest accuracy and/or precision within the range of pressures between about 0 pascal to about-101,325 pascal (−14.70 psi), or between about-45,000 pascal (−6.53 psi) and about-90,000 pascal (−13.05 psi), or between about-83,737 pascal (−12 psi) and about-96,527 pascal (−14 psi). In some embodiments, the power requirement for the vacuum sensor can range from 2.5 volts DC to 10 volts DC. In some embodiments, the vacuum sensor **50** can be an analog gauge with an output voltage. In the self-contained embodiment of the FIG. **2**A, the vacuum sensor **50** is powered by one or more battery **52**. Based on the power requirements of the vacuum sensor **50**, and the power requirements of other components of the aspiration monitoring system **48** described herein, in some embodiments the one or more battery **52** can range between 1.5 volts and nine volts. Also contained within the housing is a measurement device **54**, which in some embodiments can comprise a microprocessor. The measurement device **54** is coupled to the vacuum sensor **50** and receives signals from the vacuum sensor **50** indicative of real time measured pressure. In some embodiments, the measurement device **54** includes a memory module **56** in which information is stored that can be used by the measurement device **54**, for example, in calculations. Information can include, for example, an array of one or more pressure values. In some embodiments, the array of one or more pressure values can be correlated with one or more different corresponding system models or catheter models. The vacuum sensor **50** can be used in some cases for detecting the presence or amount of vacuum or negative pressure alone, for the purpose of monitoring whether the vacuum source **6** (e.g., syringe) is significantly full, and thus needs to be changed. The vacuum sensor **50** can be used in some cases for detecting whether there is a vacuum or negative pressure in the system or not. For example, whether the vacuum or negative pressure has been applied or not (e.g., the vacuum source has been turned on or off).

[0114] One or more communication devices **58***a*, **58***b*, **58***c* are included within the aspiration monitoring system **48** and are coupled to the measurement device **54**. Each of the one or more communication devices **58***a-c* are configured to generate a type of alert comprising an alert signal **60***a-c*, in response at least in part to activity and output of the measurement device **54**. In some embodiments, the communication device **58***a* can include one or more LEDs (light emitting diodes) configured to generate a visible alert via a visible alert signal **60***a*, such as light that is continuously illuminated, or is illuminated in a blinking pattern. In some embodiments, the LEDs can be oriented on multiple sides of the communication device **58***a*, so that they can be easily seen from a variety of different locations. In some embodiments, lights other than LEDs can be used. Light pipes or other lighting conduits can also be incorporated in embodiments, to further place visual indicators at multiple locations and/or orientations. In some embodiments, the communication device **58***b* can include one or more vibration generators configured to generate a tactile alert via a tactile alert signal **60***b*, which can include, but is not limited to, vibration or heat. In some embodiments, the vibration device can be similar to a video game controller. In some embodiments, the vibration generator can comprise a piezoelectric device which is configured to vibrate when a voltage is applied. In some embodiments, the communication device **58***c* can include one or more sound generating devices configured to generate an audible alert via an audible alert signal **60***c*, such as a continuous noise, or a repeating noise. The communication device **58***c* in some embodiments can comprise a loudspeaker for generation of any variety of sounds, at any variety of frequencies (Hz) or sound pressures (dB) within the human audible range and/or human tolerance range. The communication device **58***c* can even be configured to generate sounds that are outside the human audible range in embodiments wherein the signal is intended to be felt as a vibration or other tactile sensation, instead of an audible sensation. In some embodiments, the sound generating device can comprise a buzzer which is configured to sound one or more audible pitches when a voltage is applied. In some embodiments a piezoelectric device, such as that described in relation to the communication device **58***b* can also serve as a sound generating device, included as communication device **58***c*. The alert signal **60***a-c* can at times serve as a “wake up” alarm for the user, in cases where the user has become too focused on other factors during the procedure.

[0115] A user of an aspiration system **2** can desire to be notified of several conditions which can occur during use of the aspiration system **2**. These potential conditions include, but are not limited to clogging, a loss of vacuum or negative pressure due to filling of the vacuum source **6** and or a breach, break or puncture in the aspiration system **2**, and the engagement or aspiration of non-fluid, solid or semi-solid material such as thrombus. The aspiration monitoring system **48** of FIG. **2**A is configured to alert users of an aspiration system **2** about real time status of the aspiration system **2**, including operational conditions, which include: whether vacuum or negative pressure is being applied or not; flow conditions, which include whether a thrombus is engaged, whether a thrombus is being actively aspirated, whether the system is leaking air, whether the system is clogged, whether the vacuum source **6** is full and/or needs to be changed; or other potential set up issues. The real time feedback provided frees a user or operator from the need of excessive personal monitoring of the vacuum source **6**, extension tubing **10**, or other portions of the aspiration system **2**, for improper or undesired flow or operation conditions, and thus allows the user to focus more attention on the patient being treated. The user is kept aware of whether a clot is being aspirated or has been aspirated, or whether there is a clog. Additionally, the user is kept aware of whether there is too large an amount of blood being removed from the patient, or whether there are fault conditions like system leak or tubing kink. A tubing kink distal to the vacuum sensor **50** can be identified (for example by an increase in measured negative pressure) and a tubing kink proximal to the vacuum sensor **50** can be identified (for example, by a loss or degradation of the negative pressure gradient). In some cases, the user may attempt to operate the catheter with a vacuum source **6** that is already full (and thus has no significant negative pressure gradient). In some cases,

a user may even forget to open the valve **8** to begin aspiration, but the aspiration monitoring system, **48** can also identify that the system is not yet functioning, and communicate a list of potential errors or specific errors (for the particular pressure waveform measured). By having the real-time awareness of the many factors related to the operating status, the procedure is made safer, the time of the procedure can be reduced, and blood loss can be reduced.

[0116] The pressure transducer **12** of the aspiration monitoring system **48** is configured to continuously measure and monitor the absolute pressure amplitude within the closed system of the aspiration system **2**, and also is configured to measure and monitor the relative pressure over time to detect noteworthy flow changes within the flow circuit of the aspiration system **2**. Some changes are discernible via absolute pressure measurement, while more subtle pressure deflections can be compared to a stored library in memory. Noteworthy conditions can be signaled to the user when appropriate. In some embodiments, the unfiltered signal can be amplified by an amplifier and filtered by a filter, for example, to increase the signal-to-noise ratio. Examples of the (background) noise **57** in an unfiltered signal can be seen in FIGS. **5**A-**5**D (labeled in FIG. **5**A). In some embodiments, one or more algorithms can be used, as described herein, to identify particular conditions of interest.

[0117] FIG. **2**B illustrates a second embodiment of an aspiration monitoring system **62** having a pressure transducer **12** having a vacuum sensor **50** disposed within the cavity **42** of a housing **40**. The vacuum sensor **50** can be powered by at least one battery **52**. In some embodiments, the pressure transducer **12** can be reusable, and can be configured to allow charging of the battery **52**, or of a capacitor (not shown) by direct charging methods, or by inductive power transfer methods and devices known in the art. Unlike the aspiration monitoring system **48** of FIG. **2**A, the aspiration monitoring system **62** of FIG. **2**B comprises a measurement device **64**, memory module **66**, and communication device **68** which are external to the pressure transducer **12**. A power module **72**, also external, can be used to power any of the measurement device **64**, memory module **66**, or communication device **68**. The communication device **68** can be any of the communication device **58***a*, **58***b*, **58***c* described in relation to the aspiration monitoring system **48** of FIG. **2**A, and are configured to product an alert via an alert signal **70**. The communication device **68** can be portable so that it can be positioned close to the user.

[0118] In some embodiments, the communication device **68** can be wearable by the user. FIG. **3** illustrates an aspiration monitoring system **78** which includes an antenna **80** coupled to a measurement device **76**. The measurement device **76** is similar to the measurement device **54** of prior embodiments, except that it wirelessly sends a communication signal **84** via the antenna **80** to a corresponding antenna **82** of a communication device **74**. In some embodiments, the communication device **74** comprises a wristband which the user wears, and which can include a vibration generator or heat generator. In some embodiments, the communication device **74** comprises an audio speaker which can be attached to equipment or even to the patient or user. In some embodiments, the communication device **74** comprises an audio speaker on an earpiece or earbud that the user can wear. In some embodiments, Bluetooth® communication technology can be used. The real time feedback supplied by the aspiration monitoring system **62** can decrease the time that the aspiration system **2** is actively aspirating without being engaged with a thrombus, thus minimizing the amount of non-thrombotic blood lost by aspiration. This can be particularly beneficial in larger bore catheters, for example in catheters having a diameter of 7 French or larger. The real time feedback can also minimize the amount of total time that catheters are tracked back-and-forth through the blood vessels, minimizing potential damage to the intima of the blood vessels, dissection of the blood vessels, or distal embolization. By lowering the risk of the aspiration catheter tip getting caught (via suction) against the blood vessel wall, the distal end of the aspiration lumen can be more aggressively designed for optimized aspiration characteristics. The technique of using the aspiration catheter can additionally be able to be performed in a more sophisticated manner, with continual or continuous knowledge of the aspiration status or negative

pressure gradient sufficiency. For example, a piece of thrombus can be aspirated, followed by a "chaser" of blood aspiration, followed by another piece of thrombus, etc.

[0119] FIG. **4**A illustrates the distal end **16** of an aspiration catheter **4** within a blood vessel **86** having at least one thrombus **88**. The aspiration catheter **4** is being advanced in a forward direction F, but the distal end **16** of the aspiration catheter **4** has not yet reached the proximal extremity **94** of the thrombus **88**. A vacuum source **6** (FIG. **1**) has been coupled to the aspiration lumen **18** of the aspiration catheter **4** and activated (i.e. the valve **8** is open) causing blood **96** to be aspirated into the aspiration lumen **18** (arrows A). Turning to FIG. **5**A, a corresponding curve **98** is represented for the normal fluid (e.g. blood) vacuum or negative pressure over time for the condition of FIG. **4**A. The curve **98** represents vacuum or negative pressure over time sensed by the vacuum sensor **50** of any of the embodiments presented. No leaks are present and no thrombus is being evacuated, and therefore the curve **98** includes a downward slope **99** when the vacuum source **6** lowers the pressure within the cavity **42** of the pressure transducer **12** to a relatively steady state. The steady pressure curve **97** continues while blood **96** is being aspirated. As the vacuum source **6** is decoupled from the aspiration lumen **18**, for example by closing the valve **8** or by detaching any two of the ports (e.g. luers), or if the vacuum source **6** fills completely with blood **96**, then an upward slope **95** is measured.

[0120] The measurement device **54**, **64** is configured to compare the curve **97** with information stored in the memory module **56**, **66** to identify this condition. In some embodiments, the measurement device **54**, **64** uses an algorithm to make the comparison. In some embodiments, the measurement device **54**, **64** then sends a signal to the communication device **58***a-c*, **74**, and the communication device **58***a-c*, **74** generates an appropriate alert. Communication device **58***a*, for example a particular color LED, can be illuminated, or an LED can flash in a particular pattern or number of flashes. Communication device **58***b* can create a characteristic sound, or can generate an audio message in a number of languages. For example, the audio message can state, "Thrombus encountered," or "No thrombus encountered." A different type of sound can be used for each of a plurality of "modes": "Thrombus encountered," "Actively flowing," and "No Vacuum." For example, a buzzing sound for "Thrombus encountered," a beep for "No vacuum," etc. The various characteristics of sound that can be varied include, but are not limited to timbre, or sound quality, spectrum, envelope, duration, phase, pitch (frequency), number of sounds (repetition). Communication device **58***c* can vibrate or heat in a characteristic pattern, for example, a certain number of repetitions or a certain frequency between repetitions. The user can determine that an additional fluoroscopic image (e.g. angiography) or other imaging modalities can be necessary to better identify the location of the thrombus **88**.

[0121] FIG. **4**B illustrates the distal end **16** of an aspiration catheter **4** advanced to a position such that the distal end **16** of the aspiration catheter **4** contacts the proximal extremity **94** of the thrombus **88**. The corresponding curve **93** in FIG. **5**B represents vacuum or negative pressure over time sensed by the vacuum sensor **50** of any of the embodiments presented. The curve **93** initially has a downward slope **99** followed by a steady pressure curve **97**, as in the condition of FIG. **4**A, graphed in FIG. **5**A, however, when the distal end **16** of the aspiration catheter **4** contacts the proximal extremity **94** of the thrombus **88**, if the aspiration causes a portion of the thrombus **88** (for example a large or relatively hard portion) to enter and become trapped in the aspiration lumen **18**, then a clog condition occurs. A similar condition occurs if the distal end **16** of the aspiration catheter **4** is caught on the thrombus **88** by a suction effect, with virtually nothing flowing through the aspiration lumen **18**. In either condition, the curve **93** includes a deviation (or disturbance) in fluid pressure **91**. If the clog (or stuck condition) continues, then a flat, depressed pressure **89** is measured.

[0122] The measurement device **54**, **64** is configured to compare the curve **93** with information stored in the memory module **56**, **66** to identify this condition. In some embodiments, the measurement device **54**, **64** uses an algorithm to make the comparison. In some embodiments, a

pre-set pressure differential ΔP.sub.1 can be stored in the memory module **56**, **66** as a threshold, whereby the measurement of a pressure difference **81** less than this threshold does not result in the measurement device **54**, **64** commanding the communication device **58***a-c*, **74** to send an alert signal **60***a-c*, **70**. In some embodiments, when the pressure difference **81** is greater than (or greater than or equal to) the pre-set pressure differential ΔP.sub.1, the measurement device **54**, **64** then sends a signal to the communication device **58***a-c*, **74**, and the communication device **58***a-c*, **74** generates an appropriate alert. Communication device **58***a*, for example a particular color LED, can be illuminated, or an LED can flash in a particular pattern or number of flashes. Communication device **58***b* can create a characteristic sound, or can generate an audio message in a number of languages. For example, the audio message can state, “Clog Condition.” Communication device **58***c* can vibrate or heat in a characteristic pattern, for example, a certain number of repetitions or a certain frequency between repetitions. When the user realizes that the clog condition is present, the user can pull on the aspiration catheter **4** and readvance it, in an attempt to contact a portion of the thrombus **88** that can be aspirated. If a portion of the thrombus is clogged in the aspiration lumen **18**, and repositioning of the aspiration catheter **4** does not produce good results, the aspiration catheter **4** can be removed and the aspiration system **2** can be repurged, for example by a positive pressurization.

[0123] FIG. **4**C illustrates the distal end **16** of the aspiration catheter **4** in a general situation during which a breach in the aspiration system **2** has occurred. For example, a break, leak, puncture, pinhole, loosening, or disconnection can cause air to be pulled into the aspiration lumen **18** of the aspiration catheter **4**, the cavity **42** of the pressure transducer **12**, of the interior of the extension tubing **10**, valve **8**, or vacuum source **6**. As graphed in the curve **85** of FIG. **5**C, a downward slope **99** and a subsequent steady pressure curve **97** are measured, but at the point in time of the breach 87 an upward slope **83** begins.

[0124] The measurement device **54**, **64** is configured to compare the curve **85** with information stored in the memory module **56**, **66** to identify this condition. In some embodiments, the measurement device **54**, **64** uses an algorithm to make the comparison. In some embodiments, the measurement device **54**, **64** then sends a signal to the communication device **58***a-c*, **74**, and the communication device **58***a-c*, **74** generates an appropriate alert. Communication device **58***a*, for example a particular color LED, can be illuminated, or an LED can flash in a particular pattern or number of flashes. Communication device **58***b* can create a characteristic sound, or can generate an audio message in a number of languages. For example, the audio message can state, “System Leak.” Communication device **58***c* can vibrate or heat in a characteristic pattern, for example, a certain number of repetitions or a certain frequency between repetitions. Upon receiving the alert, the user will check the components of the aspiration system **2** and either fix the breach or replace one or more of the components of the aspiration system **2**. For example, in some cases, the communication device **58***a-c*, **74** can alert the user when the measurement device **54**, **64** confirms a loss of applied vacuum or negative pressure, allowing the user to change or recharge the vacuum source **6**, which has become depleted (e.g. by filling with blood and/or thrombus).

[0125] FIG. **4**D illustrates the distal end **16** of the aspiration catheter **4** during the successful aspiration of pieces or portions **90** of the thrombus **88**. In some cases, the pieces or portions **90** can follow a tortuous path **92**, due to disturbances or collisions with the inner wall of the aspiration lumen **18** while being pulled through the aspiration lumen **18**. In some cases, the pieces or portions **90** can catch and slip within the inner wall of the aspiration lumen **18**, for example, due to variance of the inner diameter of the aspiration lumen **18** along the length. Either of these situations can cause a corresponding series of increases and decreases in the pressure being sensed by the pressure transducer **12**, while the pieces or portions **90** are traveling through the aspiration lumen **18**. As graphed in the curve **79** of FIG. **5**D, a downward slope **99** and a subsequent steady pressure curve **97** are measured, but as the pieces or portions **90** of thrombus **88** travel down the aspiration lumen **18** of the aspiration catheter **4**, a deviation **77** of fluid pressure comprising a one or more

decreases and increases in pressure (increases and decreases in vacuum or negative pressure) is measured. As the pieces or portions **90** of thrombus **88** exit the proximal end of the aspiration lumen **18** of the aspiration catheter **4**, a second steady pressure curve **75** is measured. The duration 67 of the deviation **77** is the amount of transit of the particular significant pieces or portions **90** of thrombus **88**. The duration 67 can range quite a bit, but in some cases can be less than a second or up to about 30 seconds. A single thrombus being aspirated can cause a single decrease in pressure (a blip) which is identified by the measurement device **54**, **64**. Subsequently, this occurrence can be communicated to the user by the communication device **58***a-c*, **74**. When again additional pieces or portions **90** of thrombus **88** are aspirated into and travel down the aspiration lumen **18** of the aspiration catheter **4**, another deviation **73** of fluid pressure comprising a one or more decreases and increases in pressure (increases and decreases in vacuum or negative pressure) is measured. At the end of the curve **79**, the vacuum source **6** is shown filling completely with blood **96** and the pieces or portions **90** of thrombus **88**, and so an upward slope **95** is measured.

[0126] The measurement device **54**, **64** is configured to compare the curve **79** with information stored in the memory module **56**, **66** to identify when the pieces or portions **90** of thrombus **88** are actively being aspirated, as in deviation **77** and deviation **73**, and when the pieces or portions of thrombus **88** are not being actively, or substantially, aspirated, as in steady pressure curve **97**, the steady pressure curve **75**, and the steady pressure curve **71**. In some embodiments, the measurement device **54**, **64** uses an algorithm to make the comparison. In some embodiments, a pre-set pressure differential ΔP.sub.2 can be stored in the memory module **56**, **66** as a threshold, whereby the measurement of a pressure difference **69** less than this threshold does not result in the measurement device **54**, **64** commanding the communication device **58***a-c*, **74** to send a first type of alert via an alert signal **60***a-c*, **70**. In some embodiments, when the pressure difference **69** is greater than (or greater than or equal to) the pre-set pressure differential ΔP.sub.2, the measurement device **54**, **64** then sends a signal to the communication device **58***a-c*, **74**, and the communication device **58***a-c*, **74** generates an appropriate alert. Communication device **58***a*, for example a particular color LED, can be illuminated, or an LED can flash in a particular pattern or number of flashes. In some embodiments, the communication device **58***a* can comprise a light whose intensity increases proportionally with the pressure. Communication device **58***b* can create a characteristic sound, or can generate an audio message in a number of languages. For example, the audio message can state, “Thrombus being aspirated.” In some embodiments, communication device **58***b* can comprise one or more noises or beeps. In some embodiments, the communication device **58***b* can comprise a particular series of beeps corresponding to each different condition. For example, three short beeps can correspond to no thrombus being aspirated, while five long, loud beeps can correspond to a system leak. In some embodiments, a plurality of different tones (pitches) can be used to alert a user about different conditions. As an example, a low pitch sound can be used for a first condition (e.g. no thrombus being aspirated) and a second, higher pitch sound can be used for a second condition (e.g. a system leak). In some embodiments, a plurality of different tones can be used to alert a user about a first condition and a second plurality (e.g. in a different combination, or with additional tones) can be used to alert a user about a second condition. Communication device **58***c* can vibrate or heat in a characteristic pattern, for example, a certain number of repetitions or a certain frequency between repetitions. When the user realizes that the thrombus is being aspirated, the user can choose to advance (or retract) the aspiration catheter **4**, for example with fluoroscopic visualization, along the length of the thrombus **88**, in an attempt to continue the aspiration of the thrombus **88**. In some cases, the user can choose to stop the advancement or retraction of the aspiration catheter **4** at a certain amount of time after the alert is generated, in order to allow the pieces or portions **90** of thrombus **88** to completely exit the aspiration lumen **18**. When the measurement device **54**, **64** identifies a subsequent steady pressure curve **75**, **71** that follows a deviation **77**, **73**, the measurement device **54**, **64** in some embodiments sends a signal that causes the communication device **58***a-c*, **74** to generate a second type of alert via an alert signal **60***a-c*, **70**.

For example, in some embodiments, communication device **58***b* can send an audio message that states, “Thrombus no longer being aspirated.” When the user realizes that the thrombus is no longer being aspirated, the user can advance or retract the aspiration catheter, in an attempt to contact another portion of the thrombus **88** that can be aspirated. In some embodiments, the deviation **77** can be positively identified as a true deviation indicating thrombus being actively aspirated, pressure difference **69** is between about 700 pascal and about 1700 pascal. In some embodiments, the deviation **77** can be positively identified as a true deviation indicating thrombus being actively aspirated, pressure difference **69** is between about 1000 pascal and about 1300 pascal. In some embodiments, the deviation **77** can be positively identified as a true deviation indicating thrombus being actively aspirated, pressure difference **69** is about 1138 pascal. The pressure difference **69** can be measured by determining a baseline pressure **63** and a peak pressure **61** and determining the absolute value difference. For example:

[00001]

Absolutevaluedifference(AVD) = .Math. (-89, 631pascal) - (-90, 769pascal) .Math. = 1138pascal

[0127] Or for example:

[00002]

Absolutevaluedifference(AVD) = .Math. (-43, 710pascal) - (-45, 102pascal) .Math. = 1281pascal

[0128] The pressure difference **81** (FIG. **5**B) can also represent a deviation that can be identified in a similar manner, after which the communication device **58***a-c*, **74** generates an appropriate alert, such as, “Clog condition.”

[0129] Because vacuum or negative pressure has a nominal value less than zero, the peak pressure **61**, as shown in FIG. **5**D, is actually a lower number than the baseline pressure **63**. In some embodiments, the measurement device **54**, **64** can also be configured to make a comparison, for example by using an algorithm, between a stored differential time t.sub.1 and a duration 65 of a single one of the more or more decreases and increases in pressure in the deviation **77**. For example, in some embodiments, the deviation can be positively identified as a true deviation indicating thrombus being actively aspirated, if the duration is between about 0.001 seconds and about 0.50 seconds. In some embodiments, the deviation can be positively identified as a true deviation indicating thrombus being actively aspirated, if the duration is between about 0.005 seconds and about 0.10 seconds. In some embodiments, the deviation can be positively identified as a true deviation indicating thrombus being actively aspirated if the duration is between about 0.05 seconds and about 0.20 seconds. In some embodiments, the measurement device **54**, **64** is configured to recognize deviation **77** after two or more decreases and increases in pressure are measured. In some embodiments, the measurement device **54**, **64** is configured to recognize deviation **77** after five or more decreases and increases in pressure are measured. In some embodiments, the measurement device **54**, **64** is configured to recognize deviation **77** after ten or more decreases and increases in pressure are measured.

[0130] The baseline pressure **63** can in some embodiments be predetermined and can be stored in the memory module **56**, **66**. In some embodiments, the baseline pressure **63** can be stored in in the memory module **56**, **66** during the manufacture of the aspiration monitoring system **48**, **62**, **78**, but the baseline pressure **63** can also be input by the user prior to or during a particular procedure. In some embodiments, there may be a baseline pressure differential, which is compared to a difference in the output of two different pressure sensors. In some embodiments, the baseline pressure **63** can be determined or otherwise defined by the measurement device **54**, **64**, **76** based on averaging of a particular number of samples of measured pressure. The baseline pressure **63** can be constructed as a moving average, such as a running average or rolling average. Several types of moving average can be used, including a simple moving average, a cumulative moving average, a weighted moving average, or an exponential moving average. In any of these cases, a threshold can be determined by the measurement device **54**, **64**, **76** based on the determined baseline pressure **63** and a known pressure differential ΔP. In some case, a pressure differential ΔP can even be

calculated by the measurement device **54**, **64**, **76** based on the determined baseline pressure **63** and a known threshold.

[0131] Insertion of the pressure transducer **12** in line in either the embodiment of FIG. **2**A or the embodiment of FIG. **2**B does not measurably change performance characteristics of the aspiration system **2**, because the cavity **42** is relatively short and has a relatively large inner diameter, and thus is not a significant source of fluid flow resistance. In some embodiments, the inner diameter can be between about 2.2 mm (0.086 inches) and about 3.2 mm (0.125 inches). In some embodiments, the measurement device **54**, **64**, **76** need not include a microprocessor, as pre-defined set points (e.g., for certain thresholds) can be included in firmware, microcontroller, or other locations. In some embodiments, including but not limited to the embodiment of FIG. **2**B, the pressure transducer **12** can be an off-the-shelf blood pressure monitor system, which is modified or augmented with other components. In some embodiments an off-the-shelf blood pressure monitor system can be used as the output of the aspiration monitoring system **48**, **62**, **78**. In some embodiments, an aspiration catheter **4** can have a pressure transducer in the distal end **16**. This pressure transducer can be used as the pressure transducer **12** of the aspiration monitoring system **48**, **62**, **78**. In some embodiments, a pressure sensor can be located within a Tuohy-Borst valve, and introducer sheath, a guiding catheter, or another component of the system through which is in fluid communication with the aspiration lumen **18**. In some embodiments, the pressure sensor can be located anywhere within the aspiration lumen of the aspiration catheter.

[0132] In some embodiments, instead of an LED, the visual alert is provided by a communication device **58***a* comprising a display which displays visual messages of text in a particular language, for example, “Thrombus encountered,” “No thrombus encountered,” “Clog condition,” “System leak,” “Loss of vacuum,” “Thrombus being aspirated,” or “Thrombus no longer being aspirated.” The visual messages can be combined with any of the other alert signals **60***a-c*, **70** described herein. The aspiration monitoring system **48**, **62**, **78** described herein give real time awareness to users performing aspiration procedures, such as the removal of thrombus via an aspiration system **2**. One skilled in the art will recognize that by knowing the real time condition of the aspiration system **2**, the user is able to immediately make changes to the procedure in order to optimize results, increase safety for the patient and/or medical personnel, reduce costs (e.g. number of vacuum sources **6** required), and reduce procedure time (also a cost benefit). Because the user is typically performing multiple tasks during an aspiration procedure, the sensory aid provided by the aspiration monitoring system **48**, **62**, **78** allows the user to focus on these tasks without having to continually attempt to monitor conditions which are often difficult to visually monitor. The user can also modify and control the aspiration monitoring system **48**, **62**, **78** via an input **59** (FIG. **2**B), which can comprise a data entry module, keyboard, or a series of buttons with a display. The input **59** can in some embodiments comprise an auditory input which accepts voice commands. Alternatively, the user can input information and control the aspiration monitoring system, **48**, **62**, **78** remotely. Some of the alerts which the user can select or deselect in the aspiration monitoring system **48**, **62**, **78** include, but are not limited to: whether the aspiration system **2** is potentially blocked or clogged, or is flowing normally; whether thrombus has been contacted or not; whether a clog has occurred; whether the vacuum source **6** is adequate, or whether it has been depleted and requires replacement; whether there is a leak in the aspiration system **2**; whether setup or connection of the components of the aspiration system **2** was done correctly or incorrectly; whether to advance the catheter distally; whether to retract the catheter; whether to continue moving the catheter at the same speed; whether to increase or decrease the speed of catheter advancement; whether thrombus is actively being aspirated; and whether thrombus stops being actively aspirated. As the user becomes familiar with the aspiration monitoring system **48**, **62**, **78**, the user can even begin to make certain responses to the system subconsciously. For example, a user can automatically pull back the catheter upon hearing a clot warning signal (e.g., three beeps), and can automatically begin advancing the catheter and/or start fluoroscopic visualization upon hearing a

free blood flow signal (e.g., two beeps). By being “at one” with the aspiration monitoring system **48**, **62**, **78** and the catheter, the user optimizes reactions and actions. This can be helpful improving the skill of having the catheter take a small “bite” of thrombus, and following the “bite” with a “chaser” of some fast flowing blood, the clean/open the lumen. This would also help minimize the chance of clogging, and would in turn reduce maintenance or corrections of the system (removing the catheter, flushing the lumen outside of the patient, replacing the catheter). The overall experience for the user is improved, as the user receives instant gratification for good results, and is instantly notified of errors or instances for concern.

[0133] In some embodiments, alternate power sources can be used, for example, standard AC power with or without an AC/DC convertor; direct connection to existing equipment (e.g. vacuum pumps, etc.); solar power. The aspiration monitoring system **48**, **62**, **78** can be packaged sterile or can be resterilizable by techniques known by those skilled in the art. In some embodiments, flow or volume gauges can be used in conjunction with or instead of the pressure gauge **12**, in order to determine, for example, a clog, or a change in the amount of vacuum or negative pressure. In some embodiments, the input **59**, power module **72**, measurement device **64**, memory module **66**, and communication device **68** (e.g., of FIG. **2**B) can all be incorporated into a single external device, which can in some cases be sold separately. In some embodiments, the external device can also have other functions, such as providing aspiration and/or injection (negative pressure and/or positive pressure) to a catheter. In other embodiments, the external device can comprise some, but not all of the input **59**, power module **72**, measurement device **64**, memory module **66**, and communication device **68**. For example, in some embodiments, a communication device **58** (FIG. **2**A) can replace the external communication device **68**, and can be carried on the aspiration monitoring system **48**, while the input **59**, power module **72**, measurement device **64**, memory module **66** (FIG. **2**B) are incorporated into a single external device. A number of combinations are possible, as described in more detail herein.

[0134] Though aspiration of thrombus has been described in detail, the aspiration monitoring system **48**, **62**, **78** has utility in any aspiration application wherein heterogeneous media is being aspirated. This can include the aspiration of emboli (including not thrombotic emboli) from ducts, vessels, or cavities of the body, or even from solid or semi-solid portions of the body, including, but not limited to, portions of fat, breasts, and cancerous tissue.

[0135] In some embodiments, the aspiration system **2** is be provided to the user as a kit with all or several of the components described, while in other embodiments, only the aspiration monitoring system **48** is provided. Though discussion herein includes embodiments for aspiration of thrombus and blood, the definition of the word “fluid” should be understood throughout to comprise liquids and gases.

[0136] In some embodiments, an additional or alternate sensor can be used to monitor flow conditions for the notification of the user, including, but not limited to: a Doppler sensor, an infrared sensor, or a laser flow detection device. In some embodiments, an externally-attached Doppler sensor can be employed. In some embodiments, an infrared sensor or a laser flow detection device can be employed around the extension tubing **10**.

[0137] Additional embodiments allow real time communication of the particular value of fluid pressure (for example the level of vacuum or negative pressure) measured by the sensor **50**. For example, as the negative pressure gradient increases, an audible sound can increase in sound intensity or in sound pressure level (dB) proportionally. Or, as the negative pressure gradient increases, the pitch (frequency) of an audible sound can made to rise, and as the negative pressure gradient decreases, the pitch can be made to fall (as does a siren). By controlling either the amplitude of a signal or the frequency of a signal by making them proportional to the fluid pressure, the system can give a user a real-time sense of whether the negative pressure gradient is increasing, decreasing, or staying the same, as well as whether the pressure is close to zero or quite different from zero. When an audible sound is used as the signal, the user's eyes can remain

focused on the procedure, whether by viewing a monitor of fluoroscopic images, the patient, or a separate piece of equipment.

[0138] FIG. **6** illustrates a graph **800** of time (x-axis) and multiple variables (y-axis). A pressure curve **802** shows a vacuum or negative pressure being applied at a pressure drop **808**, and a maintenance of vacuum or negative pressure **810***a* with a decrease in vacuum or negative pressure **812** and an increase in vacuum or negative pressure **814**. A removal of vacuum or negative pressure **816** is shown at the end of the pressure curve **802**. In some cases, the decrease in vacuum or negative pressure **812** can be caused by a temporary or permanent leak or detachment within the system or by filling of the vacuum source (e.g., syringe). In FIG. **6**, the decrease in vacuum or negative pressure **812** is shown as temporary, as a subsequent maintenance of vacuum or negative pressure **810***b* is illustrated. The increase in vacuum or negative pressure **814** can in some cases be caused by thrombus being sucked through the system and can occur for a short or long amount of time, and can be steady or intermittent. Though the amount of vacuum or negative pressure applied in the pressure curve **802** varies, in some embodiments, it may only be desirable to show to a user only whether the vacuum or negative pressure is generally being applied or not being applied. The measurement device **54**, **64**, **76** can be configured to apply an algorithm to the signal from the vacuum sensor **50** (pressure sensor) that calculates an inverse value, represented by the dashed curve **804**. The measurement device **54**, **64**, **76** further can apply an algorithm that increases, amplifies or otherwise augments the signal for ease of identification, for example within the human range of audible identification (hearing). For example, a modified signal curve **806** can be created that has the following general mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **802**.

[00003]SoundPressureLevel(dB) = $A + B \times (1 / \text{fluidpressure})$ [0139] where A is a first constant, and [0140] B is a second constant

[0141] In one particular example, a modified signal curve **806** can be created that has the following mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **802**.

[00004]SoundPressureLevel(dB) = $70 + 20 \times (1 / \text{fluidpressure(kPa)}$ [0142] where dB is units in decibels, and [0143] kPa is units of kiloPascal

[0144] The modified signal curve **806** can be constructed of an algorithm such that the sound pressure level drops below the audible level of human hearing at relatively small amounts of vacuum or negative pressure, thus giving the user an “on/off” awareness of the vacuum or negative pressure being applied.

[0145] FIG. **7** illustrates a graph **820** of time (x-axis) and multiple variables (y-axis). A pressure curve **822** shows a vacuum or negative pressure being applied at a pressure drop **828**, and a maintenance of vacuum or negative pressure **830***a* with a decrease in vacuum or negative pressure **832** and an increase in vacuum or negative pressure **834**. A removal of vacuum or negative pressure **836** is shown at the end of the pressure curve **822**. In some cases, the decrease in vacuum or negative pressure **832** can be caused by a temporary or permanent leak or detachment within the system or by filling of the vacuum source (e.g., syringe). In FIG. **7**, the decrease in vacuum or negative pressure **832** is shown as temporary, as a subsequent maintenance of vacuum or negative pressure **830***b* is illustrated. The increase in vacuum or negative pressure **834** can in some cases be caused by thrombus being sucked through the system and can occur for a short or long amount of time, and can be steady or intermittent. In some cases or configurations, it may be desirable for the user to have a very specific real-time or close to real-time characterization of the amount or level of vacuum (negative pressure gradient in general) being applied. The measurement device **54**, **64**, **76** can be configured to apply an algorithm to the signal from the vacuum sensor **50** (pressure sensor) that calculates an absolute value, represented by the dashed curve **824**. The measurement device **54**, **64**, **76** further can apply an algorithm that increases, amplifies or otherwise augments the signal for ease of identification, for example within the human range of audible identification (hearing).

For example, a modified signal curve **826** can be created that has the following general mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **822**.

[00005]SoundPressureLevel(dB) = $A + B \times$ .Math. (fluidpressure) .Math. [0146] where A is a first constant, and [0147] B is a second constant

[0148] In one particular example, a modified signal curve **826** can be created that has the following mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **822**.

[00006]SoundPressureLevel(dB) = $2 \times$ .Math. (fluidpressure(kPa)) .Math. [0149] where dB is units in decibels and, [0150] kPa is units of kiloPascal

[0151] The modified signal curve **826** can be constructed of an algorithm such that the sound pressure level seems to the user to follow the amount of vacuum or negative pressure being applied, thus becoming louder as the vacuum or negative pressure is increased.

[0152] FIG. **8** illustrates a graph **840** of time (x-axis) and multiple variables (y-axis). A pressure curve **842** shows a vacuum or negative pressure being applied at a pressure drop **848**, and a maintenance of vacuum or negative pressure **850***a* with a decrease in vacuum or negative pressure **852** and an increase in vacuum or negative pressure **854**. A removal of vacuum or negative pressure **856** is shown at the end of the pressure curve **842**. In some cases, the decrease in vacuum or negative pressure **852** may be caused by a temporary or permanent leak or detachment within the system or by filling of the vacuum source (e.g., syringe). In FIG. **8**, the decrease in vacuum or negative pressure **852** is shown as temporary, as a subsequent maintenance of vacuum or negative pressure **850***b* is illustrated. The increase in vacuum or negative pressure **854** may in some cases be caused by thrombus being sucked through the system and may occur for a short or long amount of time, and can be steady or intermittent. As mentioned, in some cases or configurations, it can be desirable for the user to have a very specific real-time or close to real-time characterization of the amount or level of vacuum (negative pressure gradient in general) being applied. The measurement device **54**, **64**, **76** can be configured to apply an algorithm to the signal from the vacuum sensor **50** (pressure sensor) that calculates an absolute value, represented by the dashed curve **844**. The measurement device **54**, **64**, **76** further can apply an algorithm that determines a frequency of an audible sound (or pitch), for example within the human range of audible identification (hearing), that varies within the human range of audible frequencies. For example, a modified signal curve **846** can be created that has the following general mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **842**.

[00007]SoundFrequency(Hz) = $A + B \times$ .Math. (fluidpressure) .Math. [0153] where A is a first constant, and [0154] B is a second constant

[0155] In one particular example, a modified signal curve **846** can be created that has the following mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **842**.

[00008]SoundFrequency(Hz) = $50 \times$ .Math. (fluidpressure(kPa)) .Math. [0156] where Hz is Hertz (1/second), and [0157] kPa is units of kiloPascal

[0158] The modified signal curve **846** can be constructed of an algorithm such that the sound frequency seems to the user to follow the amount of vacuum or negative pressure being applied. In this embodiment, the pitch of the sound becomes “higher” when vacuum is increased (fluid pressure decreases), and “lower” when the vacuum or negative pressure is decreased. Alternatively, the opposite can instead by chosen, wherein the pitch of the sound becomes lower when vacuum or negative pressure is increased.

[0159] FIG. **9** illustrates a graph **860** of time (x-axis) and multiple variables (y-axis). A pressure curve **862** shows a vacuum or negative pressure being applied at a pressure drop **868**, and a maintenance of vacuum or negative pressure **870** with a one or more decreases and increases in pressure **872**. These one or more decreases and increases in pressure **872** (or increases and

decreases in vacuum or negative pressure) can represent, in some instances, clot being sucked through aspiration lumen of an aspiration catheter. In some cases, a single decrease in pressure **873** (increase in vacuum or negative pressure) can occur. The single decrease in pressure **873** can in some cases be extended in duration, as shown in FIG. **9**, as can any one of the one or more decreases and increases in pressure **872**. In some cases or configurations, it can be desirable for the user to have a very specific real-time or close to real-time characterization of the instances when these small perturbations are occurring, as they can correspond to the catheter finding and aspirating a portion of thrombus. The measurement device **54**, **64**, **76** be configured to apply an algorithm that determines a frequency of an audible sound (or pitch), for example within the human range of audible identification (hearing), that varies within the human range of audible frequencies. For example, a modified signal curve **866** can be created that has the following general mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **862**.

[00009]SoundFrequency(Hz) = $A + B \times$ (fluidpressure) [0160] where A is a first constant, and

[0161] B is a second constant

[0162] In one particular example, a modified signal curve **866** can be created that has the following mathematical relationship with the signal from the vacuum sensor **50** represented by the pressure curve **862**.

[00010]SoundFrequency(Hz) = $40 \times$ (fluidpressure(kPa)) [0163] where Hz is Hertz (1/second), and

[0164] kPa is units of kiloPascal

[0165] It should be noted that in this equation, no absolute value is used, but rather the actual value of fluid pressure. Or in some cases, an absolute (or negative) value can be used.

[0166] The modified signal curve **866** can be constructed of an algorithm such that the sound maintains a steady pitch until the clot is being sucked through the catheter, at which time the pitch changes slightly, but distinctly, away from a steady pitch. For example, in some embodiments, the pitch can change between about 20 Hz and about 2000 Hz to correspond to a pressure change of between about one kPa to about two kPa, or between about 40 Hz and about 80 Hz.

[0167] In any of the examples, the modification of signals can include any type of signal conditioning or signal modification that can be performed, including, but not limited to filtering, amplification, or isolation. The modified signal curve **806**, **826**, **846**, **866** is used to determine the output signal to be generated by the communication device **58**, **68**, **74**. As mentioned, if the output signal of the communication device **58**, **68**, **74** is configured to be an audible sound, the sound pressure level can be varied, or the sound frequency can be varied. In some embodiments, the output signal of the communication device **58**, **68**, **74** can have both its sound pressure level and sound frequency varied. In one embodiment, the sound frequency varies continuously in proportion to fluid pressure, but at one or more particular thresholds of fluid pressure, the sound pressure level can be caused to vary quite suddenly and strikingly. Thus, there is a two-part communication occurring, a continuous real-time status indicator, with an intermittent, alert indicator (failure, danger, etc.). In some cases, the continuous real-time status indicator can represent a first continuous signal and the alert indicator can represent a second alert signal. In other cases, the continuous real-time status indicator and the alert indicator can be combined or integrated into the same signal. In some embodiments, other characteristics of psychoacoustics can be varied using variable sound generation devices. In some embodiments, the spectral envelope can be varied. In some embodiments, timbre can be changed to varies levels between light and dark, warm and harsh, or different noise “colors” (pink, white, blue, black, etc.).

[0168] Though an audible output from the communication device **58**, **68**, **74** has been described with the examples from FIGS. **6-9**, other communication signals can be used, including visual or tactile signals. Tactile signals can also include vibration devices or heat generation devices, either of which could be varied (as described) in relation to the measured fluid pressure. Either the amplitude or the frequency could analogously be varied in communication signals that include

signals other than the audible signals already described. For example, the intensity of a light can be varied, or the frequency (e.g., color) of a light can be varied. The amplitude of displacement of a vibration device can be varied (or other techniques that vary the vibration intensity) or the frequency of the vibration can be varied.

[0169] In some cases, a pseudo-continuous analog can be used in place of a truly variable output. For example, instead of a single light whose intensity is continuously varied, an array of multiple lights, for example and array comprising multiple LEDs, can be used, with an increased number of LEDs being lit when the level of vacuum or negative pressure is increased, and a decreased number of LEDs being lit when the level of vacuum or negative pressure is decreased. The same can be possible with an array comprising multiple vibrating elements, wherein more elements begin vibrating upon an increase or decrease, depending on the application, of fluid pressure.

[0170] In any of the embodiments described in relation to FIGS. **6-9**, the equations for sound pressure level or for sound frequency which depend on fluid pressure as a variable, can depend on actual measured fluid pressure, or an absolute value of actual measured fluid pressure, but can also use measured fluid pressure in an alternative manner. For example, with a baseline pressure **63** either pre-set, pre-determined, or determined or calculated by any other method (averaging, etc.), the differential between the measured pressure and the baseline pressure **63** can be used as the variable on which to base the particular dependency (e.g., proportionality).

[0171] Thus, a base mathematical relationship used with the proportionality described with respect to the embodiment of FIG. **6** can be represented as:

[00011]SoundPressureLevel(dB) = $A + B \times (1 / \quad P)$ [0172] where A is a first constant, [0173] B is a second constant, and [0174] ΔP is a difference or differential between a baseline pressure and a measured fluid pressure.

[0175] Likewise, a base mathematical relationship used with the proportionality described with respect to the embodiment of FIG. **7** can be represented as:

[00012]SoundPressureLevel(dB) = $A + B \times$ .Math. (P) .Math. [0176] where A is a first constant, [0177] B is a second constant, and [0178] ΔP is a difference or differential between a baseline pressure and a measured fluid pressure.

[0179] Likewise, a base mathematical relationship used with the proportionality described with respect to the embodiment of FIG. **8** can be represented as:

[00013]SoundFrequency(Hz) = $A + B \times$ .Math. (P) .Math. [0180] where A is a first constant, [0181] B is a second constant, and [0182] ΔP is a difference or differential between a baseline pressure and a measured fluid pressure.

[0183] Likewise, a base mathematical relationship used with the proportionality described with respect to the embodiment of FIG. **9** can be represented as:

[00014]SoundFrequency(Hz) = $A + B \times (\quad P)$ [0184] where A is a first constant, [0185] B is a second constant, and [0186] ΔP is a difference or differential between a baseline pressure and a measured fluid pressure.

[0187] A pressure transducer **912** of an aspiration monitoring system **900** is illustrated in FIG. **10**, for coupling to an aspiration system including an aspiration catheter **4**. The pressure transducer **912** includes a housing **40**, a first port **44**, a second port **46** and a cable **902** for carrying a signal. The cable **902** includes an interface **904**, or plug, which is configured to connect to a port **906** of a console **908** of the aspiration monitoring system **900**. The housing **40** of the pressure transducer **912** includes a cavity **42** extending between the first port **44** and the second port **46**. The console **908** is powered by a power module **972**, which is connected to the console **908**, and can comprise a source of AC or DC power. The console **908** can include a measurement device **964**, a memory module **966** and a communication device **968**, which can be coupled to each other as described in the prior embodiments and configured such that the communication device **968** is capable of creating a signal **970**, which can be an alert signal, a continuous signal, a combined signal, or other type of signal. The console **908** can also include wired or wireless connections to other interfaces

or displays which can be found in health care sites, such as a monitor **931**. In some embodiments, the monitor **931** can be a monitor which also displays fluoroscopy or angiogram images, or a monitor which also displays electrocardiography or blood pressure graphics or other information. The monitor **931** can have a portion that maintains the status of the aspiration. For example, it can read "Thrombus being aspirated" or "No thrombus detected." The pressure transducer **912** (housing **40**, ports **44**, **46**, cable **902**, interface **904**) can be sold sterile, and can be configured to output a signal that is received by the console **908**, for example the measurement device **964** of the console **908**. The pressure transducer **912** can have its own internal source of power (e.g., the battery **52** in FIG. **2**A), or can be powered by its connection to the console **908**, or alternatively, by its connection to the aspiration catheter **4**, or even the extension tubing **10**. In some embodiments, the console **908** can be configured to identify and/or recognize the pressure transducer **912**, for example, to recognize the particular model of the pressure transducer **912**. In some embodiments, the console **908** can be configured to measure a resistance between two electrical contacts in the pressure transducer **912** in order to identify the type (e.g., model) of pressure transducer. In some embodiments, the console **908** can be configured to read an RFID chip on the pressure transducer **912**. The console **908** can also be configured to connect to two or more different models of pressure transducer. The port **906**, can comprise at least one port, which can comprise two or more ports, each port configured to allow connection of a different model of pressure transducer.

[0188] An aspiration system **1000** in FIG. **11** includes an aspiration console **1001** having a connector **1002**, or hub, (e.g., male luer) for connecting to an aspiration catheter **4**, for example, to a connector **22** (e.g., female luer) of the aspiration catheter **4**. The aspiration console **1001** is powered by a power module **972**, which is connected to the aspiration console **1001**, and can comprise a source of AC or DC power. The aspiration console **1001** can include a canister **1006** for collecting the aspirated materials, and can include a vacuum pump **1004** for creating a vacuum or negative pressure with which to create the aspiration. Tubing **1008** can be connected between the canister **1006** and the connector **1002**. In some embodiments, the canister **1006** is removable or replaceable. An aspiration monitoring system **900** includes a pressure sensor **1010** (e.g., a vacuum sensor) in fluid communication with the tubing **1008**. The tubing **1008** can instead comprise a lumen formed inside fabricated parts. The aspiration monitoring system **900** is shown in more detail in FIG. **12**, and can include some or all of the features described in relation to FIG. **10**. The aspiration console **1001** can also include wired or wireless connections to other interfaces or displays which can be found in health care sites, such as a monitor **931**. In some embodiments, the monitor **931** can be a monitor which also displays fluoroscopy or angiogram images, or a monitor which also displays electrocardiography or blood pressure graphics or other information. By combining all communication related to the procedure on or at a single monitor or single monitor location, uninterrupted focus can be achieved by the user, who can be freely dedicated to the safe advancement and placement of the aspiration catheter in proximity to the thrombus.

[0189] A system for forced (or assisted) aspiration **1100** in FIG. **13** includes an aspiration/injection console **1101** having a first connector **1016**, or hub, (e.g., male luer) for connecting to an injection lumen **1020** of a forced aspiration catheter **1013**, and a second connector **1012**, or hub (e.g., male luer) for connecting to an aspiration lumen **1018** of the forced aspiration catheter **1013**. The first connector **1016** is configured to connect to connector **1024** (e.g., female luer) of a y-connector **1022** and the second connector **1012** is configured to connect to connector **1026** of the y-connector **1022** at a proximal end **14** of the forced aspiration catheter **1013**. The aspiration/injection console **1101** is powered by a power module **972**, which is connected to the aspiration console **1101**, and can comprise a source of AC or DC power. The aspiration console **1101** can include a canister **1106** for collecting the aspirated materials, and can include a vacuum pump **1104** for creating a vacuum or negative pressure with which to create the aspiration. Tubing **1108** can be connected between the canister **1106** and the connector **1012**. A positive pressure pump **1014** is coupled to a fluid source **1032** (e.g., a saline bag) and is configured to inject infusate out the connector **1016** at a high

pressure. An aspiration monitoring system **900** includes a pressure sensor **1110** (e.g., a vacuum sensor) in fluid communication with the tubing **1108**. The tubing **1108** can instead comprise a lumen formed inside fabricated parts. The aspiration monitoring system **900** is shown in more detail in FIG. **14**, and can include some or all of the features described in relation to FIG. **10**. At a distal end **16** of the forced aspiration catheter **1013**, the injection lumen **1020** terminates in an orifice **1028**, which is configured to create a jet **1030** formed from the high pressure infusate exiting the orifice **1028**. The jet **1030** enters the aspiration lumen **1018**, thus creating suction at the distal end **16** of the forced aspiration catheter **1013**, which forces materials (e.g., thrombus) into the aspiration lumen **1018**, and into the canister **1106**. The aspiration/injection console **1101** can also include wired or wireless connections to other interfaces or displays which can be found in health care sites, such as a monitor **931**. In some embodiments, the monitor **931** can be a monitor which also displays fluoroscopy or angiogram images, or a monitor which also displays electrocardiography or blood pressure graphics or other information.

[0190] In an alternative embodiment, the forced aspiration catheter **1013** of the aspiration catheter **4** can have an additional lumen or guide channel for placement of an additional device or tool. In some embodiments, the guidewire lumen **26** can be used as this additional lumen, and can extend the entire length or most of the length of the catheter, so that the lumen is accessible from the proximal end **14**. The additional device or tool can comprise a laser fiber, a mechanical screw, a vibrating wire or a variety of other modalities for disrupting thrombus or other material.

[0191] In any of the embodiments presented, the system can be configured so that most or all of the components are supplied together. For example, a catheter and an aspiration monitoring system that are permanently attached to each other. In some embodiments, the aspiration catheter and/or the aspiration monitoring system can include configurations that purposely make it difficult to reprocess (e.g., clean or resterilize) them, thus protecting from potential uses that are not recommended or warranted, and which can risk patient infection and/or device malfunction. For example, the sensor or the portion adjacent the sensor can be purposely difficult to access or clean. Alternatively, one or more batteries can be impossible to access or change.

[0192] In some embodiments, it can be desired to have other descriptive warnings that can be tied to pressure measurement or pressure measurement combined with another measured attribute. For example, if a sensor (accelerometer or temperature sensor) within the aspiration catheter is used to detect catheter movement, a change in this sensor can be tied to the pressure sensor. In this manner, a catheter that is engaged with a thrombus at its tip and is moved (e.g., begins to be pulled out of the patient) can then cause a warning: “Warning, do not move catheter; risk of thromboembolus.”

[0193] FIG. **15** is a diagrammatic figure depicting an assisted aspiration system **510**. The aspiration system **510** includes a remote hand piece **512** that contains a fluid pump **526** and an operator control interface **506**. In one contemplated embodiment, the system **510** is a single use disposable unit. The aspiration system **510** can also include extension tubing **514**, which contains a fluid irrigation lumen **502** and an aspiration lumen **504**, and which allows independent manipulation of a catheter **516** without requiring repositioning of the hand piece **512** during a procedure performed with the aspiration system **510**. Extension tubing **514** can also act as a pressure accumulator. High pressure fluid flow from the pump **526**, which can comprise a displacement pump, pulses with each stroke of the pump **526** creating a sinusoidal pressure map with distinct variations between the peaks and valleys of each sine wave. Extension tubing **514** can be matched to the pump **526** to expand and contract in unison with each pump pulse to reduce the variation in pressure caused by the pump pulses to produce a smooth or smoother fluid flow at tip of catheter **516**. Any tubing having suitable compliance characteristics can be used. The extension tubing **514** can be permanently attached to the pump **526** or it can be attached to the pump **526** by a connector **544**. The connector **544** is configured to ensure that the extension tubing **514** cannot be attached to the pump **526** incorrectly.

[0194] An interface connector **518** joins the extension tubing **514** and the catheter **516** together. In

one contemplated embodiment, the interface connector **518** can contain a filter assembly **508** between high pressure fluid injection lumen **502** of the extension tubing **514** and a high pressure injection lumen **536** of the catheter **516** (FIG. **17**). The catheter **516** and the extension tubing **514** can be permanently joined by the interface connector **518**. Alternatively, the interface connector **518** can contain a standardized connection so that a selected catheter **516** can be attached to the extension tubing **514**. In some embodiments, the filter assembly **508** can be removably coupled to the extension tubing **514** by a quick disconnect connection. A pressure transducer of an embodiment of the aspiration monitoring system presented herein can be located at a point along the aspiration lumen **504** or any extension of the aspiration lumen **504**.

[0195] Attached to the hand piece **512** are a fluid source **520** and a vacuum source **522**. A standard hospital saline bag can be used as fluid source **520**; such bags are readily available to the physician and provide the necessary volume to perform the procedure. Vacuum bottles can provide the vacuum source **522** or the vacuum source **522** can be provided by a syringe, a vacuum pump or other suitable vacuum source. The filter assembly **508** serves to filter particulate from the fluid source **520** to avoid clogging of the high pressure injection lumen **536** and an orifice **542** (FIG. **17**). As described herein, distal sections of the high pressure injection lumen **536** can be configured with small inner diameters, and to the filter assembly **508** serves to protect their continuing function. By incorporating one of a variety of catheters **516** into the assisted aspiration system **510**, for example with varying lumen configurations (inner diameter, length, etc.), a variety of aspiration qualities (aspiration rate, jet velocity, jet pressure) can be applied in one or more patients. These aspiration qualities can be further achieved by adjustment of the pump **526**, to modify pump characteristics (flow rate, pump pressure). In some embodiments, the catheter **516** can be used manually, for example, without the pump **526**, and controlled by hand injection. The manual use of the catheter **516** can be appropriate for certain patient conditions, and can serve to reduce the cost of the procedure.

[0196] In one contemplated embodiment, the catheter **516** has a variable stiffness ranging from stiffer at the proximal end to more flexible at the distal end. The variation in the stiffness of the catheter **516** can be achieved with a single tube with no radial bonds between two adjacent tubing pieces. For example, the shaft of the catheter **516** can be made from a single length of metal tube that has a spiral cut down the length of the tube to provide shaft flexibility. Variable stiffness can be created by varying the pitch of the spiral cut through different lengths of the metal tube. For example, the pitch of the spiral cut can be lower (where the turns of the spiral cut are closer together) at the distal end of the device to provide greater flexibility. Conversely, the pitch of the spiral cut at the proximal end can be greater (where the turns of the spiral cut are further apart) to provide increased stiffness. A single jacket covers the length of the metal tube to provide for a vacuum tight (air tight, outside to inside) catheter shaft. Other features of catheter **516** are described with reference to FIG. **17**, below.

[0197] FIG. **16** is a diagrammatic view showing more detail of the hand piece **512** and the proximal portion of assisted catheter aspiration system **510**. The hand piece **512** includes a control box **524** where the power and control systems are disposed. The pump **526** can be a motor driven displacement pump that has a constant output. This pump displacement to catheter volume, along with the location of the orifice **542** (exit) of the catheter high pressure lumen **536** within the aspiration lumen **538** (FIG. **17**), ensures that no energy is transferred to the patient from the saline pump as all pressurized fluid is evacuated by the aspiration lumen. A prime button **528** is mechanically connected to a prime valve **530**. When preparing the device for use, it is advantageous to evacuate all air from the pressurized fluid system to reduce the possibility of air embolization. By depressing the prime button **528**, the user connects the fluid source **520** to the vacuum source **522** via the pump **526**. This forcefully pulls fluid (for example 0.9% NaCl solution, or “saline”, no “normal saline”, or heparinized saline) through the entire pump system, removing all air and positively priming the system for safe operation. A pressure/vacuum valve **532** is used to

turn the vacuum or negative pressure on and off synchronously with the fluid pressure system. One contemplated valve **532** is a ported one-way valve. Such a valve is advantageous with respect to manual or electronic valve systems because it acts as a tamper proof safety feature by mechanically and automatically combining the operations of the two primary systems. By having pressure/vacuum valve **532**, the possibility of turning the vacuum or negative pressure on without activating the fluid system is eliminated.

[0198] The operator control interface **506** is powered by a power system **548** (such as a battery or an electrical line), and can comprise an electronic control board **550**, which can be operated by a user by use of one or more switches **552** and one or more indicator lamps **554**. The control board **550** also monitors and controls several device safety functions, which include over pressure and air bubble detection and vacuum or negative pressure charge. A pressure sensor **564** monitors pressure, and senses the presence of air bubbles. Alternatively, an optical device **566** can be used to sense air bubbles. In one contemplated embodiment, the pump pressure is proportional to the electric current needed to produce that pressure. Consequently, if the electric current required by pump **526** exceeds a preset limit, the control board will disable the pump by cutting power to it. Air bubble detection can also be monitored by monitoring the electrical current required to drive the pump at any particular moment. In order for a displacement pump **526** to reach high fluid pressures, there should be little or no air (which is highly compressible) present in the pump **526** or connecting system (including the catheter **516** and the extension tubing **514**). The fluid volume is small enough that any air in the system will result in no pressure being generated at the pump head. The control board monitors the pump current for any abrupt downward change that can indicate that air has entered the system. If the rate of drop is faster than a preset limit, the control board will disable the pump by cutting power to it until the problem is corrected. Likewise, a block in the high pressure lumen **536**, which can be due to the entry of organized or fibrous thrombus, or a solid embolus, can be detected by monitoring the electrical current running the pump **526**. In normal use, the current fluxuations of the pump **526** are relatively high. For example, the pump can be configured so that there is a variation of 200 milliAmps or greater in the current during normal operation, so that when current fluxuations drop below 200 milliAmps, air is identified, and the system shuts down. Alternatively, current fluxuations in the range of, for example, 50 milliAmps to 75 milliAmps can be used to identify that air is in the system. Additionally, an increase in the current or current fluxuations can indicate the presence of clot or thrombus within the high pressure lumen **536**. For example, a current of greater than 600 milliAmps can indicate that thrombus it partially or completely blocking the high pressure lumen **536**, or even the aspiration lumen **538**.

[0199] A vacuum line **556**, connected to the vacuum source **522**, can be connected to a negative pressure sensor **558**. If the vacuum or negative pressure of the or negative pressure source **522** is low or if a leak is detected in the vacuum line **556**, the control board **550** disables the pump **526** until the problem is corrected. The negative pressure sensor **558** can also be part of a safety circuit **560** that will not allow the pump **526** to run if a vacuum is not present. Thereby a comprehensive safety system **562**, including the safety circuit **560**, the pressure sensor **564** and/or the optical device **566**, and the negative pressure sensor **558**, requires both pump pressure and vacuum or negative pressure for the system to run. If a problem exists (for example, if there is either a unacceptably low pump pressure or an absence of significant vacuum or negative pressure), the control board **550** will not allow the user to operate the aspiration system **510** until all problems are corrected. This will keep air from being injected into a patient, and will assure that the aspiration system **510** is not operated at incorrect parameters.

[0200] FIG. **17** is a diagrammatic view of the distal end portion **568** of the assisted catheter aspiration system **510**, showing more details of the catheter **516**. The catheter **516** is a single-operator exchange catheter and includes a short guidewire lumen **534** attached to the distal end of the device. The guidewire lumen **534** can be between about 1 and about 30 cm in length, or between about 5 and about 25 cm in length, or between about 5 and about 20 cm in length, or

approximately 13.5 cm in length. An aspiration lumen **538** includes a distal opening **540** which allows a vacuum or negative pressure (for example, from vacuum source **522**) to draw thrombotic material into the aspiration lumen **538**. A high pressure lumen **536** includes a distal orifice **542** that is set proximally of distal opening **540** by a set amount. For example, distal orifice **42** can be set proximally of distal opening **540** by about 0.0508 cm (0.020 inches), or by 0.0508 cm±0.00762 cm (0.020 inches±0.003 inches) or by another desired amount. The orifice **542** is configured to spray across the aspiration lumen to macerate and/or dilute the thrombotic material for transport to vacuum source **522**, for example, by lowering the effective viscosity of the thrombotic material. The axial placement of the fluid orifice **542** is such that the spray pattern interaction with the opposing lumen wall produces a spray mist and not a swirl pattern that could force embolic material out from the distal opening **540**. The system can be configured so that the irrigation fluid leaves the pump at a pressure of between about 3,447,378 pascal (500 psi) and about 10,342,135 pascal (1500 psi). In some embodiments, after a pressure head loss along the high pressure lumen **536**, the irrigation fluid leaves orifice **542** at between about 4,136,854 pascal (600 psi) and about 8,273,708 pascal (1200 psi), or between about 4,481,592 pascal (650 psi) and about 5,860,543 pascal (850 psi). In some cases, it can be possible (and even desired) to use the assisted catheter aspiration system **510** without operating the pump **526**, and thus use the catheter **516** while providing, for example, a hand saline injection via a syringe. Or, in some cases, the assisted catheter aspiration system **510** can be used without the pump **526** attached, with the saline injections done by hand using a syringe through the high pressure lumen **536**. If a clog occurs, the syringe can be removed and the pump **526** attached and initiated, for example, for the purpose of unclogging the high pressure lumen **536**.

[0201] When normal blood flow is achieved after unblocking occlusions or blockages from atherosclerotic lesions and/or thrombosis, there is sometimes a risk of reperfusion injury. This can be particularly significant following thrombectomy of vessels feeding the brain for treatment of thromboembolic stroke, or following thrombectomy of coronary vessels feeding the myocardium. In the case of the revascularization of myocardium following a coronary intervention (e.g. thrombectomy). Reperfusion injury and microvascular dysfunction can be mechanisms that limit significant or full recovery of revascularized myocardium. The sudden reperfusion of a section of myocardium that had previously been underperfused can trigger a range of physiological processes that stun or damage the myocardium. Distal coronary emboli, such as small portions of thrombus, platelets and atheroma, can also play a part. Controlled preconditioning of the myocardium at risk has been proposed to limit the effect of reperfusion injury and microvascular dysfunction. The embodiments of the thrombectomy systems **100**, **300** presented herein can be combined with additional features aimed at allowing flow control, in order to limit the potential dangers due to reperfusion following thrombectomy.

[0202] FIG. **18** illustrates a multi-purpose system **1200** comprising a multi-purpose catheter **1202** having an infusion/injection port **1204** and an aspiration port **1206**. The infusion/injection port **1204** and the aspiration port **1206** can each comprise luer connectors, such as female luer lock connectors. A tubing set **1208** and a pressure sensor **1210** are connected in line with a vacuum source **1212**. A cable **1214** carries signals from the pressure sensor **1210** to an aspiration monitoring system **1216** (FIG. **19**), and connects to the aspiration monitoring system **1216** via an interface **1218**, or plug, which is configured to connect to a port **1220** of a console **1222** of the aspiration monitoring system **1216**. Apparatus and methods described herein can be used to monitor aspiration using the aspiration monitoring system **1216**. In one manner of use, a syringe **1224** (FIG. **18**) can be used to manually inject through the injection port **1204** and injection lumen **1225** (e.g., high pressure lumen) of the multi-purpose catheter **1202**. The syringe **1224** can have an injectable volume of about 5 ml or less, or in some embodiments about 1 ml or less. The injection lumen **1225** in some embodiments can be configured for injection of saline at a relatively high pressure, or at either high or low pressures. If the valve **1226** (e.g., stopcock) is closed, blocking the

vacuum source **1212** from applying a vacuum or negative pressure to the aspiration lumen **1227** via the aspiration port **1206**, then injection through the injection lumen **1225** causes injectate to be delivered to a site in the blood vessel near the distal exit of the injection lumen **1225** (at the distal end of the multi-purpose catheter **1202**). Or, if the vacuum source **1212** is removed from, or simply not coupled to, the aspiration lumen **1227**, then injection through the injection lumen **1225** can also cause injectate to be delivered to a site in the blood vessel near the distal exit of the injection lumen **1225**. Either of these techniques can be utilized to apply a medicant to a blood vessel wall, or to an atherosclerotic plaque, or to a thrombus. In some cases, a clot busting drug (tissue plasminogen activator-tPA, thrombokinase, urokinase, thrombin, plasmin) is infused into a clot or thrombus, allowing it to act over a period of time. One purpose can be to soften the thrombus over time. Lytics, glycoprotein inhibitors (GPIs), vasodilators, and other drugs can be used to dilate the blood vessel, or treat disease in the area. The controlled, precision, local delivery allows an efficient use of the drug, with the desired amount delivered to the tissue to be treated with minimal runoff or waste. As many of these drugs are quite expensive, this efficiency reduces procedural costs. Because of the precision diameter of the injection lumen **1225**, and its known length, the injection lumen **1225** contains a known volume, or dead space. This additionally allows a known, controlled, precision injection of medicant. A representative injection lumen **1225** can have a length of 150 cm and have an inner diameter of 0.038 cm (0.015 inches), and thus a total volume of only 0.17 ml. The injection lumen **1225** volume can be varied, by controlling the diameter of the inner diameter of the injection lumen **1225** and/or the length of the injection lumen **1225**. For example, the injection lumen **1225** volume can be between about 0.08 ml and about 0.26 ml, or between about 0.14 ml and about 0.20 ml. By injecting through the injection lumen **1225** with a small bore syringe (e.g., 1 ml) or with a precision pump, an accurate measurement of the medicant delivered can be made. If, however, the valve **1226**, or stopcock, is opened, connecting the vacuum source **1212** to the aspiration port **1206** and applying a vacuum or negative pressure on the aspiration lumen **1227**, a forced aspiration is commenced, as described herein. As described, the injection lumen **1225** can serve either a closed system (aspiration) or an open system (injection of infusate). At the beginning of a procedure, it is not always known what different actions will be required, thus the use of the multi-purpose catheter **1202** and multi-purpose system **1200** can eliminate the need to use multiple catheters (e.g., both a microcatheter and a single function aspiration catheter).

[0203] FIGS. **20-24** illustrate a multi-purpose system **1240** comprising a multi-purpose catheter **1242** having an infusion/injection port **1244** and an aspiration port **1246**. Cooled saline can be injected from a saline bag **1248** (FIG. **23**) through a tubing set **1250**, attached to the saline bag **1248** via a spike **1252**. A pump **1254** (FIG. **24**), which can include a displacement pump, such as a piston pump, includes an interface **1256** for attaching a cassette **1258** (FIG. **20**). In some embodiments, the pump **1254** has moving portions that connect to a moving piston **1255** in the cassette **1258** to inject controlled amounts of fluid. As described in relation to the multi-purpose system **1200** of FIG. **18**, the injection can serve either a closed system (aspiration) or an open system (injection of infusate), depending on whether a valve **1260** which couples a vacuum source **1262** to the aspiration port **1246** via extension tubing **1264** is open or closed, or simply whether the vacuum source **1262** is attached or not attached. A pressure sensor **1266** communicates with the interior of the extension tubing **1264**, but can communicate with the interior of other parts of the flow path. A cable **1268** carries signals from the pressure sensor **1266** to an aspiration monitoring system **1270** (FIG. **22**), and connects to the aspiration monitoring system **1270** via an interface **1272**, or plug, which is configured to connect to a port **1274** of a console **1276** of the aspiration monitoring system **1270**. The utility of the multi-purpose systems **1200**, **1240** in multiple modes is facilitated by the sterile fluid path combined with precision volume control (either by small syringe **1224**, or by the precision pump **1254**). In addition, the aspiration monitoring system **1216**, **1270** allows real-time feedback to the user, further facilitating controlled delivery and/or aspiration.

[0204] The multipurpose system **1200**, **1240** optimizes interventional procedures, such as

percutaneous coronary interventions (PCIs), for simplicity, case flow, and cost. Infusing drugs intracoronary prepares clot for aspiration by placing highly concentrated pharmaco agents directly at the lesion site, at a location which can be more distal (e.g., more superselective) than that which is typically accessible by the tip of a guiding catheter. This can minimize the volume of drug/medicant/agent used. By limiting the amount of certain medicants, systemic complications (bleeding, etc.) can be minimized or eliminated. The direct application of the medicant, for example at the thrombus itself, allows it to soften or disaggregate the thrombus. The maceration of the thrombus, for example by a saline jet **1278** (FIG. **21**) injected through the injection lumen **1257** of the multi-purpose catheter **1242**, keeps the catheter aspiration lumen **1259** patent at all times without interruption, and allows standardized catheter advancement technique, for example, moving the catheter slowly from a proximal location to a distal location in the vessel (in relation to the thrombus). The maceration also dilutes the proximally flowing aspirate for optimal aspiration efficiency. In certain situation, aspiration can be performed until the normal blood flow is restored (at least to a significant level), and then the vacuum source **1262** can be closed off via the valve **1260** and cooled injectate can be infused into the blood vessel. The resultant selective cooling of this area serves to reduce reperfusion injury by potentially slowing ischemic cell metabolism. The injection of cooled infusate can be used any time post-aspiration, pre-stenting, without having to remove an aspiration device, advance a new injection device. Because the multi-purpose catheter **1202**, **1242** is already in place, this critical operation can be started immediately. By having these functionalities all on one catheter, there is also a cost saving to the user.

[0205] In aspiration mode, the aspiration monitoring system **1216**, **1270** is able to monitor proper function of the aspiration circuit at all times. The user knows when warnings are communicated or when the system (e.g., motor) shuts down, that a key event has occurred, an event that needs attending. This knowledge helps the user avoid plunging the catheter distally, potentially causing distal embolism. In infusion/infusate cooling mode, the pump **1254** pumps at a predetermined constant volume or speed to deliver constant temperature cooling infusate. Core temperature feedback (e.g., via rectal, esophageal, ear or other temperature probes) can be used to indicate to the system that further cooling must stop. For example, a core body temperature below 35° C. or below 34° C. The feedback of a temperature below the threshold can be used to shut down the pump and/or to send a warning. The infusate path, which is precision and direct to the catheter tip and/or ischemic area, results in concentrated cooling, causing the least systemic hypothermic potential. By bypassing the aspiration lumen (e.g., with the valve **1260** closed), unintentional embolic debris is less likely to be infused back into the blood vessel, and less likely to thus be sent downstream to critical areas. This eliminates the need to exchange devices after flow has been restored.

[0206] In some cases, in infusion mode, infusate is injected into the fluid injection lumen **1225**, **1257** with a relatively low pressure. In some cases, maceration is performed at a relatively high pressure. In some cases, the multi-purpose system **1240** can be used without the pump **1254** attached, with the saline injections done by hand using a syringe attached to the infusion/injection port **1244**. If a clog occurs, the syringe can be removed and the pump **1254** attached and initiated, for example, for the purpose of unclogging the injection lumen **1257**. In an exemplary procedure, a user places a catheter similar to the multi-purpose catheter **1202** of FIG. **18** or multi-purpose catheter **1242** of FIGS. **20-21** in the vasculature. Initially, the user can choose to have neither a pump **1254**, nor a syringe **1224** (FIG. **18**) attached to the multi-purpose catheter **1202**, **1242**. The user can then commence aspiration through the aspiration lumen **1227**, **1259** via a vacuum source **1212**, **1262**, thus utilizing the multi-purpose catheter **1202**, **1242** as a simple (vacuum or negative pressure only) aspiration catheter. If at any time, the user determines that additional positive pressure injection of saline and/or medicant is needed, for example, to overcome clogging, overcome slow aspiration, or to increase maceration or dilution of the thrombus, the user can attach the pump **1254** or the syringe **1224** to the infusion/injection port **1204**, **1244** and begin injecting the

saline and/or medicant.

[0207] In one embodiment, an aspiration system includes an elongate catheter having a proximal end and a distal end, the catheter including an aspiration lumen having a proximal end and a distal end and a high pressure injection lumen having a proximal end and a distal end and extending from a proximal end of the catheter to a location adjacent a distal end of the aspiration lumen, and at least one orifice at or near the distal end of the high pressure injection lumen and configured to allow high pressure liquid injected through the high pressure injection lumen to be released into the aspiration lumen, wherein the proximal end of the high pressure injection lumen is configured to be repeatably coupled to and uncoupled from one or more injection modules. In some embodiments, the one or more injection modules include a first injection module and a second injection module. In some embodiments, the first injection module comprises a pump and the second injection module comprises a syringe. In some embodiments, the second injection module comprises a syringe having a volume of about 5 ml or less. In some embodiments, the second injection module comprises a syringe having a volume of about 1 ml or less. In some embodiments, the second injection module comprises a syringe containing a drug.

[0208] FIGS. **25** through **33** illustrate several different embodiments of devices having a pressure sensor **1300**, which is configured to function as a component in an aspiration monitoring system sharing some or all of the functionality of any one of the aspiration monitoring systems **48**, **62**, **78**, **900**, **1216**, **1270** presented herein. FIG. **25** illustrates an aspiration catheter **1302** having a distal end **1304** and a proximal end **1306**, the proximal end **1306** comprising a female luer connector **1308**. The pressure sensor **1300** is in fluid communication with (e.g., fluidly coupled to) a lumen of the aspiration catheter **1302**. FIG. **26** illustrates a tubing set **1310** having a male luer **1312** and a female luer **1314**, extension tubing **1316**, and a stopcock **1318**. The pressure sensor **1300** is in fluid communication with a lumen of the extension tubing **1316**. FIG. **27** illustrates a stopcock **1320** having a male luer **1322**, a female luer **1324**, and a valve **1326**, the valve **1326** located proximally of the pressure sensor **1300**. The pressure sensor **1300** is in fluid communication with an internal cavity of the stopcock **1320**. FIG. **28** illustrates a stopcock **1328** having a male luer **1330**, a female luer **1332**, and a valve **1334**, the valve **1334** located distally of the pressure sensor **1300**. The pressure sensor **1300** is in fluid communication with an internal cavity of the stopcock **1328**. FIG. **29** illustrates a syringe **1336** having a male luer **1342**, a barrel **1338**, and a plunger **1340**. The syringe **1336** can include a locking feature **1344**, which allows the plunger **1340** to be locked in relation to the barrel **1338**, such as a VacLok® syringe. The pressure sensor **1300** is located distally of the barrel **1338** and is in fluid communication with an internal cavity of the barrel **1338**.

[0209] FIG. **30** illustrates a syringe **1346** having a male luer **1352** (i.e., luer connector, luer lock), a barrel **1348**, and a plunger **1350**. The syringe **1346** can include a locking feature **1344**. The pressure sensor **1300** is in fluid communication with an internal cavity of the barrel **1348**, and can be directly connected to either the barrel **1348** or the male luer **1352**, or a hollow transition **1351** between them. FIG. **31** illustrates an aspiration system **1354** comprising a syringe **1356** having a male luer **1357**, a barrel **1358** and a plunger **1360**. The syringe **1356** can include a locking feature **1344**. The aspiration system **1354** also comprises a connector assembly **1361** comprising a male luer **1362**, a valve **1364**, and a female luer **1365** (connected under the male luer **1357** in FIG. **31**). The pressure sensor **1300** is in fluid communication with an internal lumen or cavity between the barrel **1358** of the syringe **1356** and the male luer **1362** of the connector assembly **1361**. FIG. **32** illustrates an aspiration system **1366** comprising a syringe **1368** having a male luer **1369**, a barrel **1370** and a plunger **1372**. The syringe **1368** can include a locking feature **1344**. The aspiration system **1366** also comprises a connector assembly **1373** comprising a male luer **1374**, a valve **1376**, and a female luer **1377** (connected under the male luer **1369** in FIG. **32**). The pressure sensor **1300** is in fluid communication with an internal lumen or cavity between the barrel **1370** of the syringe **1368** and the male luer **1374** of the connector assembly **1373**. FIG. **33** illustrates an aspiration system **1378** comprising a syringe **1380** having a male luer **1382**, a barrel **1384** and a plunger **1386**.

The syringe **1380** can include a locking feature **1344**. The aspiration system **1378** further comprises a tubing set **1388** having a male luer **1390** and a female luer **1392**. A valve **1394** is located either proximal or distal to the pressure sensor **1300**. Extension tubing **1396** can be utilized to connect one or more of the components of the tubing set **1388**, but in some cases, the components can be connected directly. The pressure sensor **1300** is in fluid communication with an internal lumen of the tubing set **1388**. The stopcock or valve in any of these embodiments can be a one-way stopcock or a three-way stopcock or a one-way valve or a three-way valve. Other embodiments can exist which combine one or more elements of each of the embodiments presented herein. These embodiments are also included within the scope of this disclosure. In any of the embodiments in which a male luer is used, it can be replaced with a female luer or another liquid-tight connector. In any of the embodiments in which a female luer is used, it can be replaced with a male luer or another liquid-tight connector. As such, either of the connector assemblies **1361**, **1373** can be connected in reverse manner to the syringes **1356**, **1368**, i.e., wherein the distal end becomes the proximal end and is thus connected to the syringe **1356**, **1368**, and wherein the proximal end becomes the distal end.

[0210] FIG. **34** illustrates a thrombectomy system **300** which incorporates the high pressure injection of a liquid, for example sterile saline solution, in order to macerate and aspirate thrombus **104**. A guiding catheter **108** has an inner lumen **110** extending between a proximal end **144** and a distal end **120**. A y-connector **148**, coupled to the proximal end **144** of the guiding catheter **108**, includes a proximal seal **150** and a sideport **152** and is configured to couple the inner lumen **110** of the guiding catheter **108** to a vacuum source **146**, as described in relation to the prior embodiments. A thrombectomy catheter **306** comprises a distal tube **314** having a distal end **316** and a proximal end **318**, the proximal end **318** incorporating one or more sealing members **324** for sealing off an annulus **342** between the guiding catheter **108** and the distal tube **314**, as described in relation to the prior embodiments. The distal tube **314** has an aspiration lumen **330**. A support/supply tube **368**, having a lumen **370**, is coupled to the distal tube **314**. The support/supply tube **368** serves as a support member for pushing and pulling the thrombectomy catheter **306**, but is also a conduit (via the lumen **370**) for high pressure saline, which is injected from the proximal end **372** to the distal end **374**. The saline is supplied from a saline source **376** (e.g., saline bag, bottle) and pressurized by a pump **378**, through a supply tube **380** and through a luer connector **382** which is connected to a luer hub **384** coupled to the support/supply tube **368**. In some embodiments, the support/supply tube **368** comprises a hypo tube. In some embodiments, the support/supply tube **368** comprises stainless steel or nitinol. The distal end **316** of the distal tube **314** can include a skive **358**, which aids in the trackability of the distal tube **314** through vasculature of a patient. In some embodiments, the inner diameter of the aspiration lumen **330** of the distal tube **314** can be approximately one French size smaller than the inner diameter of the inner lumen **110** of the guiding catheter **108**. In some embodiments, the thrombectomy catheter **306** can include a support tube or support shaft to replace the support/supply tube, and not comprise a lumen **370**. Thus, aspiration is only controlled by evacuation of the inner lumen **110** of the guiding catheter **108** in combination of the aspiration lumen **330** of the distal tube **314**, and injection of a high pressure liquid is not necessary. Other embodiments of the thrombectomy catheter **306** are described in U.S. Pat. No. 9,433,427, issued Sep. 6, 2016, and entitled “Systems and Methods for Management of Thrombosis,” which is hereby incorporated by reference in its entirety for all purposes

[0211] FIG. **35** illustrates the proximal end of a guiding catheter **108** used with aspiration catheters, such as the thrombectomy catheter **306** of FIG. **34**. A hemostasis valve **389** of y-connector **390** seals over both the support/supply tube **391** and the guidewire **28**. The hemostasis valve **389** (e.g., Touhy-Borst, longitudinally spring-loaded seal, etc.) must be adjusted to allow catheter and/or guidewire **28** movement (translation, rotation), but must keep air from being pulled into the lumens during aspiration. Because of the continual adjustment often required to the hemostasis valve **389**, for example, to aid movement of the catheter and/or guidewire, the hemostasis valve **389** can create

significant variability in the amount of air that can leak. A leak (e.g., at location **393**) can be fast, and can be unknown to the user. A pressure sensor **394** used in conjunction with any of the aspiration monitoring systems described herein allows the user to know immediately if the seal of the hemostasis valve **389** of the y-connector **390** is not correctly sealed. Additionally, any leaks between the distal luer **388** of the y-connector **390** and the luer hub **386** of the guiding catheter **108** can be detected by the aspiration monitoring system. Furthermore, any leaks between a luer **392** of the pressure sensor **394** and a sideport **395** of the y-connector **390** or between a luer connector **396** of the extension tube **387** and a luer fitting **397** of the pressure sensor **394** can be detected by the aspiration monitoring system. The aspiration monitoring system can be configured to be integral or attachable to any component of the aspiration circuit (e.g., aspiration catheter, syringe/vacuum source), or can be connected in series (at any point) between these components. In some embodiment, the aspiration monitoring system can comprise a flow or pressure sensor or detector that is in series or in parallel with the components, or is configured to be placed in series or in parallel with the components. In any of these configurations, a number of different leak locations can be assessed by the aspiration monitoring system of the embodiments disclosed herein. The aspiration monitoring system can be configured to detect: changes, relative changes, absolute changes, thresholds, absolute values, the presence of or the lack of pressure and/or flow. The aspiration monitoring system can be configured to determine the operation status of a system including a catheter having an aspiration lumen. In some cases, the aspiration monitoring system can be configured to provide information about the operation of the system that is not discernable from typical clues such as angiography, sound, feel, or other visual, auditory, tactile or other feedback from the system itself.

[0212] FIG. **36** illustrates an aspiration system **1400** comprising an aspiration catheter **1402** comprising an elongate shaft **1401** including an aspiration lumen **1404** having an open distal end **1405** and a proximal end **1406** configured to couple to a peristaltic pump **1408**. The peristaltic pump **1408** can be a roller pump having a base **1426**, a pressure shoe **1428** carried by the base **1426**, and a rotatable head **1430**, rotatably coupled to the base **1426**, and carrying two or more rollers **1432***a-d*. The rollers **1432***a-d* are arrayed around a perimeter **1434** of the rotatable head **1430**. The rotatable head **1430** is configured to be rotatable in at least a first rotational direction **1436** with respect to a rotational axis **1499**. The rotatable head **1430** can be rotated by a motor **1497**, either directly, or with a gear train **1495**. The peristaltic pump **1408** can be battery powered, and the battery(ies) can be rechargeable by wired or wireless means. The peristaltic pump **1408** can alternatively, or additionally be powered by a power cord **1493** configured to connect to a power supply. An extension tube **1438** having a distal end **1440** and a proximal end **1442**, and having a lumen **1444** extending therethrough, is hydraulically coupled to the proximal end **1406** of the aspiration lumen **1404** via a connector **1424**. The extension tube **1438** can be supplied (e.g., sterile) with the aspiration catheter **1402**, or can be packaged and supplied separately. A Touhy-Borst seal **1446** carried on the connector **1424** is configured to be loosened/opened to allow the insertion of a guidewire **1448** through the connector **1424** and the aspiration lumen **1404**. The aspiration lumen **1404** can thus be used to track the aspiration catheter **1402** over the guidewire **1448** through a subject's vasculature. The Touhy-Borst **1446** can be tightened to seal over the guidewire **1448**, to maintain hemostasis. Other types of seals can be incorporated in place of the Touhy-Borst **1446**, including a spring-loaded, longitudinally compressible and actuatable seal. The extension tube **1438** includes a male luer **1450** at its distal end **1440**, for connecting to a female luer **1452** of the connector **1424**. The male luer **1450** can include a stopcock **1454**, which is configured to be turned to select between an open position (shown) or a closed position. The extension tube **1438** and its components can be supplied sterile as a single unit. Alternatively, the extension tube **1438** can be integral with the aspiration lumen **1404**, or can be permanently attached to the connector **1424**. In use, a compressible portion **1437** of the extension tube **1438** is placed within the pressure shoe **1428** of the peristaltic pump **1408** such that rotation of the rotatable head **1430** in the rotational

direction **1436** causes fluid to be forced through the lumen **1444** of the extension tube **1438** from the distal end **1440** to the proximal end **1442**, via compression of the compressible portion **1437** by the rollers **1432**, one at a time. The single insertion step to couple the compressible portion **1437** to the peristaltic pump **1408** is simple, quick, reliable, and does not involve any connection that has to seal (e.g., luer, etc.). It is also easier to visualize whether a peristaltic pump is successfully operating, vs. a vacuum pump or evacuated syringe. This may be because, under relatively high vacuum or negative pressure conditions, blood tends to cavitate, thus filling the space of a container (e.g., canister or syringe) at an accelerated rate due to the excess gaseous volume. The gaseous bubbles may also make it more difficult to see inside and visually inspect the condition. Optionally, an interface **1456** on the peristaltic pump **1408** is configured to allow a user to input information or commands to the peristaltic pump **1408** or other components of the system **1400**. Otherwise, hardware or firmware can be pre-programmed with specific run parameters (motor speed, rotation speed, etc.). In some embodiments, there are only two rollers **1432**. In other embodiments, there are three rollers **1432**. In still other embodiments, as shown, there are four rollers **1432**. In an alternative embodiment, instead of rollers, smooth, radiused bumps of a rigid material slide over the compressible portion **1437**, compressing it. In this alternative embodiment, the compressible portion **1437** and/or the bumps can be treated with a lubricious material or can be constructed from significantly lubricious materials to lover the sliding friction between the compressible portion **1437** and the bumps. Returning to the embodiment of FIG. **36**, the compressible portion **1437** can comprise silicone tubing, polyurethane tubing, polyvinyl chloride tubing, or other compressible tubing. The compressible section **1437** can be a relatively short section that is attachable to and detachable from the peripheral ends of the extension tube **1438**, or in other embodiments, can comprise the entirety of the extension tube **1438** between the distal end **1440** and the proximal end **1442**. The proximal end **1442** of the extension tube **1438** can be coupled to a hub **1457** of a canister **1458** having an interior **1460**, to allow fluid **1459** passing through the extension tube **1438** to pass into the interior **1460**. An additional hub **1462** in the canister **1458** can be left open (as shown) to allow the unfilled interior **1460** to match atmospheric pressure. Alternatively, the canister **1458** can be replaced by another type of receptacle, such as a bag, or more specifically an empty infusion bag, configured for collecting aspirate therein.

[0213] The aspiration catheter **1402** additionally has a high pressure injection lumen **1410** for injecting saline from a fluid source **1479**, for example, via a high pressure pump **1412**. A tubing set **1464** can include a pump cartridge **1466** having a piston, or bellows, or other movable element that the pump **1412** can manipulate using an internal motor **1491**, thus pressurizing saline (or other fluid) from the fluid source **1479** with a significantly high pressure such that the saline is forced through the injection lumen **1410** of the aspiration catheter **1402**. The tubing set **1464** includes proximal end **1468** having a spike **1489**, or other connecting element, for hydraulically coupling the tubing set **1464** to the fluid source **1479**. The tubing set **1464** further has a distal end **1470**, which can comprise a male luer, and which is configured to hydraulically couple the tubing set **1464** to the injection lumen **1410** via a female luer **1472**. The tubing set **1464** can be supplied sterile as a single unit, or alternatively can be permanently attached to the aspiration catheter **1402**. In use, injected saline is forced through the injection lumen **1410** by the pump **1412** and exits an orifice **1474** at a distal end **1476** of the injection lumen **1410**. The injection lumen **1410** can extend within a separate tube **1478** (injection tube) that is substantially or entirely within the shaft **1401**. In some embodiments, the tube **1478** is attached to the internal wall of the shaft **1401** only at a distal end portion **1403**. Thus, the free-floating nature of the remainder of the tube **1478** within the aspiration lumen **1404** increases the flexibility and trackability of the shaft **1401**. There also a reduced chance of the tube **1478** being kinked because of flexing of the shaft **1401**, because the bending of the shaft **1401** is not directly applied to the tube **1478**. The high pressure saline is forced through the injection tube **1478** and out the orifice **1474**, causing a jet **1487**. The jet **1487** is within the aspiration lumen **1404**, just proximal the open distal end **1405** which can create a Venturi effect

that forces blood or thrombus that is external and adjacent the open distal end **1405** into the aspiration lumen **1404**. The operation of the peristaltic pump **1408** with the rotatable head **1430** rotating in the first rotational direction **1436** moves fluid and thrombus from the open distal end **1405** of the aspiration lumen **1404** to the proximal end **1442** of the extension tube **1438** by continually and forceably moving the fluid column within the lumen **1444** of the extension tube **1438**, which pulls the fluid column within the aspiration lumen **1404** along with it. The combination of the operation of the peristaltic pump **1408** and the jet **1487** created by the high pressure saline cause the maceration of thrombus, and the movement/flow of material (saline/blood/macerated thrombus/small pieces of thrombus) through the aspiration lumen **1404** from the open distal end **1405** to the proximal end **1406**, through the interior **1485** of the connector **1424**, and through the lumen **1444** of the extension tube **1438** from its distal end **1440** to its proximal end **1442**, and finally into the interior **1460** of the canister **1458**. Thus, thrombus within a blood vessel of a subject can be macerated and removed by use of the system **1400**. Blood vessels can include peripheral blood vessels, coronary blood vessels, or blood vessels within the head or neck of the subject, including carotid arteries or cerebral arteries.

[0214] An aspiration monitoring system **1414** comprising a pressure transducer **1416** can be coupled, for example, between the distal end **1440** of the extension tube **1438** and the connector **1424** and/or the proximal end **1406** of the aspiration lumen **1404** of the aspiration catheter **1402**. The aspiration monitoring system **1414** can include any of the features described in relation to the other aspiration monitoring systems **48**, **62**, **78**, **900**, **1216**, **1270** disclosed herein. Signals from the pressure transducer **1416** are carried on an electric cable **1480** to an input **1482** of the pump **1412**. A controller **1484** within the pump **1412** is configured to control the operation of the pump **1412**, including motor **1491**, but the controller **1484** can also be configured to control the operation of the peristaltic pump **1408**, via a cable **1486**, or wirelessly. The controller **1484** can comprise a microcontroller. The controller **1484** can alternatively be located within the peristaltic pump **1408**, or can be located at another location. Control using signals of measured pressure from the pressure transducer **1416** adds an additional safety element to the system **1400**. Furthermore, a non-functional system **1400** or particular component of the system **1400** can be quickly identified. For example, a leak, incomplete connection, incomplete priming of one of the lumens, rupture, or breakage can cause changes in the signal from the pressure transducer **1416**, thus allowing their identification. Unallowably high pressures can also be quickly identified, and the controller **1484** is configured to automatically shut down the pump **1412**, thus protecting the motor **1491** of the pump **1412** from burnout or overheating, and the failure or danger associated therewith. The peristaltic pump **1408** can also be shut down by the controller **1484**. In some embodiments, the peristaltic pump **1408** is configured to be shut down by the controller **1484** after the pump **1412** is shut down (e.g., after a finite delay). The delay can be between about 0.01 second and about 1.00 second, or between about 0.10 second and about 0.25 second. The integrity of the tube **1478** is also protected, e.g., avoiding unnaturally high pressures that could lead to burst. In some embodiments, the peristaltic pump **1408** can be battery powered, and the controller **1484** can be located within the peristaltic pump **1408**, thus providing a self-contained peristaltic pump **1408** which can be easily moved from one location to another. In some embodiments, the peristaltic pump **1408** can even be easily cleanable and sterilizable, such that it can be placed within a sterile field, such as a sterile field in the vicinity of a patient. In some embodiments, the pump **1412** is configured to remain in a non-sterile area, while the peristaltic pump **1408** is configured for sterile use. A push button **1411** can be carried on the peristaltic pump **1408**, and can be configured for activation by a user, for example, a user who is scrubbed for contact of sterile articles only. The push button **1411** can be configured to start or stop the operation of the peristaltic pump **1408**. Additionally, the push button can be configured to start or stop the operation of the pump **1412** (e.g., via the cable **1486**). In some embodiments, the peristaltic pump **1408** and the pump **1412** are combined into a single console. This allows for a smaller size that can be mounted on a standard IV pole.

[0215] In some embodiments, activation of the push button **1411** by a finger of a user starts the operation of the peristaltic pump **1408**, and then starts the operation of the pump **1412**, with a slight delay after the peristaltic pump **1408** is started. The delay is useful to assure that some aspiration, or a significant amount of aspiration, is being applied to the aspiration lumen **1404** prior to the injection of pressurized fluid (e.g., saline) through the injection lumen **1410**. Thus, blood vessels or other vasculature in the vicinity of the open distal end **1405** are spared any injection of fluid from a high pressure jet, as it is instead aspirated through the aspiration lumen **1404**, along with any aspirated thrombus or blood. In addition, in some embodiments, activation of the push button **1411** by a finger of a user during the operation of the pump **1412** and the peristaltic pump **1408** stops the operation of the pump **1412** and the operation of the peristaltic pump **1408** at the same time. In other embodiments, a delay can be applied, for example, such that the pump **1412** is stopped, and then the peristaltic pump **1408** is stopped slightly afterwards. The length of the delays described can be between about 0.01 second and about 1.00 second, or between about 0.10 second and about 0.25 second. In some embodiments, the controller **1484** is configured to change the rotational speed of the rotatable head **1430** of the peristaltic pump **1408**, for example, increase the speed or decrease the speed. In some embodiments, the controller **1484** is configured to change the flow rate (injection rate) of the pump **1412**, for example, increase the injection rate or decrease the injection rate. In some embodiments, the controller **1484** is configured to change the speed/rate of both pumps **1408**, **1412** at the same time. In some embodiments, the controller **1484** is configured to change the speed/rate of one of the pumps **1408**, **1412** and then change the speed/rate of the other of the pumps **1408**, **1412** after a particular delay. Any of these commands from the controller **1484** can be in response to changes in the signal received from the pressure transducer **1416**, The peristaltic pump **1408** in its peak pulse (e.g., sinusoidal peak amplitude) provides a significant negative pressure gradient such that the difference between a clog state pressure transducer **1416** reading and a free flow state pressure transducer **1416** reading is amplified. Thus, a larger number of potential thromboembolic events are avoided, such as thrombus being release from the open distal end **1405** of the aspiration lumen **1404** of the aspiration catheter **1402**. The pressure variations on the pressure transducer **1416** tend to be significantly greater when using a peristaltic pump **1408** than when using a vacuum pump, or other vacuum source (e.g., evacuated syringe). One significant advantage is that the user can be made clearly aware when clot/thrombus is not being aspirated, and thus, when aspiration is free flow, causing loss of blood without removal of thrombus **1402**. It is much easier to be aware of the status at the open distal end **1405** of the aspiration catheter. Current vacuum pumps do not have a similar clear-cut manner of demonstrating active vs. resting states. The user is thus notified, and the pumps **1408**, **1412** are stopped to minimize blood loss, and to allow repositioning onto thrombus. Peristaltic pumps **1408** also tend to be less noisy than vacuum pumps, and less likely to disturb communication of medical personnel during a procedure, or increase stress.

[0216] Stopping the peristaltic pump **1408** leaves at least one roller **1432** in a position compressing the compressible portion **1437** of the extension tube **1438**. Thus, an open/close valve or pinch valve, or stopcock, or other valve is not needed. The fact that the rotatable head **1430** is already moving means that roller **1432** moves to the occluding position rapidly, without a large inertial requirement, when the peristaltic pump **1408** is stopped. This can thus be faster than the activation of standard electrically-activated pinch valves, which are initially motionless and need to be placed into motion prior to pinching. The motor **1497** can comprise a stepper motor that is directed (e.g., by the controller **1484**) such that the rotatable head directs one of the rollers **1432** to occlude the lumen **1444** of the extension tube **1438** at the compressible portion **1437**. In FIG. **36**, the roller **1432***c* is in position (if the motor **1497** were stopped) to occlude the lumen **1444**. Thus, the peristaltic pump **1408** itself can inherently minimize the potential of distal embolization, as stoppage of pump immediately or almost immediately creates stasis. Alternatively, a non-stepper motor, such as a brushless DC motor, can be utilized along with an encoder (e.g., optical encoder),

or another type of position sensor, in place of a stepper motor. Additionally, unmacerated clot can thus be stopped from entering the aspiration lumen **1404**. As discussed, in other embodiments, the rollers **1432** can be replaced by non-rotating bumps or protrusions, that slide over the compressible portion **1437** of the extension tube **1438**, instead of rolling over. In some embodiments, the bumps/protrusions and/or the external surface of the compressible portion **1437** can be coated with a silicone, hydrophilic, or other lubricious material to lower the friction.

[0217] The controller **1484** can be configured to control the operation of the pump **1412** to cause the pump **1412** to inject pressurized fluid in a pulsatile manner. The high pressure jet is applied in a pulsatile fashion to optimize the cutting ability of the jet on a piece of thrombus. For example, a portion of thrombus that is aspirated into the open distal end **1405** of the aspiration lumen **1404** of the aspiration catheter **1402** can be more readily severed by a pulsating jet, much in the manner that a reciprocating saw. The controller **1484** is configured to operate the pump **1412** to pressurize fluid through the injection lumen such that the one or more jets are pulsatile. The controller **1484** is also configured to operate the peristaltic pump **1408** to further aid that that pressurized fluid injected through the injection lumen causes the one or more jets to be pulsatile. For example, the controller **1484** can send a signal to cause a sinusoidal variation in the speed of the motor **1491**. The degree of pulsatility (pulse rate, peak pulse, pulse wave shape, rise time, on time, off time) can be tailored and controllably applied by the controller **1484** on the pump **1412** and/or the peristaltic pump **1408**.

[0218] The use of a peristaltic pump **1408** assures that the interior of the aspiration lumen **1404** and lumen **1444** of the extension tube **1438**, and its contents, are not contacted, thus further assuring maintenance of sterility. The use of a peristaltic pump **1408** also causes minimal or virtually no cavitation to blood being removed. If there were any cavitation during aspiration, proximal to the peristaltic pump **1408**, after the blood and aspirate passes through the rollers **1432**, the blood is exposed to atmospheric pressure, and the cavitation disappears. Thus, it is easier to judge the amount of blood that has been collected or is being collected into the canister **1458** for it is not obscured by bubbles or foam, such that an indicative volume of collected blood is clearly visible and reliable to measure. Additionally, it is easier to reuse the blood quickly, if, for example, it is to be reinjected into the subject. It is also safer and more reliable to infuse blood that does not have significant air bubbles. The use of a vacuum source such as a vacuum bottle or evacuated syringe can tend to create a larger amount of cavitation. Thus, the peristaltic pump **1408** can be used in order to provide an efficient procedure, and also to maximize the volume of blood that can be reinjected/reinfused. The tubing set **1464** separates the extension of the injection lumen **1410** from the aspiration lumen **1404** at the male luer **1410** of the connector **1424**, thus only the compressible portion **1437** of the extension tube **1438** need be compressed by the rollers **1432**. Other portions of the aspiration catheter **1402** are thus not compressed by the rollers **1432**, and therefore are not in danger of being crushed or otherwise damaged. The distal end **1483** of the aspiration catheter **1402** can in some embodiments resemble that of the catheter **516** of FIG. **17**. The aspiration catheter **1402** can in some embodiments be replaced by the thrombectomy system **300** of FIG. **34**, or the other embodiments of the thrombectomy catheter **306** described in U.S. Pat. No. 9,433,427, issued Sep. 6, 2016, and entitled “Systems and Methods for Management of Thrombosis,” which is hereby incorporated by reference in its entirety for all purposes. The use of the peristaltic pump **1408** has additional advantages in comparison to a vacuum pump. The peristaltic pump **1408** can be configured to be controlled by the controller **1484** such that it runs only when the pump **1412** is injecting. Thus, the noise is reduced in comparison to a system using a vacuum pump, as the vacuum pump is on (operating) the entire time.

[0219] FIG. **37** illustrates a subject **1500** in a hospital bed **1502** or table being injected with blood in three different modalities. During thrombectomy procedures, thrombus/clot is removed from the blood vessels of the subject **1500**. In some instances, the blood volume of the patient becomes abnormally low, and fluids or blood need to be reinjected into the patient. In a first modality, the peristaltic pump **1408** of the system **1400** of FIG. **36** is shown. The aspiration catheter **1402** is

inserted in the subject **1500** and the aspiration (thrombectomy) procedure is being performed. Instead of the canister **1458**, the extension tube **1438** at its distal end **1442** is connected to a return conduit **1505** comprising an intravascular (IV) line **1504** which is inserted into a vein of the subject **1500**. The blood is driven by the rollers **1432** of the peristaltic pump **1408** so that it passes through a blood filter **1506**, which removes any residual thrombus or particulate prior to the blood being infused into the veins of the subject. Heparin, or other additives can also be added to the blood as it is being injected into the subject **1500** at port **1481**, which communicates with the intravascular (IV) line **1504**. As the blood only flows through a single sterile composite conduit, an efficient, cleanly reinfusion method is provided. The blood can be purified, for example, to remove red blood cells or portions of red blood cells that have undergone hemolysis. One such reinfusion device is the Haemonetics Cell Saver® Elite+ Autotransfusion System. It is believed that peristaltic pumps **1408** cause less damage to blood cells, and thus less cleaning can be needed, if any. Thus, a higher yield of blood after using the Cell Saver is possible because of the advantages of the peristaltic pump **1408**. Also, the blood can be easily transferred to the Cell Saver in a non-contact manner, directly from the extension tube **1438**, that is not possible in the transfer from a collection container used with a vacuum source. The blood can even be kept sterile upon being sent directly into the Cell Saver. In some embodiments, the extension tube **1438** can be significantly translucent, so that the thrombus can be assessed during aspiration. A video camera or magnifying element (low power microscope, etc.) can be focused on the extension tube **1438** to better identify the state of the thrombus being aspirated (quantity, amount of maceration). There can be an almost real-time feedback of the condition of the thrombus being removed from within the vasculature of the patient.

[0220] In a second modality, blood is collected in a prior procedure in the canister **1458** (FIG. **36**). The blood can then be filtered, or even spun in a centrifuge to obtain particular components. Heparin, or other additives can also be added to the blood. The blood is then placed in a blood bag **1508** (or blood bottle) and infused into the vein of the subject **1500** using a passive drip through an IV line **1510** (e.g., via gravity alone). In other cases, a pressurizable bag **1512** can be used around the blood bag **1508** to increase the compression on the blood bag **1508**, thus increasing the flow rate into the vein. In some cases, the blood can even by injected directly into the arterial system, for example, through an arterial line (a-line). The blood can additionally be purified as described above.

[0221] In a third modality, blood is collected in a prior procedure in the canister **1458** (FIG. **36**). The blood can then be filtered, or even spun in a centrifuge to obtain particular components. Heparin, or other additives can also be added to the blood. The blood is then placed into a blood bag **1514**, and pumped into a vein of the subject **1500** using an infusion pump **1516**. Insertion points **1518***a*, **1518***b*, **1518***c* are shown for the first, second, and third modalities, respectively. The blood can additionally be purified as described above.

[0222] FIG. **38** illustrates an alternative aspiration system **1400′** comprising an aspiration catheter **1402′** comprising an elongate shaft **1401′** including an aspiration lumen **1404′** having an open distal end **1405′** and a proximal end **1406′** configured to couple to the peristaltic pump **1408**. The peristaltic pump **1408** can be a roller pump having a base **1426**, a pressure shoe **1428** carried by the base **1426**, and a rotatable head **1430**, rotatably coupled to the base **1426**, and carrying two or more rollers **1432***a-d*. The rollers **1432***a-d* are arrayed around a perimeter **1434** of the rotatable head **1430**. The rotatable head **1430** is configured to be rotatable in at least a first rotational direction **1436** with respect to a rotational axis **1499**. The rotatable head **1430** can be rotated by a motor **1497**, either directly, or with a gear train **1495**. The peristaltic pump **1408** can be battery powered, and the battery (ies) can be rechargeable by wired or wireless means. The peristaltic pump **1408** can alternatively, or additionally be powered by a power cord **1493** configured to connect to a power supply. An extension tube **1438** having a distal end **1440** and a proximal end **1442**, and having a lumen **1444** extending therethrough, is hydraulically coupled to the proximal end **1406′** of

the aspiration lumen **1404′** via a connector **1424′**. The extension tube **1438** can be supplied (e.g., sterile) with the aspiration catheter **1402′**, or can be packaged and supplied separately. A Touhy-Borst seal **1446′** is coupleable and decouplable to the connector **1424′** (e.g., via luer connections **1750**, **1752**) and is configured to be loosened/opened to allow the insertion of a guidewire **1448** through the connector **1424′** and the aspiration lumen **1404′**. The aspiration lumen **1404′** can thus be used to track the aspiration catheter **1402′** over the guidewire **1448** through a subject's vasculature. The Touhy-Borst **1446′** can be tightened to seal over the guidewire **1448**, to maintain hemostasis. Other types of seals can be incorporated in place of the Touhy Borst **1446′**, including a spring-loaded, longitudinally compressible and actuatable seal. The distal end **1440** of the extension tube **1438** is slipped over a first barb fitting **1754** of a y-connector **1756**. A second extension tube **1760** has a distal end **1761** that is slipped over a second barb fitting **1758** of the y-connector **1756**. A third extension tube **1762** has a proximal end **1763** that is slipped over a third barb fitting **1764** of the y-connector **1756**. The second extension tube **1760** and third extension tube **1762** are configured to operate under negative pressure without collapsing, and can comprise standard suction tubing. A distal end **1765** of the third extension tube **1762** is coupled to a female luer **1452′** sideport of the connector **1424′**, either permanently by molding, or an adhesive bond or weld, or by an attachable and detachable connection, such as a luer **1766**. The lengths of each of the second extension tube **1760** and third extension tube **1762** can be varied. In some embodiments, the third extension tube **1762** is relatively short, and the y-connector **1756** is configured to be located in a sterile area near the patient. In other embodiments, the third extension tube **1762** is configured to be relatively long, and the y-connector **1756** is configured to be located in a non-sterile area, away from the patient. The second extension tube **1760** is optional, as the third extension tube **1762** can have a much longer length and the pressure transducer **1416**/aspiration monitoring system **1414** can be attached directly to the y-connector **1756** at the location of the barb fitting **1758**. This connection can be direct, and so the barb fitting **1758** is also optional. With the longer third extension tube **1762**, the y-connector **1756** and the aspiration monitoring system **1414** can both be close to the pump **1412**, and can both reside in a non-sterile area.

[0223] In use, a compressible portion **1437** of the extension tube **1438** is placed within the pressure shoe **1428** of the peristaltic pump **1408** such that rotation of the rotatable head **1430** in the rotational direction **1436** causes fluid to be forced through the lumen **1444** of the extension tube **1438** from the distal end **1440** to the proximal end **1442**, via compression of the compressible portion **1437** by the rollers **1432**, one at a time. Optionally, an interface **1456** on the peristaltic pump **1408** is configured to allow a user to input information or commands to the peristaltic pump **1408** or other components of the system **1400′**. Otherwise, hardware or firmware can be pre-programmed with specific run parameters (motor speed, rotation speed, etc.). In some embodiments, there are only two rollers **1432**. In other embodiments, there are three rollers **1432**. In still other embodiments, as shown, there are four rollers **1432**. As described, the rollers **1432** can be replaced by bumps or protrusions. The compressible portion **1437** can comprise silicone tubing, polyurethane tubing, polyvinyl chloride tubing, or other compressible tubing. The compressible section **1437** can be a relatively short section that is attachable to and detachable from the peripheral ends of the extension tube **1438**, or in other embodiments, can comprise the entirety of the extension tube **1438** between the distal end **1440** and the proximal end **1442**. The proximal end **1442** of the extension tube **1438** can be coupled to a hub **1457** of a canister **1458** having an interior **1460**, to allow fluid **1459** passing through the extension tube **1438** to pass into the interior **1460**. An additional hub **1462** in the canister **1458** can be left open (as shown) to allow the unfilled interior **1460** to match atmospheric pressure. Alternatively, the canister **1458** can be replaced by a bag, such as an empty infusion bag, configured for collecting aspirate therein.

[0224] The aspiration catheter **1402′** additionally has a high pressure injection lumen **1410′** for injecting saline from a fluid source **1479**, for example, via a high pressure pump **1412**. A tubing set **1464** can include a pump cartridge **1466** having a piston or bellows or other movable element that

the pump **1412** can manipulate using an internal motor **1491**, thus pressurizing saline (or other fluid) from the fluid source **1479** with a significantly high pressure such that the saline is forced through the injection lumen **1410′** of the aspiration catheter **1402′**. The tubing set **1464** includes proximal end **1468** having a spike **1489**, or other connecting element for hydraulically coupling the tubing set **1464** to the fluid source **1479**. The tubing set **1464** further has a distal end **1470** (which can include a male luer) which is configured to hydraulically couple to the injection lumen **1410′** via a female luer **1472′**. In use, injected saline is forced through the injection lumen **1410′** by the pump **1412** and exits an orifice **1474′** at a distal end **1476′** of the injection lumen **1410′**. The injection lumen **1410′** can extend within a separate tube **1478′** (injection tube) that is substantially entirely within the shaft **1401′**. In some embodiments, the tube **1478′** is attached to the internal wall of the shaft **1401′** only at a distal end portion **1403′**. Thus, the free-floating nature of the remainder of the tube **1478′** within the aspiration lumen **1404′** increases the flexibility and trackability of the shaft **1401′**. The high pressure saline is forced through the injection tube **1478′** and out the orifice **1474′**, causing a jet (similar to jet **1487** of FIG. **36**). The jet is aimed within the aspiration lumen **1404′**, just proximal the open distal end **1405′** which can create a Venturi effect that forces blood or thrombus that is external and adjacent the open distal end **1405′** into the aspiration lumen **1404′**. The combination of the operation of the peristaltic pump **1408** and the jet created by the high pressure saline cause the maceration of thrombus, and the movement/flow of material (saline/blood/macerated thrombus/small pieces of thrombus) through the aspiration lumen **1404′** from the open distal end **1405′** to the proximal end **1406′**, through the female luer **1452′** of the connector **1424′**, and through the lumen **1444** of the extension tube **1438** from its distal end **1440** to its proximal end **1442**, and finally into the interior **1460** of the canister **1458**. Thus, thrombus within a blood vessel of a subject can be macerated and removed by use of the system **1400′**. Blood vessels can include peripheral blood vessels, coronary blood vessels, or blood vessels within the head or neck of the subject, including carotid arteries or cerebral arteries.

[0225] An aspiration monitoring system **1414** comprising a pressure transducer **1416** can be coupled, for example, proximal to the connector **1424′** and/or proximal to the proximal end **1406′** of the aspiration lumen **1404′** of the aspiration catheter **1402′**, such that the pressure transducer **1416** is hydraulically coupled to the aspiration lumen **1404′**. In the aspiration system **1400′** of FIG. **38**, the aspiration monitoring system **1414** is spaced a distance from the y-connector **1756** by a relatively long second extension tube **1760** (or alternatively by a relatively long third extension tube **1762**, as in the aspiration system **2100** of FIG. **74**) such that the aspiration monitoring system **1414** resides in a non-sterile area. Thus, the aspiration monitoring system **1414** can be set up, prepped, calibrated, and operated by a technologist, sales representative, nurse, or other medical personnel that has not “scrubbed” and thus does not need to maintain sterility. For example, the aspiration monitoring system **1414** can be located near the pump **1412**, or on the same table as the pump **1412**. The aspiration monitoring system **1414** can include any of the features described in relation to the other aspiration monitoring systems **48**, **62**, **78**, **900**, **1216**, **1270** disclosed herein. Signals from the pressure transducer **1416** are carried on an electric cable **1480** to an input **1482** of the pump **1412**. A controller **1484** within the pump **1412** is configured to control the operation of the pump **1412**, including motor **1491**, but the controller **1484** can also be configured to control the operation of the peristaltic pump **1408**, via a cable **1486**, or wirelessly. The controller **1484** can comprise a microcontroller. The controller **1484** can alternatively be located within the peristaltic pump **1408**, or can be located at another location. Control using signals of measured pressure from the pressure transducer **1416** adds an additional safety element to the system **1400′**. Additionally, a non-functional device (because of a leak, incomplete connection, incomplete priming, rupture, blockage) can be quickly identified. Unallowably high pressures can also be quickly identified, protecting the motor **1491** of the pump **1412** from burnout or overheating danger. The integrity of the tube **1478′** is also protected, e.g., avoiding unnaturally high pressures that could lead to burst.

[0226] The aspiration catheter **1402′** is similar to the aspiration catheter **1402** of FIG. **36**, except

that the female luer **1452′** is located distally on the connector **1424′** from the female luer **1472′**. Thus, aspirated blood/thrombus/saline enters the female luer **1452′** without ever having to contact interior irregularities **1425′** (in geometry, shape) within the connector **1424′**, that can otherwise cause flow resistance, or cause thrombus to catch (e.g., between the tube **1478′** and the interior of the connector **1424′**.

[0227] A foot pedal **1451** has a base **1453** and a pedal **1455** that is coupled to the base **1453** and movable or activatable by application of the foot of a user. The pedal **1455** can be spring-loaded and depressible by application of a moment or a compressive force, or can instead comprise a membrane switch. The pedal **1455**, when activated, can in some embodiments toggle on and off, and in other embodiments can be activatable when a force, a pressure, or a moment is applied, and inactivated when the force, pressure, or moment is not applied. A first cable **1461** carries signals from the foot pedal **1451** to pump **1412** via a plug **1465** that is connected to an input jack **1467**. In some embodiments, activation of the pedal **1455** by the foot of a user starts the operation of the pump **1412** and starts the operation of the peristaltic pump **1408** at the same time, as a signal through the first cable **1461** is received by the controller **1484**, which commands the pump **1412** to start and, via the cable **1486**, commands the peristaltic pump **1408** to start. In some embodiments, activation of the pedal **1455** by the foot of a user starts the operation of the peristaltic pump **1408**, and then starts the operation of the pump **1412**, with a slight delay after the peristaltic pump **1408** is started. The delay is useful to assure that some aspiration, or a significant amount of aspiration, is being applied to the aspiration lumen **1404′** prior to the injection of pressurized fluid (e.g., saline) through the injection lumen **1410′**. Thus, blood vessels or other vasculature in the vicinity of the open distal end **1405′** are spared any injection of fluid from a high pressure jet, as it is instead aspirated through the aspiration lumen **1404′**, along with thrombus or blood. In some embodiments, the plug **1465** of the foot pedal **1451** can include a resistor **1759**, and the pump **1412** can include an identification circuit **1757** configured to read the resistance value of the resistor **1759**. For example, the resistor **1759** can complete a partial Wheatstone bridge carried on the identification circuit **1757**, such that the pump **1412** can recognize the foot pedal **1451**, and operate accordingly. Alternatively, the resistor **1759** can reside in the foot pedal **1451** itself, instead of the plug **1465**. The cable **1461** can provide the electrical connection to the resistor **1759** in that particular case. Alternatively, the resistor **1759** can be replaced by an RFID chip that is configured to be powered and read by the identification circuit **1757**.

[0228] In addition, in some embodiments, activation of the pedal **1455** by the foot of a user during the operation of the pump **1412** and the peristaltic pump **1408** stops the operation of the pump **1412** and the operation of the peristaltic pump **1408** at the same time. In other embodiments, a delay can be applied, for example, such that the pump **1412** is stopped, and then the peristaltic pump **1408** is stopped slightly afterwards. The length of the delays described can be between about 0.01 second and about 1.00 second, or between about 0.10 second and about 0.25 second. The operation (on/off) of the pump **1412** and/or peristaltic pump **1408** via the foot pedal **1451** allows hands-free activation, enabling a single user to manipulate the aspiration catheter **1402′** and guidewire **1448** with both hands. The location of the foot pedal **1451** can be tactilely found with the foot of the user, while the user maintains visual contact with the patient and/or any monitors, or even other medical personnel. Alternatively, a second cable **1463** carries signals from the foot pedal **1451** directly to the peristaltic pump **1408** via a plug **1469** that is connected to an input jack **1471**. Thus, the operation of the foot pedal **1451** can be configured to control the operation of the peristaltic pump **1408** in embodiments, for example, in which there is no cable **1486**. However, in the embodiment of FIG. **38**, which includes the cable **1486**, the cable **1463** is not required.

[0229] In other embodiments, the foot pedal **1451** can be replaced by another type of switch, including, but not limited to a toggle on/off push button or hand switch, an audio-activated switch (voice activated, clap activated, click activated), an optical switch (beam/light sensor for hand or foot interruption), or any other kind of switch that can be activated by medical personnel. The

switch can be remote (e.g., in a control room) or can be located near the procedural area. The switch can also be a sterile switch or sterilizable for location on a sterile area.

[0230] In some cases, the activation and deactivation (turning on and off) of the aspiration flow applied by the peristaltic pump **1408** on the aspiration lumen **1404′** can be done by leaving the peristaltic pump **1408** in a running condition, while the user opens and closes the stopcock **1454**. In some embodiments, the controller **1484** controls the initiation of both the peristaltic pump **1408** and the pump **1412** at substantially the same time. In some embodiments, the controller **1484** controls the initiation the peristaltic pump **1408** and, following a particular delay, the initiation of the pump **1412**. The delay can be within the ranges previously described.

[0231] The controller **1484** also monitors and controls several device safety functions, which include over pressure detection, air bubble detection, and vacuum or negative pressure charge. An additional pressure transducer **1415′** carried on the connector **1424′** monitors pressure (i.e. injection pressure), and senses the presence of air bubbles. Alternatively, or in conjunction, an optical device **1417′** can be used to sense air bubbles. In one contemplated embodiment, the pump pressure is proportional to the electric current needed by the pump **1412** to produce that particular pressure. Consequently, if the electric current required by pump **1412** exceeds a preset limit, the controller **1484** will disable the pump **1412** by cutting power to it. Air bubble detection can also be monitored by monitoring the electrical current required to drive the pump **1412** at any particular moment. In order for a pump **1412** to reach high fluid pressures, there should be little or no air (which is highly compressible) present in the pump **1412** or connecting system (including the aspiration lumen **1404′** of the aspiration catheter **1402′** and the tubing set **1464**). The fluid volume is small enough that any air in the system will result in no pressure being generated at the pump head. A sufficient volume of liquid is needed proximally to flush any finite amount of air through. The controller **1484** monitors the pump **1412** current for any abrupt downward change that can indicate that air has entered the system. If the rate of drop is faster than a preset limit, the controller **1484** will disable the pump **1412** by cutting power to it until the problem is corrected.

[0232] In some embodiments, a fluid level sensor **1473** is carried on the side of the canister **1458** and is configured to sense when the canister **1458** has approached or reached its full level. The fluid level sensor **1473** is configured to output a signal through a cable **1475** that is attached to via an input **1477** (plug/jack) at the pump **1412**. The signal from the fluid level sensor **1473** can be received by the controller **1484** which can be configured to immediately stop the pump **1412** and, via cable **1486**, the peristaltic pump **1408** at the same time, or with a delay therebetween, as previously described. The fluid level sensor **1473** can comprise an optical sensor, and the canister **1458** can have a clear wall, to allow the optical sensor to measure the reflection variations when fluid is not adjacently present or when fluid is adjacently present. Alternatively, the fluid level sensor **1473** can comprise a piezoresistive pressure sensor that is within the volume **1460** of the canister **1458** at the desired height that represents a “full” canister **1458**. Other types of fluid sensors are also contemplated, including floats, strain gauges, laser sensors, ultrasonic sensors, or capacitive sensors. In each of these embodiments, a signal is sent wirelessly or through cable **1475** so that the peristaltic pump **1408** and/or pump **1412** can be shut down when a “full” level is reached.

[0233] In some embodiments, the peristaltic pump **1408** and the pump **1412** are combined into a single console. This allows for a smaller size that can be mounted on a standard IV pole. FIG. **74** illustrates an aspiration system **2100** that has all the features of the aspiration system, **1400′** of FIG. **38**, but the peristaltic pump features **2108** and the injection pump features **2112** are both included on a single console **2102**. The third extension tube **1762** is elongated and the aspiration monitoring system **1414** is directly coupled or couplable to the y-connector **1756**. The aspiration monitoring system **1414** can reside in a non-sterile area. Thus, the aspiration monitoring system **1414** can be set up, prepped, calibrated, and operated by a technologist, sales representative, nurse, or other medical personnel that has not “scrubbed” and thus does not need to maintain sterility. For

example, the aspiration monitoring system **1414** can be located on the same table as the console **2102**. The cable **1486** of the system **1400′** of FIG. **38** is not necessary, as similar connectivity is located inside the console **2100**. The cable **1463** of the system **1400′** of FIG. **38** is also not necessary, as the cable **1461** is capable of transferring all of the signals to and from the foot pedal **1451**. The luer **1766** can be attachable and detachable, or in other embodiments can be permanently bonded to the female luer **1452′** of the connector **1424′**.

[0234] FIG. **39** illustrates an alternative aspiration system **1400″** comprising the aspiration catheter **1402′** of FIG. **38**. However, a centrifugal pump **1409** is substituted in place of the peristaltic pump **1408**. The proximal end **1442** of the extension tube **1438** coupled to an inlet **1413** which allows the aspirate to enter a chamber **1419**. An impeller **1421** is rotatably held within the chamber **1419** by a first bearing **1423** and a second bearing **1427**. A first seal **1429** and second seal **1431** allow the impeller **1421** to rotate (curved arrow) without the aspirate leaking. A motor **1433** is configured to rotate the impeller **1421**. The aspirate is forced out an outlet **1435** into an exit tube **1439** which is coupled to the hub **1457** of the canister **1458**. A user interface **1441** can be manipulated by a user to operate the centrifugal pump **1409**. In some embodiments, an Angiodynamics AngioVac centrifugal pump can be used as the centrifugal pump **1409**.

[0235] The aspiration catheters **1402**, **1402′** of FIGS. **36**, **38**, and **39** are illustrated as having pressurized fluid injection through injection lumens **1410**, **1410′**. However, other embodiments of the aspiration systems **1400**, **1400′** in which the aspiration catheters **1402**, **1402′** are replaced by a standard aspiration catheter, not having an injection lumen, such as the aspiration catheter **4** of FIG. **1**.

[0236] As an alternative to collecting the aspirated material in a blood bag, blood bottle, or the canister **1458**, aspirated components (blood, thrombus, saline, slurry, etc.) can be placed into a reinfusion device, such as a Stryker ConstaVac (CBCII) Blood Conservation System, or a Haemonetics OrthoPAT Orthopedic Perioperative Autotransfusion System. The blood can be purified by the reinfusion device, for example, to remove red blood cells or portions of red blood cells that have undergone hemolysis. One such reinfusion device is the Haemonetics Cell Saver® Elite+ Autotransfusion System.

[0237] In some embodiments, the blood can be cooled prior to being injected. In some embodiments, the blood can be heated prior to being injected. In some embodiments, other drugs can be added to the blood prior to it being inserted. In some cases, the blood can be diluted with saline, to decrease its viscosity, or decrease its hematocrit. This can allow for decrease hemolysis to occur. In some cases, blood collected in the canister **1458**, or blood coming from the extension tube **1438**, can even be used as donor blood, to infuse into a different patient.

[0238] In some embodiments, an additional or alternate sensor can be used to monitor flow conditions for the notification of the user, including, but not limited to: a Doppler sensor, an infrared sensor, or a laser flow detection device. In some embodiments, an externally-attached (non-contact) Doppler sensor can be employed. In some embodiments, an infrared sensor or a laser flow detection device can be employed around the extension tubing **1438**. The alternate sensor (e.g., flow sensor, etc.) can be located at a number of different locations along the aspiration path, including on or in the extension tube **1438**, distal to the impeller **1421** of the centrifugal pump **1409**, or on or in the exit tube **1439** proximal to the impeller **1421** of the centrifugal pump **1409**. Or in embodiments using a peristaltic pump **1408**, the alternate sensor can be located on or in the extension tube **1438**, distal or proximal to the rotatable head **1430** of the peristaltic pump **1408**.

[0239] An aspiration system **1600** utilizing an ultrasound sensor **1602** is shown in FIGS. **40-42**. The aspiration system **1600** is similar to the aspiration system **1400′** of FIG. **38**, with the addition of the ultrasound sensor **1602** and other related components. Alternative embodiments can utilize the teachings of other aspiration system embodiments disclosed herein. The ultrasound sensor can be configured for an analog output (e.g., with varying voltage output), for example, with a range of 0 Volts DC to 1 Volt DC, or 0 Volts DC to 5 Volts DC, or 0 Volts DC to 10 Volts DC. Turning to

FIG. **41**, the ultrasound sensor **1602** is inserted within a sideport **1606** of a y-connector **1604**. The y-connector **1604** has a distal connector **1608** attached to a proximal end **1603** of tubing **1610**. The tubing **1610** is slid over barbs **1605** which comprise the distal connector **1608**. A distal end **1607** of the tubing **1610** is coupled to the proximal end **1406**′ of the aspiration lumen **1404**′ of the aspiration catheter **1402**′, via a connector **1609** and the aspiration monitoring system **1414**, attached to the female luer **1452**′ of the connector **1424**′. A proximal connector **1612** of the y-connector **1604** is connected to a friction fitting **1616** of an extension tube **1614**. The proximal connector **1612** also comprises barbs, The extension tube **1614** is connectable to the peristaltic pump **1608**, but can alternatively be coupled to the centrifugal pump **1409**, or one of the vacuum sources described herein. The ultrasound sensor **1602** is positioned so that its distal end **1618** is adjacent aspiration flow (straight arrow). A fitting **1620** at the proximal end of the ultrasound sensor **1602** is configured to secure the ultrasound sensor **1602** to the sideport **1606** in its desired position. This can be a friction fit, a screw attachment, a snap, and adhesive bond, a thermal bond, or other securement means. The output of the ultrasound sensor (e.g., voltage) is communicated through a cable **1622**. A strain relief **1601** coupled to the cable **1622** and the fitting **1620** serves to protect the first end **1611** of the cable **1622** from damage due to bending, tension, or compression.

[0240] In one embodiment, the ultrasound sensor **1602** has an analog channel that outputs a signal referenced to ground that varies between 0 to 5 Volts DC. For very small flow rates, the signal is often sinusoidal, but in the higher flow rates commonly occurring during the aspiration of clot/thrombus/blood the flow is substantial enough that it saturates the channel and appears as a variable digital pulse stream, roughly proportional to flow. The pulse frequency is relatively high on this channel. In other words, a pseudo-digital on/off occurs when flow rates exceed a particular value. This particular value can be adjusted by connecting appropriate electronics. Along with the pseudo-digital properties of the channel, a dedicated digital I/O pin is utilized that feeds a high-priority interrupt handler. This allows the counting of rising signal transitions in this pulse stream very efficiently over a fixed interval of time. The pulse count above/below one or more pre-determined thresholds is ultimately what determines whether the overall system is in a free-flow or clot removal state and to what degree.

[0241] FIG. **42** illustrates a console **1624** having an input jack **1626** into which a plug **1628** at the second end **1613** of the cable **1622** attaches. The console **1624** includes an internal measurement device **1630** which is configured to count the number of times N during a predetermined time period P that a signal being output by the ultrasound sensor **1602** surpasses a predetermined threshold amplitude A. The measurement device **1630** is further configured to determine whether the number of times N is (a) greater than (or greater than or equal to) or (b) less than (or less than or equal to) a predetermined value V. For example, in one embodiment, a predetermined time period P is entered into the measurement device **1630** (e.g., via a user interface **1632**) as 0.33 seconds. An algorithm within the measurement device **1630** counts the number threshold crossings that are output by the ultrasound sensor **1602** during this predetermined time period P. The measurement device **1630** then applies a particular logic scheme. In some embodiments, this logic scheme can simply be “flow” or “no flow.” For example, if there are between 0 counts and 150 counts within the time period P, then a “no flow” condition is identified and if there are 151 or greater counts within the time period P, then a “flow” condition is identified. The measurement device **1630** can comprise a microprocessor. A communication device **1634** carried on the console **1624** can be controlled by the measurement device **1630**, or by a separate controller, to identify a first communication mode for the “no flow” condition and a second communication mode for the “flow” condition. In some embodiments, the first communication mode can comprise the non-existence of a signal (e.g., no light lit, no sound produced, no vibration or heat produced) from the communication device **1634**, and the second communication mode can comprise a light lit, or a message shown (e.g., the word “flow”), or an audio message played (a voice stating “aspiration occurring”), or an audio warning (e.g., “beep”), or a mechanical warning (e.g., vibration). The

amplitude of the communication (e.g., dB of sound, intensity of light, etc.) can be increased by pressing increase button **1615** or decreased by pressing decrease button **1617**. The current level of the amplitude is displayed on display **1619**. The display can comprise a series of LEDs **1621** that are configured to be lit up such that a higher amplitude corresponds to a larger number of the LEDs being lit.

[0242] In other embodiments, the first communication mode and the second communication mode can each include some perceptible signal (audible, visual, tactile), each one different from the other. In other embodiments, a more complex logic scheme can be used. For example, for a predetermined time period P of 0.33 seconds, if there are between 0 counts and 150 counts within the time period P, then a “no flow” condition is identified; if there are between 151 and 225 counts within the time period P, then a “low flow” condition is identified; if there are between 226 and 350 counts within the time period P, then a “medium flow” condition is identified; and, if there are 351 counts or greater, then a “high flow” condition is identified. The “no flow” condition can correspond to a first communication mode, the “low flow” condition to a second communication mode, the “medium flow” condition to a third communication mode, and the “high flow” condition to a fourth communication mode. The first communication mode can be treated by the communication device **1634** remaining silent and/or non-visual/non-vibrational/non heating, etc. The second communication mode can be treated by the communication device beeping (via audio speaker) or flashing (via LED or other light) at a frequency of 2 Hz. The third communication mode can be treated by the communication device beeping (via audio speaker) or flashing (via LED or other light) at a frequency of 4 Hz. The fourth communication mode can be treated by the communication device beeping (via audio speaker) or flashing (via LED or other light) at a frequency of 10 Hz. In another embodiment, the second communication mode can be treated by the communication device beeping (via audio speaker) or flashing (via LED or other light) at a frequency of 0.5 Hz. The third communication mode can be treated by the communication device beeping (via audio speaker) or flashing (via LED or other light) at a frequency of 1 Hz. The fourth communication mode can be treated by the communication device beeping (via audio speaker) or flashing (via LED or other light) at a frequency of 2 Hz. Additionally, or alternatively, the intensity of the signal can increase from the second to the fourth communication modes. For example, by 10 dB from second to third and by 10 more dB from third to fourth. Or, by 5 dB, each time.

[0243] In an alternative embodiment, the ultrasound sensor **1602** can have an analog-to-digital module, and can output digital signals only, particular to 1 (flow at or above a particular threshold flow rate) or 0 (flow below a particular threshold flow rate).

[0244] The predetermined time period P, can be between about 0.01 seconds and about 1.00 seconds, or between about 0.10 seconds and about 0.50 seconds, or between about 0.20 seconds and about 0.40 seconds. The predetermined time period P can be adjustable by a user, for example, via the user interface **1632**.

[0245] In certain aspiration procedures, when thrombus is not being sufficiently aspirated but aspiration continues, an unacceptably large volume of blood can be aspirated from the patient. This can cause dehydration, decreased blood pressure, or even exsanguination of the patient, all potentially serious events which can risk the success of the procedure and endanger the patient. The ability to be aware at all times whether the blood is being aspirated at an unacceptable rate is an important factor for achieving a high degree of safety and efficiency.

[0246] Systems for catheter aspiration are disclosed herein which are configured to communicate flow status and/or flow rate information to a user as determined by weighing the fluid, blood, thrombus, or other materials being aspirated from the patient over a period of time.

[0247] FIG. **43** illustrates an aspiration system **200** comprising an aspiration catheter **202** comprising an elongate shaft **201** including an aspiration lumen **204** having an open distal end **205** and a proximal end **206** configured to couple to a peristaltic pump **208**. The peristaltic pump **208** can be a roller pump having a base **226**, a pressure shoe **228** carried by the base **226**, and a rotatable

head **230**, rotatably coupled to the base **226**, and carrying two or more rollers **232***a-d*. The rollers **232***a-d* are arrayed around a perimeter **234** of the rotatable head **230**. The rotatable head **230** is configured to be rotatable in at least a first rotational direction **236** (e.g., by a motor, directly, or with a gear train, as shown in FIG. **36**). The peristaltic pump **208** can be battery powered, and the battery (ies) can be rechargeable by wired or wireless means. The peristaltic pump **208** can alternatively, or additionally be powered by a power cord configured to connect to a power supply. An extension tube **238** having a distal end **240** and a proximal end **242**, and having a lumen **244** extending therethrough, is hydraulically coupled to the proximal end **206** of the aspiration lumen **204** of the aspiration catheter **202** via a connector **224**. The extension tube **238** can be supplied (e.g., sterile) with the aspiration catheter **202**, or can be packaged and supplied separately. A Touhy-Borst seal **246** carried on the connector **224** is configured to be loosened/opened to allow the insertion of a guidewire **248** through the connector **224** and the aspiration lumen **204**, which can be used to track the aspiration catheter **202** through a subject's vasculature. The Touhy-Borst **246** can be tightened to seal over the guidewire **248**, to maintain hemostasis. Other types of seals can be incorporated in place of the Touhy-Borst **246**, including a spring-loaded, longitudinally compressible and actuatable seal. The extension tube **238** includes a male luer **250** at its distal end **240**, for connecting to a female luer **252** of the connector **224**. Or, as shown, an aspiration monitoring system **214** can be attached therebetween. The male luer **250** can include a stopcock **254**, which is configured to be turned to select between an open position (shown) or a closed position. Alternatively, the extension tube **238** can be integral with the aspiration lumen **204**, or can be permanently attached to the connector **224**. In use, a compressible portion **237** of the extension tube **238** is placed within the pressure shoe **228** of the peristaltic pump **208** such that rotation of the rotatable head **230** (e.g., via input to an interface **256** by a user) in the rotational direction **236** causes fluid to be forced through the lumen **244** of the extension tube **238** from the distal end **240** to the proximal end **242**, via compression of the compressible portion **237** by the rollers **232**, one at a time. In some embodiments, there are only two rollers **232**. In other embodiments, there are three rollers **232**. In still other embodiments, as shown, there are four rollers **232**. As described, the rollers **232** can be replaced by bumps or protrusions. The compressible portion **237** can comprise silicone tubing, polyurethane tubing, polyvinyl chloride tubing, or other compressible tubing. The compressible portion **237** can be a relatively short section that is attachable to and detachable from the peripheral ends of the extension tube **238**, or in other embodiments, can comprise the entirety of the extension tube **238** between the distal end **240** and the proximal end **242**. The proximal end **242** of the extension tube **238** can be coupled to a hub **257** formed on a cap **213** of a canister **258**, the canister **258** having an interior **260**, to allow fluid **259** passing through the extension tube **238** to pass into the interior **260**. An additional hub **262** in the canister **258** can be provided, and can be left open (as shown) to allow the unfilled interior **260** to match atmospheric pressure.

[0248] In use, a distal section of the aspiration catheter **202** is inserted into the vasculature of a subject such that the open distal end **205** is adjacent or within a thrombus. Then, fluid, including thrombus, is aspirated into the aspiration lumen **204** by action of the peristaltic pump **208** and removed by use of the aspiration system **200**. Blood vessels treated can include peripheral blood vessels, pulmonary blood vessels, such as pulmonary arteries, coronary blood vessels, or blood vessels within the head or neck of the subject, including carotid arteries or cerebral arteries.

[0249] The aspiration system **200** further comprises an aspiration monitoring system **1800** which is configured to provide information to a user concerning the status of aspiration. The aspiration monitoring system **1800** functions by measuring the fluid **259** which has accumulated at the bottom of the interior **260** of the canister **258** at a plurality of points in time, thus estimating a (volumetric) flow rate of the fluid **259** issuing out the lumen **244** of the extension tube **238**. The aspiration monitoring system **1800** comprises a scale **1802** (or balance) having a base **1804**. A weighing platform **1806** is coupled to and movable with respect to the base **1804** (e.g., along a vertical axis V), such that the weight of the fluid **259** accumulated at the bottom of the canister **258** causes a

signal **1808** indicative of the weight to be output. The scale can be configured to output a signal **1808** indicative of weight, or, in some embodiments, the particular elevation (above sea level) at which the scale **1802** resides can be input into the scale **1802** such that a value of mass can be output. A standard setting can assume that the procedure occurs at sea level, and can calculate mass accordingly. In some embodiments, the scale **1802** can even include an altimeter or other sensor to automatically determine elevation, such that mass can be output. Regardless, even when a weight is output, changes to the weight of the fluid **259** over time are proportional to changes to mass of the fluid **259** over time, at any particular elevation. Thus, the signal **1808** can be indicative of mass or indicative of weight, while remaining within the scope of allowing changes in the mass of the fluid **259** over time to be demonstrated. Thus, the system **200** can predict the loss of blood from the patient by its assessment of total cumulative weight/mass of blood captured in the canister **258**. Weight/mass of blood measured can be converted by the system **200** into volume of blood (ml) lost.

[0250] The signal **1808** is sent to a processor **1810**. See also, FIG. **44**. The processor **1810**, which can comprise a microprocessor, includes a clock that allows the combination of time data with weight or mass values from the signal. In some embodiments, the scale **1802** can include a tare button or control, such that the tare weight of the canister **258** can be subtracted out from the amount being weighed by the scale **1802**. Thus, the scale **1802** is "zeroed" and only the weight or mass of the fluid **259** in the canister **258** is weighed at each time point. The sample rate at which values in the signal **1808** are obtained along with the time stamp can range between about 0.01 Hz and about 10 kHz, or between about 0.02 Hz and about 1 kHz, or between about 1 Hz and about 100 Hz. A processed signal **1812** is output to a graphic display **1814** for viewing by a user. In some embodiments, the graphic display **1814** can display an x-y graph **1816**, wherein the x-axis represents time and the y-axis represents weight or mass of the fluid **259** within the canister **258**. In other embodiments, the graphic display **1814** can display an x-y graph **1816**, wherein the x-axis represents time and the y-axis represents flow rate. The flow rate (FR) can be calculated from the formula:

[00015]$$FR = (W_c - W_p) / (T_c - T_p),$$

wherein [0251] W.sub.c is the current value for weight of the fluid **259** [0252] W.sub.p is the previous value of weight of the fluid **259** [0253] T.sub.c is the current time stamp value [0254] T.sub.p is the previous time stamp value

[0255] In other embodiments, the flow rate (FR) can be calculated from the formula:

[00016]$$FR = (W_c - W_{pn}) / (T_c - T_{pn}),$$

wherein

[0256] W.sub.c is the current value for weight of the fluid **259** [0257] W.sub.pn is the n.sup.th prior value of weight of the fluid **259** [0258] T.sub.c is the current time stamp value [0259] T.sub.pn is the n.sup.th prior time stamp value

[0260] In other embodiments, the flow rate can be constructed as a moving average, such as a running average or rolling average. Several types of moving average can be used, including a simple moving average, a cumulative moving average, a weighted moving average, or an exponential moving average.

[0261] Instead of an x-y graph, a visual display comprising one or more LED lights can be used. For example, a higher flow rate can be indicated by a range of shades of green, while a lower flow rate can be indicated by a range of shades of red. Alternatively, the intensity of a light can be changed in response to changes in the flow rate, or changes in weight or mass. For example, the intensity of the light can be proportional to the measured/calculated flow rate. A loudspeaker can present the changes in weight/mass over time or changes in flow rate over time as a continuous or continual sound having a pitch that changes proportionally with changes in value. For example, a higher pitch with a larger flow rate. The sound intensity can alternatively be varied (higher flow rate=higher dB).

[0262] Changes in the flow rate can be indicative of a number of operation occurrences in the aspiration system **200**. For example, a flow rate that suddenly decreases a significant amount can be indicative of thrombus becoming clogged within the aspiration lumen **204** or the lumen **244** of the extension tube **238**. In some cases, a reduction in the flow rate of 90% or more can be indicative of clogging. When a clog occurs, the volume of fluid being aspirated and dispensed into the canister **258** can be severely limited. A loudspeaker **1818** is also configured to produce an audible alarm, when a threshold value of flow rate is crossed. A threshold flow rate can be input into a memory **1822** of the scale **1802** using a user interface **1820**. When the flow rate decreases to a value below the threshold flow rate, the loudspeaker **1818** is made to sound an alarm. In some embodiments, a controller **215** in the peristaltic pump **208** can be coupled to the processor **1810** (wired or wireless) and can be configured to activate the alarm of the loudspeaker **1818**. When the flow rate increases above the threshold flow rate, the loudspeaker **1818** can be deactivated such that the alarm is no longer sounded. Alternatively, the loudspeaker **1818** can be replaced by, or augmented with a visual alarm and/or a tactile alarm. The visual alarm can include one or more light, including one or more LEDs. The tactile alarm can include a vibration device, such as a piezoelectric, or a weight-offset rotational device.

[0263] Changes in the flow rate can also be indicative of other changes in status, such as a rupture in a wall of one of the tubular members or a disconnection of one of the connections. In one of these leak conditions, the flow rate can be significantly reduced, and thus identified by the flow rate changes measured by the aspiration monitoring system **1800**. The system **200** can be configured to activate the alarm (e.g., via the loudspeaker **1818**) when a free flow of blood is detected. In other words, when the system is apparently aspirating only blood, and not aspirating thrombus. Thus, the measured flow rate crossing above a particular threshold stored in memory **1822** indicative of free flowing blood would cause the controller **215** to activate the alarm.

[0264] A secondary aspiration monitoring system **214** comprising a pressure transducer **216** can be coupled, for example, between the distal end **240** of the extension tube **238** and the connector **224** and/or proximal end **206** of the aspiration lumen **204** of the aspiration catheter **202**. Signals from the pressure transducer **216** can be carried wirelessly or by a cable (not shown) to the controller **215**. The controller **215** can comprise a microcontroller. The controller **215** can be located within the peristaltic pump **208**, or can alternatively be located at another component or location. Control using measured pressure adds an additional safety element to the system **200**. Additionally, a non-functional device (because of a leak, incomplete connection, incomplete priming, rupture, blockage) can be quickly identified. Unallowably high pressures or low pressures can also be quickly identified, protecting the motor of the peristaltic pump **208** from burnout or overheating danger. Data from the pressure transducer **216** and the scale **1802** can be used together to optimize or create a more correct signal indicative of aspiration flow, or indicative of the presence of clot/thrombus, or the presence of a clog, or the presence of a burst or disconnection in the fluid circuit.

[0265] A foot pedal **251** is illustrated having a base **253** and a pedal **255** that is coupled to the base **253** and movable or activatable by application of the foot of a user. The pedal **255** can be spring-loaded and depressible by application of a moment or a compressive force, or can instead comprise a membrane switch. The pedal **255**, when activated, can in some embodiments toggle on and off, and in other embodiments can be activatable when a force, a pressure, or a moment is applied, and inactivated when the force, pressure, or moment is not applied. A cable **263** carries signals from the foot pedal **251** to the peristaltic pump **208** via a plug **269** that is connected to an input jack **271**. The pedal **255** can be activated by the foot of a user to start or stop the operation of the peristaltic pump **208**.

[0266] In other embodiments, the foot pedal **251** can be replaced by another type of switch, including, but not limited to a toggle on/off push button or hand switch, an audio-activated switch (voice activated, clap activated, click activated), an optical switch (beam/light sensor for hand or

foot interruption), or any other kind of switch that can be activated by medical personnel. The switch can be remote (e.g., in a control room) or can be located near the procedural area. The switch can also be a sterile switch or sterilizable for location on a sterile area.

[0267] In some cases, the activation and deactivation (turning on and off) of the aspiration flow applied by the peristaltic pump **208** on the aspiration lumen **204** can be done by leaving the peristaltic pump **208** in a running condition, while the user opens and closes the stopcock **254**. Alternatively, a pinch valve (not shown) coupled to the extension tube **238** can be used for opening and closing the lumen **244**, and thus starting and stopping aspiration. The pinch valve can be operated by a foot pedal (similar to the foot pedal **251**), or can be operated by another control (e.g., on the interface **256** of the peristaltic pump **208**).

[0268] After collecting the aspirated material in a blood bag, blood bottle, or the canister **258**, aspirated components (blood, thrombus, saline, slurry, etc.) can be placed into a reinfusion device, such as a Stryker ConstaVac (CBCII) Blood Conservation System, or a Haemonetics OrthoPAT Orthopedic Perioperative Autotransfusion System.

[0269] In some embodiments, the blood can be cooled prior to being injected. In some embodiments, the blood can be heated prior to being injected. In some embodiments, other drugs can be added to the blood prior to it being inserted. In some cases, the blood can be diluted with saline, to decrease its viscosity, or decrease its hematocrit. This can allow for decrease hemolysis to occur. In some cases, blood collected in the canister **258**, or blood coming from the extension tube **238**, can even be used as donor blood, to infuse into a different patient.

[0270] In some embodiments, an additional or alternate sensor can be used to monitor flow conditions for the notification of the user, including, but not limited to: a Doppler sensor, an infrared sensor, or a laser flow detection device. In some embodiments, an externally-attached (non-contact) Doppler sensor can be employed. In some embodiments, an infrared sensor or a laser flow detection device can be employed around the extension tubing **238**. The alternate sensor (e.g., flow sensor, etc.) can be located at a number of different locations along the aspiration path, including on or in the extension tube **238**, either proximal to or distal to the rotatable head **230** of the peristaltic pump **208**.

[0271] FIG. **45** illustrates a forced aspiration system **400** comprising an aspiration catheter **402** comprising an elongate shaft **401** including an aspiration lumen **404** having an open distal end **405** and a proximal end **406** configured to couple to a peristaltic pump **408**. The peristaltic pump **408** can be a roller pump having a base **426**, a pressure shoe **428** carried by the base **426**, and a rotatable head **430**, rotatably coupled to the base **426**, and carrying two or more rollers **432***a-d*. The rollers **432***a-d* are arrayed around a perimeter **434** of the rotatable head **430**. The rotatable head **430** is configured to be rotatable in at least a first rotational direction **436** (e.g., by a motor, directly, or with a gear train, as shown in FIG. **36**). The peristaltic pump **408** can be battery powered, and the battery (ies) can be rechargeable by wired or wireless means. The peristaltic pump **408** can alternatively, or additionally be powered by a power cord configured to connect to a power supply. An extension tube **438** having a distal end **440** and a proximal end **442**, and having a lumen **444** extending therethrough, is hydraulically coupled to the proximal end **406** of the aspiration lumen **404** of the aspiration catheter **402** via a connector **424**. The extension tube **438** can be supplied (e.g., sterile) with the aspiration catheter **202**, or can be packaged and supplied separately. A Touhy-Borst seal **446** carried on the connector **424** is configured to be loosened/opened to allow the insertion of a guidewire **448** through the connector **424** and aspiration lumen **404**, which can be used to track the aspiration catheter **402** through a subject's vasculature. The Touhy-Borst **446** can be tightened to seal over the guidewire **448**, to maintain hemostasis. Other types of seals can be incorporated in place of the Touhy-Borst **246**, including a spring-loaded, longitudinally compressible and actuatable seal. The extension tube **438** includes a male luer **450** at its distal end **440**, for connecting to a female luer **452** of the connector **424**. Or, as shown, an aspiration monitoring system **414** can be attached therebetween. The male luer **450** can include a stopcock

454, which is configured to be turned to select between an open position (shown) or a closed position. Alternatively, the extension tube **438** can be integral with the aspiration lumen **404**, or can be permanently attached to the connector **424**. In use, a compressible portion **437** of the extension tube **438** is placed within the pressure shoe **428** of the peristaltic pump **408** such that rotation of the rotatable head **430** (e.g., via input to an interface **456** by a user) in the rotational direction **436** causes fluid to be forced through the lumen **444** of the extension tube **438** from the distal end **440** to the proximal end **442**, via compression of the compressible portion **437** by the rollers **432**, one at a time. In some embodiments, there are only two rollers **432**. In other embodiments, there are three rollers **432**. In still other embodiments, as shown, there are four rollers **432**. As described, the rollers **432** can be replaced by bumps or protrusions. The compressible portion **437** can comprise silicone tubing, polyurethane tubing, polyvinyl chloride tubing, or other compressible tubing. The compressible portion **437** can be a relatively short section that is attachable to and detachable from the peripheral ends of the extension tube **438**, or in other embodiments, can comprise the entirety of the extension tube **438** between the distal end **440** and the proximal end **442**. The proximal end **442** of the extension tube **438** can be coupled to a hub **457** of a canister **458** having an interior **460**, to allow fluid **459** passing through the extension tube **438** to pass into the interior **460**. An additional hub **462** in the canister **458** can be left open (as shown) to allow the unfilled interior **460** to match atmospheric pressure. A filter **443** (optional) is placed in line between the extension tube **438** and canister **458** to catch thrombus that is aspirated from the patient. The filter **443** can have clear side walls so that the physician or other medical staff can visually assess the thrombus, such as the size of each piece, the number or pieces, the total amount of thrombus (e.g., volumetrically) or the condition of the thrombus or residual thrombus (organized/fibrous, or soft). The buildup of the thrombus within the filter **443**, or lack thereof, can be utilized as a cue for moving the open distal end **405** of the aspiration catheter **402** to a different location, or temporarily or permanently stopping the procedure, or even increasing or decreasing the speed of the pump(s).

[0272] The aspiration catheter **402** additionally has a high pressure injection lumen **410** for injecting saline from a fluid source **499**, for example, via a high pressure pump **412**. A tubing set **464** can include a pump cartridge **466** having a piston or bellows or other movable element that the pump **412** can manipulate using an internal motor (not shown), this applying a high pressure to saline from the fluid source **499** such that the saline is forced through the injection lumen **410** of the aspiration catheter **402**. The tubing set **464** includes proximal end **468** having a spike **497** or other element for hydraulically coupling it to the fluid source **499**. The tubing set **464** further has a distal end **470** (which can include a male luer) which is configured to hydraulically couple to the injection lumen **410** via a female luer **472**. Injected saline is forced through the injection lumen **410** by the pump **412** and exits an orifice **474** at a distal end **476** of the injection lumen **410**. The injection lumen **410** can be within a tube **478** that is substantially or entirely within the shaft **401**. In some embodiments, the tube **478** is attached to the internal wall of the shaft **401** only at a distal end portion **403**. Thus, the free-floating nature of the remainder of the tube **478** within the aspiration lumen **404** increases the flexibility and trackability of the shaft **401**. The high pressure saline is forced through the orifice **474**, causing a jet. The jet is aimed within the aspiration lumen **404**, just proximal the open distal end **405** which can create a Venturi effect that forces blood or thrombus external and adjacent the open distal end **405** into the aspiration lumen **404**. The combination of the operation of the peristaltic pump **408** and the jet caused by the high pressure saline cause the maceration of thrombus, and the movement/flow of material (saline/blood/macerated thrombus/small pieces of thrombus) through the aspiration lumen **404** from the open distal end **405** to the proximal end **406**, through the connector **424**, and through the lumen **444** of the extension tube **438** from its distal end **440** to its proximal end **442**, and finally into the interior **460** of the canister **458**. Thus, thrombus within a blood vessel of a subject can be macerated and removed by use of the system **400**. Blood vessels treated can include peripheral blood vessels, pulmonary blood vessels, such as pulmonary arteries, coronary blood vessels, or

blood vessels within the head or neck of the subject, including carotid arteries or cerebral arteries.
[0273] The forced aspiration system **400** further comprises an aspiration monitoring system **1800** which is configured to provide information to a user concerning the status of aspiration. The aspiration monitoring system **1800** functions by measuring the fluid **459** which has accumulated at the bottom of the interior **460** of the canister **458** at a plurality of points in time, thus estimating a flow rate of the fluid **459** issuing out the lumen **444** of the extension tube **438**. The aspiration monitoring system **1800** comprises a scale **1802** (or balance) having a base **1804**. A weighing platform **1806** is coupled to and movable with respect to the base **1804** (e.g., along a vertical axis V), such that the weight of the fluid **459** accumulated at the bottom of the canister **458** causes a signal **1808** indicative of the weight to be output. The scale can be configured to output a signal **1808** indicative of weight, or, in some embodiments, the particular elevation (above sea level) at which the scale **1802** resides can be input into the scale **1802** such that a value of mass can be output. In some embodiment, the scale **1802** can even include an altimeter or other sensor to automatically determine elevation, such that mass can be output. Regardless, even when a weight is output, changes to the weight of the fluid **459** over time are proportional to changes to mass of the fluid **459** over time, at any particular elevation. Thus, the signal **1808** can be indicative of mass or indicative of weight, while remaining within the scope of allowing changes in the mass of the fluid **459** over time to be demonstrated. Thus, the system **400** can predict the loss of blood from the patient by its assessment of total cumulative weight/mass of blood captured in the canister **458**. Weight/mass of blood measured can be converted by the system **400** into volume of blood (ml) lost.
[0274] The signal **1808** is sent to a processor **1810**. See also, FIG. **44**. The processor **1810**, which can comprise a microprocessor, includes a clock that allows the combination of time data with weight or mass values from the signal. In some embodiments, the scale **1802** can include a tare button or control, such that the tare weight of the canister **458** can be subtracted out from the amount being weighed by the scale **1802**. Thus, the scale **1802** is “zeroed” and only the weight or mass of the fluid **459** in the canister **458** is weighed at each time point. The sample rate at which values in the signal **1808** are obtained along with the time stamp can range between about 0.01 Hz and about 10 kHz, or between about 0.02 Hz and about 1 kHz, or between about 1 Hz and about 100 Hz. A processed signal **1812** is output to a graphic display **1814** for viewing by a user. In some embodiments, the graphic display **1814** can display an x-y graph **1816**, wherein the x-axis represents time and the y-axis represents weight or mass of the fluid **459** within the canister **458**. In other embodiments, the graphic display **1814** can display an x-y graph **1816**, wherein the x-axis represents time and the y-axis represents flow rate. The flow rate (FR) can be calculated from the formula:
[00017]$$FR = (W_c - W_p) / (T_c - T_p),$$
wherein [0275] W.sub.c is the current value for weight of the fluid **459** [0276] W.sub.p is the previous value of weight of the fluid **459** [0277] T.sub.c is the current time stamp value [0278] T.sub.p is the previous time stamp value
[0279] In other embodiments, the flow rate (FR) can be calculated from the formula:
[00018]$$FR = (W_c - W_{pn}) / (T_c - T_{pn}),$$
wherein [0280] W.sub.c is the current value for weight of the fluid **459** [0281] W.sub.pn is the n.sup.th prior value of weight of the fluid **459** [0282] T.sub.c is the current time stamp value [0283] T.sub.pn is the n.sup.th prior time stamp value
[0284] In other embodiments, the flow rate can be constructed as a moving average, such as a running average or rolling average. Several types of moving average can be used, including a simple moving average, a cumulative moving average, a weighted moving average, or an exponential moving average.
[0285] Instead of an x-y graph, a visual display comprising one or more LED lights can be used. For example, a higher flow rate can be indicated by a range of shades of green, while a lower flow

rate can be indicated by a range of shades of red. Alternatively, the intensity of a light can be changed in response to changes in the flow rate or changes in weight or mass. For example, the intensity of the light can be proportional to the measured/calculated flow rate. A loudspeaker can present the changes in weight/mass over time or changes in flow rate over time as a continuous or continual sound having a pitch that changes proportionally with changes in value. For example, a higher pitch with a larger flow rate. The sound intensity can alternatively be varied (higher flow rate=higher dB).

[0286] Changes in the flow rate can be indicative of a number of operation occurrences in the forced aspiration system **400**. For example, a flow rate that suddenly decreases a significant amount can be indicative of thrombus becoming clogged within the aspiration lumen **404** or the lumen **444** of the extension tube **438**. In some cases, a reduction in the flow rate of 90% or more can be indicative of clogging. When a clog occurs, the volume of fluid being aspirated and dispensed into the canister **458** can be severely limited. A loudspeaker **1818** is also configured to produce an audible alarm, when a threshold value of flow rate is crossed. A threshold flow rate can be input into memory **1822** of the scale **1802** using a user interface **1820**. When the flow rate decreases to a value below the threshold flow rate, the loudspeaker **1818** is made to sound an alarm. In some embodiments, the controller **484** on the pump **412**, or a different controller in one of the other components can be coupled to the processor **1810** (wired or wireless) and can be configured to activate the alarm of the loudspeaker **1818**. When the flow rate increases above the threshold flow rate, the loudspeaker **1818** can be deactivated such that the alarm is no longer sounded. Alternatively, the loudspeaker **1818** can be replaced by, or augmented with a visual alarm and/or a tactile alarm. The visual alarm can include one or more light, including one or more LEDs. The tactile alarm can include a vibration device, such as a piezoelectric, or a weight-offset rotational device.

[0287] Changes in the flow rate can also be indicative of other changes in status, such as a rupture in a wall of one of the tubular members or a disconnection of one of the connections. In one of these leak conditions, the flow rate can be significantly reduced, and thus identified by the flow rate changes measured by the aspiration monitoring system **1800**. The system **400** can be configured to activate the alarm (e.g., via the loudspeaker **1818**) when a free flow of blood is detected. In other words, when the system is apparently aspirating only blood, and not aspirating thrombus. Thus, the measured flow rate crossing above a particular threshold stored in memory **1822** indicative of free flowing blood would cause the controller **484** to activate the alarm.

[0288] A secondary aspiration monitoring system **414** comprising a pressure transducer **416** can be coupled, for example, between the distal end **440** of the extension tube **438** and the connector **424** and/or proximal end **406** of the aspiration lumen **404** of the aspiration catheter **402**. Signals from the pressure transducer **416** are carried on an electric cable **480** to an input **482** of the pump **412**. The controller **484** within the pump **412** is configured to control the operation of the pump **412**, but also can be configured to control the operation of the peristaltic pump **408**, via a cable **486**, or wirelessly. The controller **484** can comprise a microcontroller. The controller **484** can alternatively be located within the peristaltic pump **408**, or can be located at another component or location. Control using measured pressure adds an additional safety element to the system **400**. Additionally, a non-functional device (because of a leak, incomplete connection, incomplete priming, rupture, blockage) can be quickly identified. Unallowably high pressures can also be quickly identified, protecting the motor of the pump **412** from burnout or overheating danger. The integrity of the tube **478** is also protected, e.g., avoiding unnaturally high pressures that could lead to a burst of the tube **478**. Data from the pressure transducer **416** and the scale **1802** can be used together to optimize or create a more correct signal indicative of aspiration flow, or indicative of the presence of clot/thrombus, or the presence of a clog, or the presence of a burst or disconnection in the fluid circuit.

[0289] The female luer **452** is located distally on the connector **424** from the female luer **472**. Thus,

aspirated blood/thrombus/saline enters the female luer **452** without ever having to contact interior irregularities **425** (in geometry, shape) within the connector **424**, that can otherwise cause flow resistance, or cause thrombus to catch (e.g., between the tube **478** and the interior of the connector **424**.

[0290] A foot pedal **451** is illustrated having a base **453** and a pedal **455** that is coupled to the base **453** and movable or activatable by application of the foot of a user. The pedal **455** can be spring-loaded and depressible by application of a moment or a compressive force, or can instead comprise a membrane switch. The pedal **455**, when activated, can in some embodiments toggle on and off, and in other embodiments can be activatable when a force, a pressure, or a moment is applied, and inactivated when the force, pressure, or moment is not applied. A first cable **461** carries signals from the foot pedal **451** to the pump **412** via a plug **465** that is connected to an input jack **467**. A second cable **463** carries signals from the foot pedal **451** to the peristaltic pump **408** via a plug **469** that is connected to an input jack **471**. In some embodiments, activation of the pedal **455** by the foot of a user starts the operation of the pump **412** and starts the operation of the peristaltic pump **408** at the same time. In some embodiments, activation of the pedal **455** by the foot of a user starts the operation of the peristaltic pump **408**, and then starts the operation of the pump **412**, with a slight delay after the peristaltic pump **408** is started. The controller **484** is programmed or programable to impart the delay, or the lack of delay. The delay is useful to assure that some aspiration, or a significant amount of aspiration, is being applied to the aspiration lumen **404** prior to the injection of pressurized fluid (e.g., saline) through the injection lumen **410**. All can be controlled by the controller **484** of the pump **412**, in response to a signal through the cable **463** from the foot pedal **451**. Thus, blood vessels or other vasculature in the vicinity of the open distal end **405** are spared any injection of fluid from a high pressure jet, as it is instead aspirated through the aspiration lumen **404**.

[0291] In addition, in some embodiments, activation of the pedal **455** by the foot of a user during the operation of the pump **412** and the peristaltic pump **408** stops the operation of the pump **412** and the operation of the peristaltic pump **408** at the same time. In other embodiments, a delay can be applied (e.g., by the controller **484**), such that the pump **412** is stopped, and then the peristaltic pump **408** is stopped slightly afterwards. The length of the delays described can be between about 0.01 second and about 1.00 second, or between about 0.10 second and about 0.25 second. The operation (on/off) of the pump **412** and/or peristaltic pump **408** via the foot pedal **451** allows hands-free activation, enabling a single user the manipulate the aspiration catheter **402** and guidewire **448** with both hands.

[0292] In other embodiments, the foot pedal **451** can be replaced by another type of switch, including, but not limited to a toggle on/off push button or hand switch, an audio-activated switch (voice activated, clap activated, click activated), an optical switch (beam/light sensor for hand or foot interruption), or any other kind of switch that can be activated by medical personnel. The switch can be remote (e.g., in a control room) or can be located near the procedural area. The switch can also be a sterile switch or sterilizable for location on a sterile area.

[0293] In some cases, the activation and deactivation (turning on and off) of the aspiration flow applied by the peristaltic pump **408** on the aspiration lumen **404** can be done by leaving the peristaltic pump **408** in a running condition, while the user opens and closes the stopcock **454**. Alternatively, a pinch valve (not shown) coupled to the extension tube **438** can be used for opening and closing the lumen **444**, and thus starting and stopping aspiration. The pinch valve can be operated by a foot pedal (similar to the foot pedal **451**), or can be operated by another control (e.g., on the interface **456** of the peristaltic pump **408** or even an interface on the pump **412**).

[0294] The controller **484** also monitors and controls several device safety functions, which include over pressure detection, air bubble detection, and vacuum or negative pressure charge. An additional pressure transducer **415** monitors pressure (i.e. injection pressure), and senses the presence of air bubbles. Alternatively, or in conjunction, an optical device **417** can be used to sense

air bubbles. In one contemplated embodiment, the pump pressure is proportional to the electric current needed to produce that pressure. Consequently, if the electric current required by pump **412** exceeds a preset limit, the controller **484** will disable the pump **412** by cutting power to it. Air bubble detection can also be monitored by monitoring the electrical current required to drive the pump **412** at any particular moment. In order for a pump **412** to reach high fluid pressures, there should be little or no air (which is highly compressible) present in the pump **412** or connecting system (including the aspiration lumen **404** of the aspiration catheter **402** and the tubing set **464**). The fluid volume is small enough that any air in the system will result in no pressure being generated at the pump head. A sufficient volume of liquid is needed proximally to flush any finite amount of air through. The controller **484** monitors the pump **412** current for any abrupt downward change that can indicate that air has entered the system. If the rate of drop is faster than a preset limit, the controller **484** will disable the pump **412** by cutting power to it until the problem is corrected.

[0295] After collecting the aspirated material in a blood bag, blood bottle, or the canister **458**, aspirated components (blood, thrombus, saline, slurry, etc.) can be placed into a reinfusion device, such as a Stryker ConstaVac (CBCII) Blood Conservation System, or a Haemonetics OrthoPAT Orthopedic Perioperative Autotransfusion System.

[0296] In some embodiments, the blood can be cooled prior to being injected. In some embodiments, the blood can be heated prior to being injected. In some embodiments, other drugs can be added to the blood prior to it being inserted. In some cases, the blood can be diluted with saline, to decrease its viscosity, or decrease its hematocrit. This can allow for decrease hemolysis to occur. In some cases, blood collected in the canister **458**, or blood coming from the extension tube **438**, can even be used as donor blood, to infuse into a different patient.

[0297] In some embodiments, an additional or alternate sensor can be used to monitor flow conditions for the notification of the user, including, but not limited to: a Doppler sensor, an infrared sensor, or a laser flow detection device. In some embodiments, an externally-attached (non-contact) Doppler sensor can be employed. In some embodiments, an infrared sensor or a laser flow detection device can be employed around the extension tubing **438**. The alternate sensor (e.g., flow sensor, etc.) can be located at a number of different locations along the aspiration path, including on or in the extension tube **438**, either proximal to or distal to the rotatable head **430** of the peristaltic pump **408**.

[0298] FIG. **46** illustrates an alternative aspiration monitoring system **1900** that shares features with the aspiration monitoring system **1800** of FIG. **44**, but is configured to weigh the fluid **259**, **459** contained in the canister **258**, **458** by suspending the canister **258**, **458** from hooks **1902**, **1904** that extend from a frame **1906** that is supported on the weighing platform **1806**. The frame **1906** comprises two vertical legs **1910**, **1912** and a crossbar **1908** coupled to each of the vertical legs **1910**, **1912**. The crossbar **1908** is configured to support the hooks **1902**, **1904** and the canister **258**, **458** (when hung). The canister **258**, **458** can include hooks, indentations, or loops that are configured to engagingly interface with one or both of the hooks **1902**, **1904**.

[0299] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments can be devised without departing from the basic scope thereof. Alternatively, instead of using the extension tube **238**, **438** that is configured to be used with a peristaltic pump **208**, **408**, an extension tube **238**, **438** can comprise a luer connector (or other sealing connector) at its proximal end, and can be configured to attached to an evacuable syringe (e.g., 20 ml or 30 ml). The syringe can be hung from the hooks **1902**, **1904** (or the equivalent) and the weight of the syringe and extension tube **238**, **438** can be tared from the scale **1802**. Thus, as the syringe fills, the increase of weight/mass of the aspirate collecting in the syringe is measured over time, in the same manner that the contents of the canister **258**, **458** is weighed. The evacuable syringe can even be replaced by a bell jar connected to a vacuum pump, again, with the bell jar and any connecting tubing tared from the measured weight/mass. FIG. **47** illustrates an aspiration system **1928** similar

to the aspiration system **200** of FIG. **43**, except that the peristaltic pump **208** and canister **258** are replaced by a vacuum pump **1930** and a vacuum chamber **1934** or bell jar having a base **1936** and a lid **1938** sealably placed thereon. The vacuum pump **1930** can be operated by controls **1999** carried on its outer surface **1997**, or can be controllable (on/off) by the foot pedal **251**. A vacuum tubing **1932** connects the vacuum pump **1930** to an interior **1940** of the vacuum chamber **1934**. A control valve **1948** is adjustable for controlling the aperture between the vacuum tubing **1932** and the interior **1940** of the vacuum chamber **1934**. The interior **1940** communicates with the lumen **244** of the extension tube **238** via the proximal end **242**, which is coupled to a port **1942** of the vacuum chamber **1934**. An adjustable valve **1946** controls an aperture between the interior **1940** of the vacuum chamber **1934** and the lumen **244** of the extension tube **238**. The vacuum pump **1930** is supported separately on a table, cart, or other support. The weight of the vacuum tubing **1932** and extension tube **238** can be tared from the readout of the scale **1802**, so that only the weight of fluid/clot, etc. pulled into the interior **1940** of the vacuum chamber **1934** is measured over time.

[0300] Thrombosis (thrombus, clot) within vasculature, including blood vessels such as arteries or veins, is a significant risk factor that can be debilitating or even cause death. Aspiration systems including aspiration catheter include aspiration-only devices as well as forced aspiration devices, which are configured to inject pressurized fluid, such as heparinized saline, into the distal portion of an aspiration lumen, to create a larger aspiration pressure gradient, and thus more significant thrombus maceration and removal. Though many of these aspiration systems are used in peripheral or coronary arteries, thromboembolic stroke involving arteries of the neck and head is also of concern. Many of the arteries of the neck and head, including cerebral arteries, the basilar artery, and other communicating arteries in proximity, are located quite a distance from traditional insertion/puncture locations, such as the femoral artery or radial artery. The pathway to these arteries can also be quite tortuous, and the vessels are often of a small caliber, such that long, small diameter catheters with a great deal of flexibility at their distal ends are utilized. Many of these design criteria confound other physical requirements of an aspiration catheter, such as a large diameter aspiration lumen for increased aspiration flow, or the multiple lumens of a force aspiration catheter, which must now fit into a small overall catheter shaft diameter.

[0301] Clogging of aspiration catheters, for example by large pieces of thrombus, is a common concern for users. Techniques to avoid clogging/choking of material within the catheter often involve rapidly, aggressively advancing the aspiration catheter or gently plucking at edges of a thrombus to insure only small pieces or portions are introduced at a time, pieces which are small enough to not clog or occlude the aspiration lumen. When a device becomes clogged during use, the potential for inadvertent dislodgment of thrombus downstream increases; this is referred to as distal embolism. As aspiration procedures of this type are often used in highly technical emergent settings, early clog detection of the aspiration catheter for the user during aspiration can contribute to the success of the procedure and clinical outcome. Some sources have reported that up to 50% of aspiration catheters used get clogged during use.

[0302] The user may have difficulty determining whether there is a vacuum or a negative pressure gradient in the system or not. For example, the user may have difficulty determining whether the vacuum or negative pressure has been applied or not (e.g., the vacuum source or negative pressure supplying pump has been turned on or off). Additionally, the user may have difficulty determining whether there has been a loss of vacuum or negative pressure in the system, for example because of the syringe (or other vacuum source or negative pressure supplying pump) being full of fluid or because of a leak in the system. Blood is relatively opaque and can coat the wall of the syringe, thus making it difficult to determine when the syringe becomes full. This makes it difficult to determine whether sufficient vacuum or negative pressure is being applied to the aspiration catheter. The vacuum or negative pressure level can change to an unacceptable level even before the syringe becomes full. Extension tubing or other tubing can also cause a loss in vacuum or negative pressure gradient in the system. Certain tubing kinks can be difficult for a user to see or

identify. It is also difficult to determine whether there is an air leak in the system, which can be another cause for a loss of vacuum or negative pressure even before the syringe becomes full of the aspirated fluid.

[0303] FIG. **48** illustrates an aspiration system **600** comprising an aspiration catheter **602** comprising an elongate shaft **601** including an aspiration lumen **604** having an open distal end **605** and a proximal end **606** configured to couple to a peristaltic pump **608**. The peristaltic pump **608** can be a roller pump having a base **626**, a pressure shoe **628** carried by the base **626**, and a rotatable head **630**, rotatably coupled to the base **626**, and carrying two or more rollers **632***a-d*. The rollers **632***a-d* are arrayed around a perimeter **634** of the rotatable head **630**. The rotatable head **630** is configured to be rotatable in at least a first rotational direction **636** (e.g., by a motor, directly, or with a gear train, not shown). The peristaltic pump **608** can be battery powered, and the battery (ies) can be rechargeable by wired or wireless means. The peristaltic pump **608** can alternatively, or additionally be powered by a power cord (not shown) configured to connect to a power supply. An extension tube **638** having a distal end **640** and a proximal end **642**, and having a lumen **644** extending therethrough, is hydraulically coupled to the proximal end **606** of the aspiration lumen **604** via a connector **624**. A Touhy-Borst seal **646** allows the insertion of a guidewire **648** through the connector **624** and aspiration lumen **604**, as described herein, and the guidewire **648** can be used to track the aspiration catheter **602** through a subject's vasculature. The Touhy-Borst **646** can be tightened to seal over the guidewire **648**, to maintain hemostasis. The extension tube **638** can include a male luer **650** at its distal end **640**, for connecting to a female luer **652** of the connector **624**. The male luer **650** can include a stopcock **654**, which is configured to be turned between an open position (shown) or a closed position. Alternatively, the extension tube **638** can be integral with the aspiration lumen **604**, or can be permanently attached to the connector **624**. In use, a compressible portion **637** of the extension tube **638** is placed within the pressure shoe **628** of the peristaltic pump **608** such that rotation of the rotatable head **630** (e.g., via input to an interface **656** by a user) in the rotational direction **636** causes fluid to be forced through the lumen **644** of the extension tube **638** from the distal end **640** to the proximal end **642**, via compression of the compressible portion **637** by the rollers **632**, one at a time. In some embodiments, there are only two rollers **632**. In other embodiments, there are three rollers **632**. In still other embodiments, as shown, there are four rollers **632**. As described, the rollers **632** can be replaced by bumps or protrusions. The compressible portion **637** or any of the compressible portions described herein can comprise silicone tubing, polyurethane tubing, polyvinyl chloride tubing, thermoplastic elastomer (TPE), such as Bioprene®, a registered trademark of Watson-Marlow or Wilmington, MA, USA, or other compressible tubing. The compressible section **637** can be a relatively short section that is attachable to and detachable from the peripheral ends of the extension tube **638**, or in other embodiments, can comprise the entirety of the extension tube **638** between the distal end **640** and the proximal end **642**. The proximal end **642** of the extension tube **638** can be coupled to a canister **658** having an interior **660**, to allow fluid **659** passing through the extension tube **638** to pass into the interior **660**. The proximal end **642** of the extension tube **638** is coupled to the canister **658** by a tubing clamp **657** which holds the extension tube **638** longitudinally without compromising the patency of the lumen **644**. To minimize fluid resistance at the proximal end **642** of the extension tube, besides an endhole **621**, there is also a plurality of sideholes **623**, similar to sump tubing. In other embodiments, the endhole **621** can be blocked off, with the outflow emanating only from the plurality of sideholes **623**. The sideholes **623** assure that the minimum area of flow resistance in the extension tube **638** is not at the proximal end **642**. The sideholes **623** help prevent against jetting into the canister **658**. Jetting of the blood would be a negative factor, adding shear stress to the blood, and causing hemolysis or platelet activation, and thus damaging or otherwise altering blood that might have been desired for reinfusion into the patient. An additional hub **662** in the canister **658** can be left open (as shown) to allow the unfilled interior **660** to match atmospheric pressure.

[0304] Because the aspiration catheter **602** is configured to be inserted into arteries that can feed to

critical organs (heart, brain, etc.), strict control of flows through the catheter allows for a higher level of security. A recognition system is provided to assure that the aspiration catheter **602** is only used with the peristaltic pump **608** and the injection pump **612**, and not with alternative devices that do not have the same levels of control regarding aspiration and injection. An identification circuit **619** within the peristaltic pump **608** is coupled to the controller **684** (e.g., via cable **686**) and also electrically connects to a first port **611** and a second port **613**. The extension tube **638** can be provided with a first tether **690** having a first identification module **607** configured to plug into or otherwise be secured in close proximity to the first port **611**. Additionally, or alternatively, the aspiration catheter **602** can be provided with a second tether **688** having a second identification module **609** configured to plug into or otherwise be secured in close proximity to the second port **613**. The controller **684** is configured to only allow the operation of the injection pump **612** and/or the peristaltic pump **608** to occur if one of both of the identification modules **607**, **609** are identified by the identification circuit **619** as being correct components (e.g., correct models, correct sizes, correct clinical applications, etc.). Thus, the pumps **612**, **608** are enabled or un-enabled by the controller **684**, depending upon the information provided by the identification modules **607**, **609**. In some embodiments one or both of the identification modules **607**, **609** make comprise an RFID (radiofrequency identification) chip, and the identification circuit **619** configured to power the RFID chips to receive and read data. In some embodiments, the identification circuit **619** can additionally be configured to write to the RFID chips. In other embodiments one or both of the identification modules **607**, **609** make comprise a resistor, and the identification circuit **619** configured to read the resistance value of the resistor. For example, the resistor can complete a partial Wheatstone bridge carried on the identification circuit **619**.
[0305] The aspiration catheter **602** additionally has a high pressure injection lumen **610** for injecting saline from a fluid source **679**, for example, via a high pressure pump **612**. A tubing set **664** can include a pump cartridge **666** having a piston or bellows or other movable element that the pump **612** can manipulate using an internal motor **691**, thus pressurizing saline or other fluid from the fluid source **679** with a significantly high pressure such that the saline is forced through the injection lumen **610** of the aspiration catheter **602**. The tubing set **664** includes proximal end **668** having a spike **689** or other element for hydraulically coupling it to the fluid source **679**. The tubing set **1464** further has a distal end **670** (which can include a male luer) which is configured to hydraulically couple to the injection lumen **610** via a female luer **672**. Injected saline is forced through the injection lumen **610** by the pump **612** and exits an orifice **674** in a hollow end piece **675** coupled to a distal end **676** of an injection tube **678**, containing the injection lumen **610**. The tube **678** can be substantially or entirely within the shaft **601**. In some embodiments, the tube **678** is attached to the internal wall of the shaft **601** only at a distal end portion **603**. Thus, the free-floating nature of the remainder of the tube **678** within the aspiration lumen **604** increases the flexibility and trackability of the shaft **601**. The high pressure saline is forced through the orifice **674**, causing a jet, or one or more jets. The jet is aimed within the aspiration lumen **604**, just proximal the open distal end **605** which can create a Venturi effect that forces blood or thrombus that is external and adjacent the open distal end **605** into the aspiration lumen **640**. The combination of the operation of the peristaltic pump **608** and the jet created by the high pressure saline cause the maceration of thrombus, and the movement/flow of material (saline/blood/macerated thrombus/small pieces of thrombus) through the aspiration lumen **604** from the open distal end **605** to the proximal end **606**, through the connector **624**, and through the lumen **644** of the extension tube **638** from its distal end **640** to its proximal end **642**, and finally into the interior **660** of the canister **658**. Thus, thrombus within a blood vessel of a subject can be macerated and removed by use of the system **600**. Blood vessels can include peripheral blood vessels, coronary blood vessels, or blood vessels within the head or neck of the subject, including carotid arteries, cerebral arteries, and basilar and communicating arteries. An aspiration monitoring system **614** comprising a pressure transducer **616** can be coupled, for example, between the distal end **640** of the extension tube **638** and the

connector **624** and/or proximal end **606** of the aspiration lumen **604** of the aspiration catheter **602**. The aspiration monitoring system **614** or any other described herein can include any of the features described in relation to aspiration monitoring systems described in U.S. Pat. App. Pub. No. 2017/0056032 to Look et al., filed Aug. 23, 2016 and published Mar. 2, 2017, which is hereby incorporated by reference in its entirety for all purposes. Signals from the pressure transducer **616** are carried on an electric cable **680** to an input **682** of the pump **612**. A controller **684** within the pump **612** is configured to control the operation of the pump **612**, including motor **691**, but the controller **684** can also be configured to control the operation of the peristaltic pump **608**, via a cable **686**, or wirelessly. The controller **684** can comprise a microcontroller. The controller **684** can alternatively be located within the peristaltic pump **608**, or can be located at another location. Control using signals of measured pressure from the pressure transducer **616** adds an additional safety element to the system **600**. Additionally, a non-functional device (because of a leak, incomplete connection, incomplete priming, rupture, blockage) can be quickly identified. Unallowably high pressures can also be quickly identified, protecting the motor **691** of the pump **612** from burnout or overheating danger. The integrity of the tube **678** is also protected, e.g., avoiding unnaturally high pressures that could lead to burst.

[0306] The female luer **652** of the aspiration catheter **602** is located distally on the connector **624** from the female luer **672**. Thus, aspirated blood/thrombus/saline enters the female luer **652** without ever having to contact interior irregularities **625** (in geometry, shape) within the connector **624**, that can otherwise cause flow resistance, or cause thrombus to catch (e.g., between the tube **678** and the interior of the connector **624**.

[0307] A foot pedal **651** has a base **653** and a pedal **655** that is coupled to the base **653** and movable or activatable by application of the foot of a user. The pedal **655** can be spring-loaded and depressible by application of a moment or a compressive force, or can instead comprise a membrane switch. The pedal **655**, when activated, can in some embodiments toggle on and off, and in other embodiments can be activatable when a force, a pressure, or a moment is applied, and inactivated when the force, pressure, or moment is not applied. A first cable **661** carries signals from the foot pedal **651** to the pump **612** via a plug **665** that is connected to an input jack **667**. A second cable **663** carries signals from the foot pedal **651** to the peristaltic pump **608** via a plug **669** that is connected to an input jack **671**. In some embodiments, activation of the pedal **655** by the foot of a user starts the operation of the pump **612** and starts the operation of the peristaltic pump **608** at the same time. In some embodiments, activation of the pedal **655** by the foot of a user starts the operation of the peristaltic pump **608**, and then starts the operation of the pump **612**, with a slight delay after the peristaltic pump **608** is started. The delay is useful to assure that some aspiration, or a significant amount of aspiration, is being applied to the aspiration lumen **604** prior to the injection of pressurized fluid (e.g., saline) through the injection lumen **610**. Thus, blood vessels or other vasculature in the vicinity of the open distal end **605** are spared any injection of fluid from a high pressure jet, as it is instead aspirated through the aspiration lumen **604**.

[0308] In addition, in some embodiments, activation of the pedal **655** by the foot of a user during the operation of the pump **612** and the peristaltic pump **608** stops the operation of the pump **612** and the operation of the peristaltic pump **608** at the same time. In other embodiments, a delay can be applied, for example, such that the pump **612** is stopped, and then the peristaltic pump **608** is stopped slightly afterwards. The length of the delays described can be between about 0.01 second and about 1.00 second, or between about 0.10 second and about 0.25 second. The operation (on/off) of the pump **612** and/or peristaltic pump **608** via the foot pedal **651** allows hands-free activation, enabling a single user the manipulate the aspiration catheter **602** and guidewire **648** with both hands. The location of the foot pedal **651** can be tactily found with the foot of the user, while the user maintains visual contact with the patient, and/or any monitors, or even other medical personnel.

[0309] In other embodiments, the foot pedal **651** can be replaced by another type of switch,

including, but not limited to a toggle on/off push button or hand switch, an audio-activated switch (voice activated, clap activated, click activated), an optical switch (beam/light sensor for hand or foot interruption), or any other kind of switch that can be activated by medical personnel. The switch can be remote (e.g., in a control room) or can be located near the procedural area. The switch can also be a sterile switch or sterilizable for location on a sterile area.

[0310] In some cases, the activation and deactivation (turning on and off) of the aspiration flow applied by the peristaltic pump **608** on the aspiration lumen **604** can be done by leaving the peristaltic pump **608** in a running condition, while the user opens and closes the stopcock **654**. In other embodiments, the stopcock can be replaced by a pinch valve (not shown) to open or compress the extension tubing **638**. The pinch valve can be operable by a foot switch or by a push button (on/off).

[0311] The controller **684** also monitors and controls several device safety functions, which include over pressure detection, air bubble detection, and vacuum or negative pressure charge. An additional pressure transducer **615** carried on the connector **624** monitors pressure (i.e. injection pressure), and senses the presence of air bubbles. Alternatively, or in conjunction, an optical device **617** can be used to sense air bubbles. In one contemplated embodiment, the pump pressure is proportional to the electric current needed by the pump **612** to produce that particular pressure. Consequently, if the electric current required by pump **612** exceeds a preset limit, the controller **684** will disable the pump **612** by cutting power to it. Air bubble detection can also be monitored by monitoring the electrical current required to drive the pump **612** at any particular moment. In order for a pump **612** to reach high fluid pressures, there should be little or no air (which is highly compressible) present in the pump **612** or connecting system (including the aspiration lumen **604** of the aspiration catheter **604** and the tubing set **664**). The fluid volume is small enough that any air in the system will result in no pressure being generated at the pump head. A sufficient volume of liquid is needed proximally to flush any finite amount of air through. The controller **684** monitors the pump **612** current for any abrupt downward change that can indicate that air has entered the system. If the rate of drop is faster than a preset limit, the controller **684** will disable the pump **612** by cutting power to it until the problem is corrected.

[0312] The aspiration catheter **602** of FIG. **48** is illustrated as having pressurized fluid injection through injection lumen **610**. However, other embodiments of the aspiration system **600** exist in which the aspiration catheter **602** is replaced by a standard aspiration catheter, not having an injection lumen.

[0313] As an alternative to collecting the aspirated material in a blood bag, blood bottle, or the canister **658**, aspirated components (blood, thrombus, saline, slurry, etc.) can be placed into a reinfusion device, such as a Stryker ConstaVac (CBCII) Blood Conservation System, or a Haemonetics OrthoPAT Orthopedic Perioperative Autotransfusion System. In some embodiments, the canister **658**, itself, can comprise the reinfusion device. Returning at least some of the aspirated blood to the patient via reinfusion helps to diminish what is one of the inherent drawbacks to aspiration, blood loss.

[0314] In some embodiments, the blood can be cooled prior to being injected. In some embodiments, the blood can be heated prior to being injected. In some embodiments, other drugs can be added to the blood prior to it being inserted. In some cases, the blood can be diluted with saline, to decrease its viscosity, or decrease its hematocrit. This can allow for decrease hemolysis to occur. In some cases, blood collected in the canister **658**, or blood coming from the extension tube **638**, can even be used as donor blood, to infuse into a different patient.

[0315] In some embodiments, an additional or alternate sensor can be used to monitor flow conditions for the notification of the user, including, but not limited to: a Doppler sensor, an infrared sensor, or a laser flow detection device. In some embodiments, an externally-attached (non-contact) Doppler sensor can be employed. In some embodiments, an infrared sensor or a laser flow detection device can be employed around the extension tubing **638**. The alternate sensor (e.g.,

flow sensor, etc.) can be located at a number of different locations along the aspiration path, including on or in the extension tube **638**, either proximal to or distal to the rotatable head **630** of the peristaltic pump **608**.

[0316] FIG. **49** illustrates an aspiration catheter **700** having an elongate shaft **702**, and with a radiopaque marker band **704** attached to the distal end **706** of the shaft **702**. The shaft **702** defines an aspiration lumen **708** having an open distal end **710**. An injection tube **712** having a distal end **714** is capped off with a microfabricated cap **716**. The microfabricated cap **716** has an inner cylindrical cavity **718** configured for placing over the distal end **714** of the injection tube **712**. An outer cylindrical surface **720** at the distal end **714** of the injection tube **712** is sealingly coupled to the microfabricated cap **716** at the inner cylindrical cavity **718**, so that the injection lumen **722** of the injection tube **712** is closed and sealed at the distal end **714** to resist a high pressure. The outer cylindrical surface **720** can be bonded to the microfabricated cap **716** at the inner cylindrical cavity **718** by at least one of an adhesive, an epoxy, a weld (e.g., ultrasonic weld, or other fusing of materials), or a solvent. Alternatively, a circumferential seal (thin elastomeric ring) can be interposed between the outer cylindrical surface **720** and the microfabricated cap **716** at the inner cylindrical cavity **718** to create a seal, and a friction fit. The microfabricated cap **716** can comprise a number of different materials, including polymers or metals. The microfabricated cap **716** can be constructed by a number of different processes, including: micromachining, micro injection molding, three-dimensional printing, photolithography, shadow masking, etching, or microforming. These processes include additive processes and subtractive processes. An orifice **730** is formed in a wall **732** of the injection tube **712** and has a similar function to the orifice **674** of FIG. **48**. High pressure fluid is forced out of the orifice **730** and into the aspiration lumen **708** (arrow) because the distal end **714** of the injection tube **712** is sealed.

[0317] An outer surface **724** of the injection tube **712** is bonded to an inner surface **726** of the aspiration lumen **708** with an adhesive **728** (or epoxy, or other joining means). The injection tube **712** is bonded at a particular rotational orientation with respect to the aspiration lumen **708** such that the orifice **730** is oriented toward an opposing surface **734** in the aspiration lumen **708**. An unbonded section **736** extends a significant portion of the length of the aspiration catheter **700** in the proximal direction, thus allowing for enhanced flexibility and trackability. The center of the orifice **730** can be located a distance d.sub.2 from the proximal end of the microfabricated cap **716**, such as between about 0.05 mm and about 10.00 mm so that a jet emanating from the orifice **730** clears the microfabricated cap **716**. The center of the orifice **730** is located a distance d.sub.1 from the open distal end **710** of the aspiration lumen **708** such that the distal end of the microfabricated cap **716** does not extend from the aspiration lumen **708**. However, in some embodiments, the microfabricated cap can be configured to extend from the aspiration lumen **708**, as long it does not have any sharp leading features.

[0318] FIG. **50** illustrates an aspiration catheter **740** having an elongate shaft **742**, and with a radiopaque marker band **744** attached to the distal end **746** of the shaft **742**. The shaft **742** defines an aspiration lumen **748** having an open distal end **750**. An injection tube **752** having a distal end **754** is capped off with a microfabricated cap **756**. The microfabricated cap **756** has an inner cylindrical cavity **758** configured for placing over the distal end **754** of the injection tube **752**. An outer cylindrical surface **760** at the distal end **754** of the injection tube **752** is sealingly coupled to the microfabricated cap **756** at the inner cylindrical cavity **758**, so that the injection lumen **762** of the injection tube **752** is closed and sealed at the distal end **754** to resist a high pressure. A reinforcement ring **795** is fit into the injection lumen **762** of the injection tube **752** at the distal end **754** to reinforce the distal end **754** and allow for higher strength seal. The reinforcement ring **795** can also be configured to allow a friction fit seal. The reinforcement ring can comprise a high strength metallic material such as stainless steel, or a rigid polymer. The outer cylindrical surface **760** can be bonded and/or sealed to the microfabricated cap **756** at the inner cylindrical cavity **758** by any of the methods or materials described in relation to the aspiration catheter **700** of FIG. **49**.

The microfabricated cap **756** can comprise any of the materials and be formed by any of the processes described in relation to the microfabricated cap **716** in FIG. **49**. An orifice **770** is formed in a wall **772** of the injection tube **752** and has a similar function to the orifice **674** of FIG. **48**. High pressure fluid is forced out of the orifice **770** and into the aspiration lumen **748** because the distal end **754** of the injection tube **752** is sealed.

[0319] An outer surface **764** of the injection tube **752** is bonded to an inner surface **766** of the aspiration lumen **748** with an adhesive **768** (or epoxy, or other joining means). The injection tube **752** is bonded at a particular rotational orientation with respect to the aspiration lumen **748** such that the orifice **770** is oriented toward an opposing surface **774** in the aspiration lumen **748**. The adhesive **768** bond extends a significant portion of the length of the aspiration catheter **740** in the proximal direction.

[0320] FIG. **51** illustrates an aspiration catheter **701** having an elongate shaft **703**, and with a radiopaque marker band **705** attached to the distal end **707** of the shaft **703**. The shaft **703** defines an aspiration lumen **709** having an open distal end **711**. An injection tube **713** having a distal end **715** is capped off with a microfabricated cap **717**. The distal end **715** is necked down from the rest of the injection tube **713** by a heating and/or tensile stretching process to create a smaller outer diameter of the distal end **715**. The microfabricated cap **717** has an inner cylindrical cavity **719** configured for placing over the reduced diameter distal end **715** of the injection tube **713**. An outer cylindrical surface **721** at the distal end **715** of the injection tube **713** is sealingly coupled to the microfabricated cap **717** at the inner cylindrical cavity **719**, so that the injection lumen **723** of the injection tube **713** is closed and sealed at the distal end **715** to resist a high pressure. The smaller diameter of the distal end **715** and the inner cylindrical cavity **719**, allow for a relatively higher strength bond, because of the thereby increased hoop strength of the distal end **715**. The outer cylindrical surface **721** can be bonded and/or sealed to the microfabricated cap **717** at the inner cylindrical cavity **719** by any of the methods or materials described in relation to the aspiration catheter **700** of FIG. **49**. The microfabricated cap **717** can comprise any of the materials and be formed by any of the processes described in relation to the microfabricated cap **716** in FIG. **49**. An orifice **731** is formed in a wall **733** of the injection tube **713** and has a similar function to the orifice **674** of FIG. **48**. High pressure fluid is forced out of the orifice **731** and into the aspiration lumen **709** because the distal end **715** of the injection tube **713** is sealed.

[0321] An outer surface **725** of the injection tube **713** is not bonded to an inner surface **727** of the aspiration lumen **709**. Instead, the microfabricated cap **717** is bonded to the inner surface **727** with an adhesive **729** (or epoxy, or other joining means). An unbonded section **737** of the injection tube **713** extends a significant portion of the length of the aspiration catheter **701** in the proximal direction, thus allowing for enhanced flexibility and trackability. The microfabricated cap **717** is bonded such that the injection tube **713** is held at a particular rotational orientation with respect to the aspiration lumen **709** such that the orifice **731** is oriented toward an opposing surface **735** in the aspiration lumen **709**.

[0322] FIG. **52** illustrates an aspiration catheter **741** having an elongate shaft **743**, and with a radiopaque marker band **745** attached to the distal end **747** of the shaft **743**. The shaft **743** defines an aspiration lumen **749** having an open distal end **751**. An injection tube **753** having a distal end **755** is capped off with a microfabricated cap **757**. The microfabricated cap **757** has an inner cylindrical cavity **759** which includes a proximal portion **799** configured for placing over the distal end **755** of the injection tube **753**. An outer cylindrical surface **761** at the distal end **755** of the injection tube **753** is sealingly coupled to the microfabricated cap **757** at the inner proximal portion **799** of the cylindrical cavity **759**, so that the injection lumen **763** of the injection tube **753** is sealed to resist a high pressure. The outer cylindrical surface **761** can be bonded and/or sealed to the microfabricated cap **757** at the proximal portion **799** of the inner cylindrical cavity **759** by any of the methods or materials described in relation to the aspiration catheter **700** of FIG. **49**. The microfabricated cap **757** can comprise any of the materials and be formed by any of the processes

described in relation to the microfabricated cap **716** in FIG. **49**. An orifice **771** is an exit of a distal portion **797** of the inner cylindrical cavity **759** that communicates with the proximal portion **799**. The inner cylindrical cavity **759** in FIG. **52** has a curved shape, but can alternatively form an L-shape, or make take a 45° angle with respect to the longitudinal axis of the aspiration catheter **741**. The angle can vary between 45° and 135°. The orifice **771** is formed in a wall **773** of the microfabricated cap **757** and has a similar function to the orifice **674** in FIG. **48**. High pressure fluid is forced through the inner cylindrical cavity **759**, out of the orifice **771**, and into the aspiration lumen **749** because the distal end **755** of the injection tube **753** is sealed.

[0323] An outer surface **765** of the injection tube **753** is bonded to an inner surface **767** of the aspiration lumen **708** with an adhesive **769** (or epoxy, or other joining means). The injection tube **753** is bonded at a particular rotational orientation with respect to the aspiration lumen **749** such that the orifice **771** is oriented toward an opposing surface **775** in the aspiration lumen **749**. An unbonded section **777** extends a significant portion of the length of the aspiration catheter **741** in the proximal direction, thus allowing for enhanced flexibility and trackability. One of more of the individual features of the aspiration catheters **700**, **740**, **701**, **741** of FIGS. **49-52** can be rearranged to create other new embodiments. The individual features each allow the production of a small diameter aspiration catheter capable of tracking into distal vasculature, such as the vasculature of the head and neck, and also provide for aspiration including high pressure forced injection.

[0324] FIGS. **53-56** illustrate an insertable injection tube **920**, and a method for using it in a patient. The patient is not shown, for simplicity, and the devices are shown in a straight configuration, but in use, it is common for the devices to be tracked through tortuosities of a patient's vasculature. In FIG. **53**, a microcatheter **924** is configured for tracking into the neurovasculature of a patient, including the Circle of Willis and the cerebral arteries. The term “microcatheter” is used loosely to describe any catheter used for tracking into the neurovasculature. A larger catheter with similar design elements is possible, whether it can be used in the Circle of Willis or not. The microcatheter **924** can be incorporated as a component of an aspiration system **922** (FIGS. **54-56**), or can be a standard microcatheter purchased separately by a user. The microcatheter **924** comprises a shaft **926** having a proximal end **928** and a distal end **930**, with a lumen **932** extending through the shaft **926**. A luer hub **934** (e.g., female luer connector) is sealingly attached to the proximal end **928** of the shaft **926**. The microcatheter **924** can have a distal radiopaque marker (not shown), which is allied in a similar manner to the radiopaque marker bands **704**, **744**, **705**, **745** in the aspiration catheters **700**, **740**, **701**, **741** of FIGS. **49-52**. A connector **936** includes a male luer **938** for connecting to the luer hub **934**, and can include a valve **940**, which can comprise a Touhy-Borst or the equivalent. The sideport **942** of the connector **936** can include a female luer for connecting to the male luer **650** of the extension tube **638** of the system **600** described in detail in relation to FIG. **48**. In FIG. **53** a user tracks the microcatheter **924** over a guidewire **944** into the blood vessels that are the region of interest. In some cases, the region of interest can be one of the cerebral arteries or other arteries in the vicinity, where a thrombus **946** (FIG. **54**) is causing a thromboembolic stroke in the patient.

[0325] In FIG. **54**, the user removes the guidewire **944** and inserts the insertable injection tube **920** through the Touhy-Borst **940** and into the connector **936** and the lumen **932** of the microcatheter **924**. The insertable injection tube **920** can include a microfabricated cap **948**, as described in any of the embodiments of FIGS. **49-52**, or can comprise an alternative configuration. However, the insertable injection tube **920** at the minimum comprises a high strength hollow tube **952** which can comprise stainless steel, nickel-titanium alloy, polyimide, or other high strength materials having sufficient column strength to be inserted through the lumen **932** of the microcatheter **924**. The microfabricated cap **924** includes an orifice **950** configured to provide a jet of pressurized fluid, similar to the orifice **771** of the microfabricated cap **757** in FIG. **52**. In FIG. **55**, the user advances the insertable injection tube **920** further through the lumen **932** of the microcatheter **924**, toward the distal end **930**. A stop **954** is bonded to the outside of the high strength hollow tube **952** and has a

front face **956** configured to butt up against a proximal face **958** of the connector **936** when the center of the orifice **950** is located at the preferred distance (e.g., d.sub.1, as in FIG. **49**) from the distal end of the microcatheter **924**. The insertable injection tube **920** can be provided with different models, each having a different length between the front face **956** and the center of the orifice **950**, and each configured to be used with a particular length of microcatheter **924**, or a particular model of microcatheter **924**, or a particular microcatheter **924** model/connector **936** model combination. In some embodiments, the connector **936** can be a component of the insertable injection tube **920**, and instead of the Touhy-Borst **940**, can instead be permanently sealed and coupled to the high strength hollow tube **952** at a proximal region. Thus, the coupling of the male luer **938** to the luer hub **934** provides the longitudinal stop that controls the d.sub.1 distance.

[0326] It may not always be possible to track an aspiration catheter **602** having high pressure injection forced aspiration capabilities (FIG. **48**) into the neurovasculature, because of the smaller diameters and tortuosities of the vessels. Thus, the insertable injection tube **920** allows a microcatheter **924** to be converted into a forced aspiration catheter. Thus, forced aspiration can occur in very distal locations, and locations that are distal to significant tortuosity, where normally microcatheters are the preferred access means. The small diameter insertable injection tube **920** is capable of being inserted through the lumen **932** of a microcatheter **924** after the microcatheter **924** is inserted into the region of interest. In alternative procedures and alternative embodiments of a system, a microcatheter **924** being inserted over a guidewire **944** can be replaced by a flow-directed catheter having a lumen configured for placement of the insertable injection tube **920** being inserted to the region of interest without a guidewire.

[0327] FIG. **57** illustrates a particular distal configuration of a distal end **913** of the insertable injection tube **920**. This configuration allows the microfabricated cap **948** and orifice **950** to be controllably and repeatably inserted through the lumen **932** of the microcatheter **924** such that the orifice is automatically oriented and the one or more jets emanating from the orifice **950** (or one or more orifices **950**) are directed against an opposite wall **929** in the lumen **932** of the microcatheter **924**. The microfabricated cap **948** has a distal taper **960**, that can comprise a fillet or a bevel, or other type of lead-in shape. The purpose of the distal taper **960** is to facilitate the insertion into the connector **936**, the luer hub **934**, or the lumen **932** (FIG. **54**), and to ease the advancement of the microfabricated cap **948** through the lumen **932**, especially when the shaft **926** is in a tortuous condition. A spline loop **962** is coupled to the microfabricated cap **948** and can be formed from a wire, such as stainless steel or cobalt-chromium-nickel-molybdenum, or can comprise a superelastic material, such as a nickel-titanium alloy. The spline loop **962** is configured to have a diameter that is slightly less than, equal to, or slightly greater than the diameter of the lumen **932** of the microcatheter **924**. Turning to FIG. **58**, a first end **921** of the spline loop **962** is bonded into a circumferential groove **923** in the microfabricated cap **948**. There is a gap **925** between the first end **921** and a second end **927** of the spline loop **962**, which allows space for the two ends **921**, **927** to approach each other, and thus the diameter of the spline loop **962** to be forced smaller, for example, by stress placed on the spline loop **962** from the wall around the lumen **932** of the microcatheter **924**. Because the rotational orientation between the spline loop **962** and the microfabricated cap **948** are fixed in relation to each other (by the bonding of the first end **921** into the groove **923**), the orifice **950** remains oriented toward an opposite wall **929** in the lumen **932**. The spline loop **962** is located at a different longitudinal position on the microfabricated cap **948** than the orifice **950**, and thus, the spline loop **962** does not block or deflect the jet emanating from the orifice **950**. In this embodiment, the spline loop **962** is slightly distal to the orifice **950**, though in other embodiments, it can instead be located proximally. In other alternative embodiments, the spline loop **962** (or any analogous structure) can actually be used to at least somewhat deflect the jet emanating from the orifice **950**, with the purpose of changing the shape or direction of the jet, for instance, deflecting it at least partially in a proximal longitudinal direction. In these alternative embodiments, therefore, it can actually be desired to have the spline loop **962** located at substantially the same longitudinal

location as the orifice **950**. In some embodiments, the microfabricated cap **948** can be replaced by a simple plug (e.g., having at least some male portion plugging the lumen), into which similar features are formed, for example by drilling or skiving.

[0328] FIG. **59**, the spline loop **962** is replaced by a spline ring **933**, which is attached to the high strength hollow tube **952** instead of to the microfabricated cap **948**. The spline ring **933** is formed from a flat wire (stainless steel or nickel-titanium alloy, or other) or from a stiff polymeric strip (polyimide or other stiff polymer), and has a shape somewhat like the number "6," extending between a first end **935** and a second end **937**. A first loop portion **939** is configured to extend around the high strength hollow tube **952** for bonding thereon, and a second loop portion **941** serves the same purpose as the spline loop **962** of FIGS. **57-58**, to guide the microfabricated cap **948** and to rotationally orient the orifice **950** within the lumen **932**. Other spline shapes can alternatively be used which also serve to maintain the microfabricated cap **948** against the wall on one side of the lumen **932**, and/or serve to resist rotation between the shaft **926** of the microcatheter **924** and either the high strength hollow tube **952** or the microfabricated tip **948** (whichever of the two includes the orifice **950**). The spline loop **962** or the spline ring **933** can each be made from a radiopaque material, or can include a radiopaque material as a base, or plating or coating. Thus, during a procedure, it will be easier to visualize on x-ray or fluoroscopy the movement of the orifice **950** down the lumen **932** of the microcatheter **924**. The microfabricated cap **948** can also or can alternatively comprise a radiopaque material or radiopaque coating or plating. The insertable injection tube **920** in the embodiments presented, is configured to be removable from the lumen **932** of the microcatheter **924**, so that the microcatheter **924** can be subsequently used for one of its other functions (delivering embolic coils or embolic materials, drugs, replacing the guidewire **944** or even aspirating through the empty lumen **932**). In alternative embodiments, the orifice **950** of the microfabricated cap **948** can be used to inject drugs or other materials into the vasculature, for example, by stopping or avoiding any vacuum or negative pressure placed on the proximal end of the lumen **932**.

[0329] FIGS. **60-63** illustrate a method for treating a patient using the aspiration system **600** of FIG. **48**, using aspiration catheter **602**, or any of the alternative aspiration catheters **700**, **740**, **701**, **741**. Alternatively, the method can be accomplished using the aspiration system **922**, or using the insertable injection tube **920** with a standard single lumen catheter, such as a microcatheter **924**, a guiding catheter, or a guide sheath (long sheath). In all of these systems, the pump **612** and the peristaltic pump **608** as described in FIG. **48** can be utilized. In FIG. **60**, an aspiration catheter **602** has been tracked into a blood vessel **943** (e.g., using a guidewire **648**) and is advanced so that the open distal end **605** is adjacent the proximal end **945** of a thrombus **947**. In some cases, aspiration utilizing the high pressure injection from the pump **612** through the tubing set **664** combined with distal-to-proximal flow impulse imparted on the extension tube **638** by the peristaltic pump **608** are not enough to cause the thrombus **947** to be sufficiently aspirated into the open distal end **605** and into the aspiration lumen **604** so that it can be macerated and aspirated. At times, the cause for this is that a space **949** distal to the thrombus **947** acts as a relative vacuum and pulls on the thrombus with a force (e.g., distally, away from the aspiration catheter **602**), thus making it difficult to aspirate the thrombus. Though the blood vessel **943** is shown in a relatively normal state, at time the blood vessel can have become collapsed because of lack of blood pressure from occlusion by the thrombus **947**. Other times, some of the thrombus **947** can have significantly solid or semi-solid portions that impede the ability to flow from a distal to proximal direction.

[0330] A user has encountered this condition while attempting to aspirate through operation of the pump **612** and peristaltic pump **608**, and the aspiration catheter **602** is inserted and advanced into the blood vessel **943** as shown in FIG. **60**. The user then can use a technique with the aspiration system **600** to alleviate the substantially no flow condition. In FIG. **61**, the user advances the aspiration catheter **602** so that the open distal end **605** of the aspiration lumen **604** is distal to the thrombus **947**. The advancement of the open distal end **605** of the aspiration catheter **602** through

or past the thrombus **947** can be done without using a guidewire **648**, but in certain instances, the guidewire **648** will need to be used to cannulate and pass through or past the thrombus **947** and then to track the aspiration catheter **602**.

[0331] In FIG. **62**, the user operates the pump **612** to inject fluid, while the peristaltic pump **608** is not being operated. Thus, pressurized fluid (e.g., heparinized saline, or saline mixed with a thrombolytic drug) is injected through the injection lumen **610** of the tube **678**, through the orifice **674**, into the aspiration lumen **604**, and then out the open distal end **605** (arrows) and into the space **949** in the blood vessel **943**. This occurs because there is no aspiration through the aspiration lumen **604**, and the stopped peristaltic pump **608** acts as a closed valve, with one of the rollers **632** compressing the compressible portion **637** of the extension tube **638**. The injection of the fluid increases the fluid volume of the space **949**, and by doing so, is able to also increase its internal pressure, thus neutralizing the prior relative vacuum effect caused by the space **949**. There is now flowable material in the space **949**, such that aspiration using the peristaltic pump **608** with the pump **612** can allow maceration and aspiration of the thrombus **947** to begin (by now turning on the peristaltic pump **608**). The aspiration catheter **602** can also be retracted as shown in FIG. **63**, to better contact the thrombus **947** and to increase the percentage of thrombus **947** being aspirated. This can be continued until all or at least a clinically significant portion of the thrombus **947** is aspirated.

[0332] Returning to FIG. **62**, in certain cases, such as thromboembolic stroke, the downstream tissue may not be receiving sufficient flow because of the occlusion caused by the thrombus **947**. The user can run the fluid from the fluid source **679** through a cooling system, such as a heat exchanger or thermoelectric cooler **951** (FIG. **48**) through which the tubing set **664** can run, and by which the fluid can be cooled. Additionally, an extracorporeal circuit **953** (FIG. **62**) can be attached to the tubing set **664**, so that blood removed from the patient (e.g., via a femoral artery, femoral vein, or jugular vein sheath **955**) is added to the fluid from the fluid source **679**, so that there is some oxygenated blood being injected into the space **949**, some which can potentially feed downstream tissue with oxygen or nutrients. The cooled fluid (saline, blood, or saline plus blood) can additionally reduce the metabolic demands of the downstream tissue by actively cooling it. The inventors have demonstrated that using a pump **612** that utilizes a removable cartridge having a piston, hemolysis can be maintained at an acceptably low value during this sort of injection and mixing of blood with the injected saline, from a mixture that includes about 10% blood, to a mixture that includes about 80% blood.

[0333] FIGS. **64-65** illustrate a method for treating a patient using the aspiration system **600** of FIG. **48**, but incorporating an aspiration catheter **957** having a translatable injection tube **959**. The aspiration catheter **957** has an elongate shaft **963** having an aspiration lumen **965** with a proximal end **971** and an open distal end **961**. The translatable injection tube **959** has an injection lumen **973** having a proximal end **975** and a distal end **977**. The distal end **977** is coupled to a microfabricated cap **979** having an orifice **981**, such that pressurized fluid injected through the injection lumen **973** exits from the orifice **981**, as in the orifice **771** in FIG. **52**. At a high enough injection pressure, the fluid can emanate from the orifice **981** in a jet. Alternatively, the distal end **977** of the injection lumen **973** can be plugged or capped, and there can be an orifice formed in the wall of the injection tube **959**, as in FIGS. **49-51**. The pump **612** and the peristaltic pump **608** as described in FIG. **48** can be utilized. In FIG. **64**, the aspiration catheter **957** has been tracked into a blood vessel **943** (e.g., using a guidewire **648**) and is advanced so that the open distal end **961** is adjacent the proximal end **945** of a thrombus **947**. A proximal female luer connector **983** is coupled to the injection lumen, **973**, and configured to couple to the male luer/distal end **670** of the tubing set **664**. A filter **985** can be interposed between the female luer connector **983** and the male luer **670**, to filter out particulate (FIG. **65**). The filter has a proximal female luer **987** and a distal male luer **989**. The filter **985** can be used with any of the embodiments described herein, in which fluid can be injected (intentionally or not) into the bloodstream of a patient.

[0334] As described, in some cases, aspiration utilizing the high pressure injection from the pump **612** through the tubing set **664** combined with distal-to-proximal flow impulse imparted on the extension tube **638** by the peristaltic pump **608** are not enough to cause the thrombus **947** to be sufficiently aspirated into the open distal end **961** and into the aspiration lumen **965** so that it can be macerated and aspirated. A stiff tube **991** is bonded coaxially over the injection tube **959** at a proximal length, or the injection tube **959**, itself, can be made stiff proximally. The stiff tube **991** and/or the female luer connector **983** and/or the attached filter **985** can be gripped by the user, such that the user is able to advance the stiff tube **991** and the injection tube **959**, in turn, distally, such that the microfabricated cap **979** and the orifice **981** are translated distally, through the thrombus **947** and into the space **949** distal to the thrombus **947**. In some cases, being translated distally into a distal portion of the thrombus **947** can be sufficient. A dynamic seal **993** (o-ring, quad ring, etc.) can be sealed over the stiff tube **991** at all longitudinal positions of the stiff tube **991**. Once the orifice **981** is located within the space **949**, the pump **612** is operated without the operation of the peristaltic pump **608** (or with a significantly low setting of the peristaltic pump), such that fluid is injected through the injection lumen **973** and out the orifice **981**, into the space **949**.
[0335] The injection of the fluid increases the fluid volume of the space **949**, and by doing so, is able to also increase its pressure, thus neutralizing the prior relative vacuum effect from the space **949**. There is now flowable material within the space **949** such that aspiration using the peristaltic pump **608** with the pump **612** can allow maceration and aspiration of the thrombus **947** to begin (by now turning on the peristaltic pump **608**). The shaft **963** of the catheter **957** can also be advanced and retracted during aspiration, to increase the percentage of thrombus **947** being aspirated. In addition, the injection tube **959** can be advanced or retracted, in relation to the catheter. The orifice **981** can be adjusted to an appropriate position inside the aspiration lumen **965**, or even slightly outside the aspiration lumen **965**. This can be continued until all or at least a clinically significant portion of the thrombus **947** is aspirated. As described, in relation to certain ischemic conditions caused by the thrombus **947**, including stroke, the user can run the fluid from the fluid source **679** through a cooling system, such as a heat exchanger or thermoelectric cooler **951** (FIG. **48**) through which the tubing set **664** can run, and by which the fluid can be cooled. Additionally, an extracorporeal circuit **953** (as in FIG. **62**) can be attached to the tubing set **664**, so that blood removed from the patient (e.g., via a femoral artery, femoral vein, or jugular vein sheath **955**) is added to the fluid form the fluid source **679**, so that there is some oxygenated blood being injected into the space **949**, some which can potentially feed downstream tissue. The cooled fluid (saline, blood, or saline plus blood) can additionally reduce the metabolic demands of the downstream tissue.
[0336] FIGS. **66-69** illustrate a method for treating a patient using the aspiration system **600** of FIG. **48**, but incorporating an aspiration catheter **967** having a translatable injection tube **969**. The aspiration catheter **967** has an elongate shaft **995** having an aspiration lumen **997** with a proximal end **999** and an open distal end **2066**. The translatable injection tube **969** has an injection lumen **2068** having a proximal end **2070** and a distal end **974**. The distal end **974** has a distal orifice **2072**, such that pressurized fluid injected through the injection lumen **2068** exits from the orifice **2072**, as in FIG. **69**. At a high enough injection pressure, the fluid can emanate in a jet. The pump **612** and the peristaltic pump **608** as described in FIG. **48** can be utilized. Turning to FIG. **68** and FIG. **70**, an occluder **976** comprising an elongate shaft **978**, and a handle **980** at its proximal end **984**, has an elastomeric occlusion element **982** coupled to its distal end **986** by a connection member **988**. The occlusion element **982** can comprise a circular ring or a spheroid or ovoid, and be formed of any elastomeric material, such as silicone, or thermoplastic elastomers. The occlusion element **982** has a diameter that is slightly larger than the diameter of the injection lumen **2068**, and is configured to significantly occlude flow distally to its particular longitudinal position within the injection lumen **2068**. The position shown in FIG. **70** shows the occlusion element **982** occluding the injection lumen **2068** at a longitudinal position that is distal to a side orifice **990** in the wall **992** in the

injection tube **969**. Thus, when the occluder **976** is in the position shown in FIGS. **68** and **70**, the orifice **2072** is blocked by the occlusion element **982**, and pressurized fluid flows through the side orifice **990** (curved arrow, FIG. **70**). The connection member **988** can comprise a radiopaque material. A radiopaque marker **994** attached to the injection tube **969** can be viewed on x-ray or fluoroscopy along with the radiopaque connection member **988** to assess the particular relative longitudinal position of the occlusion element **982** with respect to the side orifice **990**. If desired, the radiopaque marker **994** can be located just proximal to the side orifice **990**, though it is shown just distal to the side orifice **990** in FIG. **70**. If the occlusion element **982** is retracted as shown in FIG. **71**, and the occluder **976** removed, as shown in FIG. **69**, injection of fluid through the injection lumen **2068** can exit the orifice **2072**. The size of the side orifice **990** can be made small enough such that, when the occluder **976** is removed, most of the fluid injected exits the orifice **2072**, due to the fact that there is more resistance through the side orifice **990** than through the orifice **2072**. Thus, with the injection tube **969** in a particular longitudinal position in relation the shaft **995**, either injection through the orifice **2072** and into the space **949**, or injection through the side orifice **990** and into the aspiration lumen **997** of the aspiration catheter **967** can be selected, using the occluder **976**.

[0337] FIG. **72** illustrates an additional or alternative embodiment and step, that can be used in conjunction with the systems and steps of FIGS. **66-69**. A blocking member **996** includes an elongate shaft **998**, which can be a larger diameter proximally and a smaller diameter distally. The blocking member **996** also includes a spiral blocking element (or feature) **899** at its distal end and a handle **897** at its proximal end. The blocking member **996** can be constructed of any of the or can include embodiments or features described in relation to blocking members described in the co-owned PCT Pub. No. PCT/US2018/029196 to Incuvate, LLC, filed Apr. 24, 2018 and published Nov. 1, 2018 as WO 2018/200566 A1, which is hereby incorporated by reference in its entirety for all purposes. The blocking element **899** is configured to be placed down the injection lumen **2068** and delivered out of the orifice **2072** and into the space **949**, as shown in FIG. **72**, to catch potential distal emboli, and protect downstream tissue (brain tissue, heart tissue, etc.). In some embodiments, the blocking element **899** can be attached to the distal end of the occluder **976**, so that they are combined into a single component. Thus, the occluding described in relation to FIGS. **68-71** can occur along with the distal protection/blocking described in relation to FIG. **72**.

[0338] An alternative mode of using the aspiration system **1400′** of FIG. **38** is shown in FIG. **73**. The controller **1484** is programmed or programmable to command the peristaltic pump **1408** to operate bidirectionally, such that the rotatable head **1430** rotates in a back-and-forth manner, as shown in double-ended, curved arrow **1701**. The back-and-forth rotation can create a “regurgitate” mode for thrombus that has been pulled into the aspiration lumen **1404′** of the aspiration catheter **1402′**. The controller **1484** can also be configured to shut down the pump **1412** while the peristaltic pump **1408** is in the “regurgitate” mode. The automatic cycling, by continual reversal of the motor, for example, allows the thrombus to be further macerated by the repetitive pulling and pushing cycles. The controller **1484** can be configured to perform a certain number of cycles and then to switch back to the aspiration direction (first rotational direction **1436** of FIG. **38**) to fully remove the thrombus.

[0339] Using FIG. **36** as an example, but applying the description globally, in any of the embodiments described utilizing the peristaltic pump **1408**, an alternative operation mode is possible, wherein the peristaltic pump **1408** can be run backwards (opposite of the first rotational direction **1436**), so that it is causing at least some of the fluid within the extension tubing lumen **1444** and/or the aspiration lumen **1404** of the aspiration catheter **1402** to be injected out of the open distal end **1405** of the aspiration lumen **1404**. For example, if the aspiration catheter **1402** is removed from the patient, material (thrombus, emboli, other clogged material) can be emptied out the open distal end **1405**, prior to reusing the aspiration catheter **1402**. In another use, with the aspiration catheter **1402** inside the vasculature, the proximal end **1442** of the extension tube **1438**

can be placed into a container filled with contrast media or a lytic drug, or other drug, the peristaltic pump **1408** can then be run backwards to inject the contrast media, or drug into the vasculature of the patient. Thus, an additional injection site or the detaching of a luer connection is not required.
[0340] In another alternative operation mode, the peristaltic pump **1408** is stopped, or caused to be stopped by the controller **1484**, and a lytic drug is used as the fluid source **1479**. The pump **1412** is then used for pulsing lytic into the patient's vasculature (e.g., at or near a thrombus) through the open distal end **1405** of the aspiration lumen **1404**, via the high pressure injection lumen **1410** of the tube **1478**. By shutting off the peristaltic pump **1408**, the injection through the injection lumen **1410** (and out the orifice **1474**) allows the lytic drug to be sent out the open distal end **1405**, into the vasculature of the patient.
[0341] FIG. **75** illustrates an aspiration system **2400** comprising an aspiration catheter **2402** comprising an elongate shaft **2401** including an aspiration lumen **2404** having an open distal end **2405** and a proximal end **2406** configured to couple to a peristaltic pump **2408**. The peristaltic pump **2408** is a roller pump having a base **2426**, a pressure shoe **2428** carried by the base **2426**, and a rotatable head **2430**, rotatably coupled to the base **2426**, and carrying two or more rollers **2432***a-d*. The rollers **2432***a-d* are arrayed around a perimeter **2434** of the rotatable head **2430**. The rotatable head **2430** is configured to be rotatable in at least a first rotational direction **2436** with respect to a rotational axis **2499**. The rotatable head **2430** can be rotated by a motor **2497**, either directly, or with a gear train **2495**. The peristaltic pump **2408** can be battery powered, and the battery (ies) can be rechargeable by wired or wireless means. The peristaltic pump **2408** can alternatively, or additionally be powered by a power cord **2493** configured to connect to a power supply. An extension tube **2438** having a distal end **2440** and a proximal end **2442**, and having a lumen **2444** extending therethrough, is hydraulically coupled to the proximal end **2406** of the aspiration lumen **2404** via a connector **2424**. The extension tube **2438** can be supplied (e.g., sterile) with the aspiration catheter **2402**, or can be packaged and supplied separately. A Touhy-Borst seal **2446** is couplable and decouplable to the connector **2424** (e.g., via luer connections **2750**, **2752**) and is configured to be loosened/opened to allow the insertion of a guidewire **2448** through the connector **2424** and the aspiration lumen **2404**. The aspiration lumen **2404** can thus be used to track the aspiration catheter **2402** over the guidewire **2448** through a subject's vasculature. The Touhy-Borst **2446** can be tightened to seal over the guidewire **2448**, to maintain hemostasis. Other types of seals can be incorporated in place of the Touhy Borst **2446**, including a spring-loaded, longitudinally compressible and actuatable seal. The distal end **2440** of the extension tube **2438** is slipped over a first barb fitting **2754** of a y-connector **2756**. A second extension tube **2760** has a distal end **2761** that is slipped over a second barb fitting **2758** of the y-connector **2756**. A third extension tube **2762** has a proximal end **2763** that is slipped over a third barb fitting **2764** of the y-connector **2756**. The second extension tube **2760** and third extension tube **2762** are configured to operate under negative pressure without collapsing, and can comprise standard suction tubing. A distal end **2765** of the third extension tube **2762** is coupled to a female luer **2452** sideport of the connector **2424**, either permanently by molding, or an adhesive bond or weld, or by an attachable and detachable connection, such as a luer **2766**. The lengths of each of the second extension tube **2760** and third extension tube **2762** can be varied. In some embodiments, the third extension tube **2762** is relatively short, and the y-connector **2756** is configured to be located in a sterile area near the patient. In other embodiments, the third extension tube **2762** is configured to be relatively long, and the y-connector **2756** is configured to be located in a non-sterile area, away from the patient. The second extension tube **2760** is optional, as the third extension tube **2762** can have a much longer length and the pressure transducer **2416**/aspiration monitoring system **2414** can be attached directly to the y-connector **2756** at the location of the barb fitting **2758**. This connection can be direct, and so the barb fitting **2758** is also optional. With the longer third extension tube **2762**, the y-connector **2756** and the aspiration monitoring system **2414** can both be close to a pump **2412**, and can both reside in a non-sterile area. In some embodiments, the pressure transducer **2416** of the

aspiration monitoring system **2414** can reside in-line with the extension tube **2438**. For example, between the peristaltic pump **2408** and the aspiration catheter **2402**.

[0342] In use, a compressible portion **2437** of the extension tube **2438** is placed within the pressure shoe **2428** of the peristaltic pump **2408** such that rotation of the rotatable head **2430** in the rotational direction **2436** causes fluid to be forced through the lumen **2444** of the extension tube **2438** from the distal end **2440** to the proximal end **2442**, via compression of the compressible portion **2437** by the rollers **2432**, one at a time. Optionally, an interface **2456** on the peristaltic pump **2408** is configured to allow a user to input information or commands to the peristaltic pump **2408** or other components of the system **2400**. Otherwise, hardware or firmware can be pre-programmed with specific run parameters (motor speed, rotation speed, etc.). In some embodiments, there are only two rollers **2432**. In other embodiments, there are three rollers **2432**. In still other embodiments, as shown, there are four rollers **2432**. As described, the rollers **2432** can be replaced by bumps or protrusions. The compressible portion **2437** can comprise silicone tubing, polyurethane tubing, polyvinyl chloride tubing, or other compressible tubing. The compressible section **2437** can be a relatively short section that is attachable to and detachable from the peripheral ends of the extension tube **2438**, or in other embodiments, can comprise the entirety of the extension tube **2438** between the distal end **2440** and the proximal end **2442**. The proximal end **2442** of the extension tube **2438** can be coupled to a hub **2457** of a canister **2458** having an interior **2460**, to allow fluid **2459** passing through the extension tube **2438** to pass into the interior **2460**. An additional hub **2462** in the canister **2458** can be left open (as shown) to allow the unfilled interior **2460** to match atmospheric pressure. Alternatively, the canister **2458** can be replaced by a bag, such as an empty infusion bag, configured for collecting aspirate therein.

[0343] The aspiration catheter **2402** additionally has a high pressure injection lumen **2410** for injecting saline from a pump **2421** comprising a syringe **2466**, for example, via a high pressure pump **2412**. The high pressure pump **2412** comprises a power injector having a motor **2479** configured to drive a lead screw **2468**. In some embodiments, the motor **2479** is configured to drive the lead screw **2468** in a clockwise direction and in a counter-clockwise direction. The lead screw is coupled to a plunger **2489** within the syringe **2466**. The syringe **2466** has a large bore **2491**, and a large internal volume, and the motor **2479** is configured to enable large torques to generate high injection pressures within the syringe **2466**. In some embodiments, the pump **2421** and the peristaltic pump **2408** can be housed within a single enclosure. In some embodiments, the pump **2412** and the peristaltic pump **2408** can be housed within a single enclosure. In some embodiments, the pump **2412**, pump **2421**, and the peristaltic pump **2408** can be housed within a single enclosure.

[0344] A tubing set **2464** is coupled to the syringe **2466**. The pump **2412** includes a controller **2484** configured to vary the speed of the motor **2479** in an oscillating or variable manner to force the saline (flow) in an oscillating or variable manner through the injection lumen **2410** of the aspiration catheter **2402**. In some embodiments, a controller **2484** is configured to operate the motor **2479** at a first motor speed at an initiation of a first injection cycle and to then adjust to a second motor speed at a time within five seconds to two minutes from the initiation of the first injection cycle, the second motor speed lower than the first motor speed. Thus, a general performance target can be quickly reached, and then adjusted to be maintained. In some embodiments, the first motor speed is between 1.5 and 3.5 times greater than the second motor speed. In some embodiments, the first motor speed is between 2 and 3 times greater than the second motor speed. In some embodiments, the first motor speed is 3.5 times to 20 times greater than the second motor speed, or 8 times to 12 times greater, or 9 to 11 times greater. In some embodiments, the second motor speed is configured to act as the main motor speed throughout the first injection cycle. Thus, the initiation of injection at the first motor speed quickly brings the injection to the chosen performance parameters and/or primes the system, and the change to the second motor speed serves to maintain these parameters, and to minimize overshoot. In some embodiments, after the motor speed is brought to the second, lower speed, the oscillation of the flow can be initiated. The tubing set **2464** further has a distal end

2470 (which can include a male luer) which is configured to hydraulically couple to the injection lumen **2410** via a female luer **2472**. In use, injected saline is forced through the injection lumen **2410** by the pump **2412** and exits an orifice **2474** at a distal end **2476** of the injection lumen **2410**. The injection lumen **2410** can extend within a separate tube **2478** (injection tube) that is substantially entirely within the shaft **2401**. In some embodiments, the tube **2478** is attached to the internal wall of the shaft **2401** only at a distal end portion **2403**. The injection tube **2410** can also be attached to the shaft **2401** at its proximal end. Thus, the free-floating nature of the remainder of the tube **2478** within the aspiration lumen **2404** or within the majority of the aspiration lumen **2404** increases the flexibility and trackability of the shaft **2401**. The high pressure saline is forced through the injection tube **2478** and out the orifice **2474**, causing a variable or oscillating (flow rate or flow velocity). The jet is aimed within the aspiration lumen **2404**, just proximal the open distal end **2405** which can create a Venturi effect that forces blood or thrombus that is external and adjacent the open distal end **2405** into the aspiration lumen **2404**. The combination of the operation of the peristaltic pump **2408** and the jet created by the high pressure saline cause the maceration of thrombus, and the movement/flow of material (saline/blood/macerated thrombus/small pieces of thrombus) through the aspiration lumen **2404** from the open distal end **2405** to the proximal end **2406**, through the female luer **2452** of the connector **2424**, and through the lumen **2444** of the extension tube **2438** from its distal end **2440** to its proximal end **2442**, and finally into the interior **2460** of the canister **2458**. Thus, thrombus within a blood vessel of a subject can be macerated and removed by use of the system **2400**. Blood vessels can include peripheral blood vessels, coronary blood vessels, or blood vessels within the head or neck of the subject, including carotid arteries or cerebral arteries.

[0345] Variability in injection flow rate, flow velocity, and/or flow back pressure of the jet can provide a high maximum shear rate, to break up and macerate thrombus or other material, but without the injection of too high a volume of saline (or other fluid). Thus, the saline can be saved, and will not need to be changed as frequently, nor will the cost be as high. In some cases, a disrupted, non-laminar flow can be created by the variability and the higher maximum shear rate, and can serve to keep the lumens of the devices and tubing patent and flowing. Furthermore, larger pressure gradients can be achieved, allowing for a higher likelihood of the initiation of thrombus in a blood vessel to be pulled or forced into the open distal end **2405** of the aspiration lumen **2404** of the aspiration catheter **2402**.

[0346] An aspiration monitoring system **2414** comprising a pressure transducer **2416** can be coupled, for example, proximal to the connector **2424** and/or proximal to the proximal end **2406** of the aspiration lumen **2404** of the aspiration catheter **2402**, such that the pressure transducer **2416** is hydraulically coupled to the aspiration lumen **2404**. In the aspiration system **2400** of FIG. **75**, the aspiration monitoring system **2414** is spaced a distance from the y-connector **2756** by a relatively long second extension tube **2760** (or alternatively by a relatively long third extension tube **2762**, as in the aspiration system **2100** of FIG. **74**) such that the aspiration monitoring system **2414** resides in a non-sterile area. Thus, the aspiration monitoring system **2414** can be set up, prepped, calibrated, and operated by a technologist, sales representative, nurse, or other medical personnel that has not “scrubbed” and thus does not need to maintain sterility. For example, the aspiration monitoring system **2414** can be located near the pump **2412**, or on the same table as the pump **2412**. The aspiration monitoring system **2414** can include any of the features described in relation to the other aspiration monitoring systems **48**, **62**, **78**, **900**, **1216**, **1270**, **1414** disclosed herein. Signals from the pressure transducer **2416** are carried on an electric cable **2480** to an input **2482** of the pump **2412**. As described, the controller **2484** within the pump **2412** is configured to control the operation of the pump **2412**, including motor **2479**, but the controller **2484** can also be configured to control the operation of the peristaltic pump **2408**, via a cable **2486**, or wirelessly. The controller **2484** can comprise a microcontroller. The controller **2484** can alternatively be located within the peristaltic pump **2408**, or can be located at another location. Control using signals of measured

pressure from the pressure transducer **2416** adds an additional safety element to the system **2400**. Additionally, a non-functional device (because of a leak, incomplete connection, incomplete priming, rupture, blockage) can be quickly identified. Unallowably high pressures can also be quickly identified, protecting the motor **2479** of the pump **2412** from burnout or overheating danger. The integrity of the tube **2478** is also protected, e.g., avoiding unnaturally high pressures that could lead to burst.

[0347] The in the aspiration catheter **2402**, the female luer **2452** is located distally on the connector **2424** from the female luer **2472**. Thus, aspirated blood/thrombus/saline enters the female luer **2452** without ever having to contact interior irregularities **2425** (in geometry, shape) within the connector **2424**, that can otherwise cause flow resistance, or cause thrombus to catch (e.g., between the tube **2478** and the interior of the connector **2424**.

[0348] A hand switch **2411** comprises an on/off button **2419** pushably carried on a housing **2423**. Signals (e.g., “on” or “off”) from the hand switch **2411** are carried by a cable **2431**, but can alternatively be carried wirelessly (e.g., to the controller **2484**). An additional pressure transducer **2427**, within the lumen **2444** can be utilized to sense the pressure within the lumen **2444**. In some embodiments, the pressure transducer **2427** is built into the hand switch **2411**. Alternatively, the pressure transducer **2416** can be utilized for this purpose. Signals from the transducer **2427** or from the transducer **2416** are carried by the cable **2431** or the cable **2480**, respectively. However, the signals can alternatively by delivered wirelessly. Thus, control of the system **2400** is available to a user who is in proximity to the hand switch **2411**. The hand switch **2411** can be configured to be movable to different locations on and along the extension tube **2438** for the convenience of the user. The control of the system **2400** via the hand switch **2411** can be configured to include turning the pump **2412** on or off, turning the peristaltic pump **2408** on or off, increasing or decreasing the speed of either or both of the pumps **2412**, **2408**, or even controlling the flow oscillator **2420** (introduced further on). Thus, the button **2419** can in some embodiments comprise a plurality of buttons.

[0349] Alternatively, or additionally to the hand switch **2411**, is a foot pedal **2451**. The foot pedal **2451** has a base **2453** and a pedal **2455** that is coupled to the base **2453** and movable or activatable by application of the foot of a user. The pedal **2455** can be spring-loaded and depressible by application of a moment or a compressive force, or can instead comprise a membrane switch. The pedal **2455**, when activated, can in some embodiments toggle on and off, and in other embodiments can be activatable when a force, a pressure, or a moment is applied, and inactivated when the force, pressure, or moment is not applied. A first cable **2461** carries signals from the foot pedal **2451** to pump **2412** via a plug **2465** that is connected to an input jack **2467**. In some embodiments, activation of the pedal **2455** by the foot of a user starts the operation of the pump **2412** and starts the operation of the peristaltic pump **2408** at the same time, as a signal through the first cable **2461** is received by the controller **2484**, which commands the pump **2412** to start and, via the cable **2486**, commands the peristaltic pump **2408** to start. In some embodiments, activation of the pedal **2455** by the foot of a user starts the operation of the peristaltic pump **2408**, and then starts the operation of the pump **2412**, with a slight delay after the peristaltic pump **2408** is started. The delay is useful to assure that some aspiration, or a significant amount of aspiration, is being applied to the aspiration lumen **2404** prior to the injection of pressurized fluid (e.g., saline) through the injection lumen **2410**. Thus, blood vessels or other vasculature in the vicinity of the open distal end **2405** are spared any injection of fluid from a high pressure jet, as it is instead aspirated through the aspiration lumen **2404**, along with thrombus or blood. In some embodiments, the plug **2465** of the foot pedal **2451** can include a resistor **2759**, and the pump **2412** can include an identification circuit **2757** configured to read the resistance value of the resistor **2759**. For example, the resistor **2759** can complete a partial Wheatstone bridge carried on the identification circuit **2757**, such that the pump **2412** can recognize the foot pedal **2451**, and operate accordingly. Alternatively, the resistor **2759** can reside in the foot pedal **2451** itself, instead of the plug **2465**. The cable **2461** can provide

the electrical connection to the resistor **2759** in that particular case. Alternatively, the resistor **2759** can be replaced by an RFID chip that is configured to be powered and read by the identification circuit **2757**.

[0350] In addition, in some embodiments, activation of the pedal **2455** by the foot of a user during the operation of the pump **2412** and the peristaltic pump **2408** stops the operation of the pump **2412** and the operation of the peristaltic pump **2408** at the same time. In other embodiments, a delay can be applied, for example, such that the pump **2412** is stopped, and then the peristaltic pump **2408** is stopped slightly afterwards. The length of the delays described can be between about 0.01 second and about 1.00 second, or between about 0.10 second and about 0.25 second. The operation (on/off) of the pump **2412** and/or peristaltic pump **2408** via the foot pedal **2451** allows hands-free activation, enabling a single user the manipulate the aspiration catheter **2402** and guidewire **2448** with both hands. The location of the foot pedal **2451** can be tactilely found with the foot of the user, while the user maintains visual contact with the patient and/or any monitors, or even other medical personnel. Alternatively, a second cable **2463** carries signals from the foot pedal **2451** directly to the peristaltic pump **2408** via a plug **2469** that is connected to an input jack **2471**. Thus, the operation of the foot pedal **2451** can be configured to control the operation of the peristaltic pump **2408** in embodiments, for example, in which there is no cable **2486**. However, in the embodiment of FIG. **75**, which includes the cable **2486**, the cable **2463** is not required. Alternatively, the controller **2484** is configured to monitor a signal from the pressure transducer **2416**, and initiate the injection (e.g., through the pump **2421**) when a particular threshold negative pressure is indicated from the pressure transducer signal. The controller **2484** can be further configured or programmed to shut the entire system down, if the threshold negative pressure is not sensed within a particular amount of time (e.g., 1 to 3 seconds, 1.5 to 2.5 seconds, etc.). In these cases, the user can be notified visually, audibly, or tactily: “no suction.”

[0351] In other embodiments, the foot pedal **2451** can be replaced by another type of switch, including, but not limited to a toggle on/off push button or hand switch, an audio-activated switch (voice activated, clap activated, click activated), an optical switch (beam/light sensor for hand or foot interruption), or any other kind of switch that can be activated by medical personnel. The switch can be remote (e.g., in a control room) or can be located near the procedural area. The switch can also be a sterile switch or sterilizable for location on a sterile area. As mentioned, in some embodiments, the pressure transducer **2416** of the aspiration monitoring system **2414** can reside in-line with the extension tube **2438**. For example, it can be located between the peristaltic pump **2408** and the aspiration catheter **2402**.

[0352] In some cases, the activation and deactivation (turning on and off) of the aspiration flow applied by the peristaltic pump **2408** on the aspiration lumen **2404** can be done by leaving the peristaltic pump **2408** in a running condition, while the user opens and closes a stopcock **1454** (e.g., FIG. **36**, **39**, or **73**), which can in some embodiments be incorporated into the system **2400** of FIG. **75**. In some embodiments, the controller **2484** controls the initiation of both the peristaltic pump **2408** and the pump **2412** at substantially the same time. In some embodiments, the controller **2484** controls the initiation the peristaltic pump **2408** and, following a particular delay, the initiation of the pump **2412**. The delay can be within the ranges previously described.

[0353] The controller **2484** also monitors and controls several device safety functions, which include over pressure detection, air bubble detection, and vacuum or negative pressure charge. An additional pressure transducer **2415** carried on the connector **2424** monitors pressure (i.e. injection pressure), and senses the presence of air bubbles. Alternatively, or in conjunction, an optical device **2417** can be used to sense air bubbles. In one contemplated embodiment, the pump pressure is proportional to the electric current needed by the pump **2412** to produce that particular pressure. Consequently, if the electric current required by pump **2412** exceeds a preset limit, the controller **2484** will disable the pump **2412** by cutting power to it. Air bubble detection can also be monitored by monitoring the electrical current required to drive the pump **2412** at any particular moment. For

example, the electrical current can be monitored by a transducer. The controller **2484** is configured to calculate an injection pressure based at least in part on the measured electrical current. In order for a pump **2412** to reach high fluid pressures, there should be little or no air (which is highly compressible) present in the pump **2412** or connecting system (including the aspiration lumen **2404** of the aspiration catheter **2402** and the tubing set **2464**). The fluid volume is small enough that any air in the system will result in no pressure being generated at the pump head. A sufficient volume of liquid is needed proximally to flush any finite amount of air through. The controller **2484** monitors the pump **2412** current for any abrupt downward change that can indicate that air has entered the system. If the rate of drop is faster than a preset limit, the controller **2484** will disable the pump **2412** by cutting power to it until the problem is corrected.

[0354] In some embodiments, a fluid level sensor **2473** is carried on the side of the canister **2458** and is configured to sense when the canister **2458** has approached or reached its full level. The fluid level sensor **2473** is configured to output a signal through a cable **2475** that is attached to via an input **2477** (plug/jack) at the pump **2412**. The signal from the fluid level sensor **2473** can be received by the controller **2484** which can be configured to immediately stop the pump **2412** and, via cable **2486**, the peristaltic pump **2408** at the same time, or with a delay therebetween, as previously described. The fluid level sensor **2473** can comprise an optical sensor, and the canister **2458** can have a clear wall, to allow the optical sensor to measure the reflection variations when fluid is not adjacently present or when fluid is adjacently present. Alternatively, the fluid level sensor **2473** can comprise a piezoresistive pressure sensor that is within the volume **2460** of the canister **2458** at the desired height that represents a “full” canister **2458**. Other types of fluid sensors are also contemplated, including floats, strain gauges, laser sensors, ultrasonic sensors, or capacitive sensors. In each of these embodiments, a signal is sent wirelessly or through cable **2475** so that the peristaltic pump **1408** and/or pump **2412** can be shut down when a “full” level is reached.

[0355] In some embodiments, the peristaltic pump **2408** and the pump **2412** are combined into a single console. This allows for a smaller size that can be mounted on a standard IV pole. In some embodiments, a separate flow oscillator **2420** can provide additional variation in flow rate, flow velocity, and/or fluid pressure. In some embodiments, the separate flow oscillator **2420** can provide all of the variation in flow rate, flow velocity, and/or fluid pressure, while the pump **2421** does not. In these particular embodiments, the pump **2421** provides a constant flow rate, flow velocity, pressure differential, one its own, but the flow oscillator **2420** creates the variation or oscillation in flow. Cable **2486***a* can be configured to transfer signals between the controller **2484** and the flow oscillator **2420**, thus allowing the controller **2484** to control the operation of the flow oscillator **2420**. In other embodiments, the controller **2484** is configured to communication with the flow oscillator **2420** (and/or other components) wirelessly.

[0356] FIG. **76** illustrates a detailed view of an injector syringe mechanism **1152** that combines elements similar to the pump **2421** comprising a syringe **2466** and the flow oscillator **2420** of the system **2400** of FIG. **75**. The injector syringe mechanism **1152** is constructed with the required power, and thus is driven by a motor **1124** having an armature **154** and a rotor **196**. The shaft **156** of the motor **1124** is drivingly coupled to a threaded screw shaft **158** for rotation by the motor **1124**. Threadedly engaging shaft **158** is a ball nut **160** which is prevented by pin **162** from rotating, but which is free to move axially along shaft **158**, the pin **162** sliding in a guide slot **164** formed in a guide bar **166** supported in the housing **168** of the injector syringe mechanism **1152**. The axial movement of ball nut **160** in response to rotation of threaded shaft **158** converts the rotary motion of the motor **1124** into linear motion. The ball nut **160** is connected to a piston tube **170** which moves with the ball nut **160** along the shaft **158**. The outer end of the piston tube **170** is supported, during its linear motion, by a seal **172** secured in an opening **174** at one end of housing **168**. The piston tube **170** abuts directly against a piston head support member **176**, which, in turn, provides mechanical support for a rubber piston cap **178**. A syringe barrel, or cartridge, **180** is mounted on

the injector housing **168** by an internally threaded nut **182** adapted to engage external threads on the end of the housing **168**. The nut **182** has a centrally located aperture **184** which receives the barrel **180**, and a seal member **186**, to permit an airtight fitting on the end of the housing **168**. A flanged portion **188** is provided on the end of the barrel **180**, and faces the housing, to facilitate a tight seal between sealing members **174** and **186** when nut **182** is tightened.

[0357] The internal diameter ID of the barrel **180** and the external diameter of piston **176** are selected to provide the clearance required to permit a flanged edge **190** of the rubber piston cap **178** to seal the interior of the syringe. It will be apparent that different sizes of syringes will require pistons having varying diameters, but the construction of this mechanism is such that the various sizes are easily connected to the injector drive mechanism. The aperture **184** in the nut **182** is sufficiently large to permit larger syringes than that illustrated, while by providing smaller diameter syringes with sufficiently large flanges, they can be used with this equipment as well. Piston member **176** and cap **178** can be driven in a forward direction (toward the right as viewed in FIG. **76**) by piston tube **170** without any mechanical connection being made between the piston **176** and the tube **170**. This arrangement is often used where it is essential to prevent reversal of the motion of the piston. Alternatively, piston **176** can be connected to piston tube **170** by means of screws **192**, to permit both forward and reverse driving of the piston **176**. Alternatively, any other type of latching mechanism can be incorporated to achieve the same effect. It will be apparent that forward motion of the piston **176** will expel fluid or any other matter within the barrel **180**, such as saline **194** (or contrast media, or a mixture of saline and contrast media). If the piston **176** is attached to the piston tube **170**, reverse driving can be used to fill the barrel **180**.

[0358] The broken-away portion of motor **1124** illustrates, in addition to armature **154**, the arrangement of the rotor **196**. In operation, direct current is commutated to the armature conductors **1127**, and the resultant alternating magnetic field interacts with the stationary magnetic field(s) of the rotor **196** to produce torque on shaft **156** in the chosen rotational direction (clockwise or counter-clockwise). Gears **198** and **2200** provide a mechanical linkage of known gearing ratio between the motor shaft **156** and tachometer generator **1122**. The tachometer can in some embodiments be electronic, or can be electro-optical.

[0359] The injector syringe mechanism **1152** includes an output **1123** configured to be detachably hydraulically coupled to a proximal end **1133** of a tubing set **2464**. The flow oscillator **2420**, aspiration catheter **2402**, extension (aspiration) tube **2438**, and peristaltic pump **2408** are shown generically in FIG. **76**, but can include any of the embodiments described herein. In the following embodiments of the flow oscillator **2420**, the flow oscillator **2420** can be used in series with the injector syringe mechanism **1152** to provide a variable flow rate, variable flow velocity, and/or variable pressure injection into the tubing set **2464**, and into the high pressure injection lumen **2410** of the aspiration catheter **2402**. The variability can in some embodiments comprise oscillation. In some embodiments, the injector syringe mechanism **1152** provides at least some of the configured variability. In other embodiments, only the flow oscillator **2420** provides the configured variability. The configured variability in either case can also include starting or stopping pumping, or reversing.

[0360] FIGS. **77-78** illustrate a flow oscillator **2420***a* on a tubing set **2464***a*, according to a first embodiment. The flow oscillator **2420***a* comprises a relief valve **2501**. In some embodiments, there can be two or more relief valves **2501**. The tubing set **2464***a* comprises an inflow tube **2500** and an outflow tube **2502**. The inflow tube **2500**, as shown in FIG. **76**, is between the injector syringe mechanism **1152** and the flow oscillator **2420***a*, and hydraulically coupled to each. The outflow tube **2502** is between the flow oscillator **2420***a* and the aspiration catheter **2402**, and hydraulically coupled to each. For example, a distal end **2504** of the inflow tube **2500** is bonded within a counterbore **2506** of a base **2508** of the flow oscillator **2420***a*. A proximal end **2510** of the outflow tube **2502** is bonded within a counterbore **2512** of the base **2508** of the flow oscillator **2420***a*. The ends **2504**, **2510** of the tubes **2500**, **2502** can be adhesively or epoxy bonded, or can be secured

over barb fittings, or other equivalents. The base **2508** of the flow oscillator **2420***a* comprises a main flow passageway **2514** extending from a proximal end **2516** to a distal end **2518** of the base **2508**. Normal injection flow is configured to pass through a lumen **2520** of the inflow tube, through the main flow passageway **2514** of the base **2508** of the flow oscillator **2420***a*, and through a lumen **2522** of the outflow tube **2502** (dashed arrows).

[0361] An inlet nozzle **2524** extends from a bifurcation **2526** transversely to the flow path (dashed arrows) of the flow passageway **2514**. A valve seat **2528** is held by a holder **2530** valve seat shaft **2532**. A compression spring **2533** is carried around the shaft **2532** and abuts a first stop **2535** on the shaft **2532** and a second stop **2537** within the interior **2529** of a bonnet **2531** that extends from the base **2508**. The valve seat **2528** is shown sealed over an aperture **2534** of the inlet nozzle **2524** in FIG. **77**, and is shown in an open condition in FIG. **78**, where it is not sealed over the aperture **2534**. The spring is selected and/or adjusted, such that a desired release pressure R.sub.P is coordinated. When the pressure P.sub.1 is below the release pressure R.sub.P, the spring **2533** maintains the valve seat **2528** in a sealing position over the aperture **2534**. When the pressure P.sub.2 is increased to or above the release pressure R.sub.P, the spring **2533** compresses sufficiently such that there is an opening of the valve seat **2528** in relation to the aperture **2534**. See solid arrows in FIG. **78** which show excess fluid passing through a bypass passage **2536**. The interior **2529** of the bonnet **2531** is sealed from the rest of the interior of the base **2508** by a structural seal **2538**, which also can help to maintain a concentric relationship of the shaft **2532** and valve seat **2528** with the interior **2529** of bonnet **2531**, and thus the aperture **2534**. The top end **2540** of the shaft **2532** is able to longitudinally translate within a cap **2542** carried on the bonnet **2531**. The shaft **2532** moves through a hole **2544** at the end of the bonnet **2531**. In some embodiments, a user can remove the cap **2542** and manipulate the top end **2540** of the shaft **2532** (e.g., by turning it, unscrewing it, screwing it in, etc.) to adjust the effective spring constant of the spring **2533**, and thus dial in a different (lower or higher) release pressure R.sub.P.

[0362] In a flow system in which the serial flow resistance due to the lumen **2522** of the outflow tube **2502** and the high pressure injection lumen **2410** of the aspiration catheter **2402** is lower than a critical flow resistance, the flow oscillator **2420***a* will not significantly cause a variable pressure or variable flow rate (or flow velocity). Instead, a constant flow rate output by the injector syringe mechanism **1152**, when increased, will reach a maximum, when the pressure in the flow oscillator **2420***a* is equal to the release pressure R.sub.P of the relief valve. However, in a high resistance, high velocity jet system, such as an injection-assisted thrombectomy aspiration catheter, such as the aspiration catheter **2402**, the flow oscillator **2420***a* will oscillate as the valve opens and closes, above and below, respectively, the release pressure R.sub.P of the relief valve. The oscillation of the pressure and the resulting flow through the high pressure injection lumen **2410** can be adjusted by a user such that it has a frequency that is effective in optimizing an aspiration (e.g., thrombectomy) procedure. In some embodiments, this comprises a 3-8 Hz oscillation. In some embodiments, this comprises a 4-7 Hz oscillation. In some embodiments, this comprises a 5-6 Hz oscillation. In some embodiments, this comprises a 5 Hz oscillation. In some embodiments, the oscillation is sinusoidal, but in others is can be “clipped” or “pinned” in shape. The relief valve **2501** can be configured to cause the clipping or pinning, e.g., at the maximum of the injection pressure curve.

[0363] FIGS. **79-81** illustrate a flow oscillator **2420***b* on a tubing set **2464***b*, according to a second embodiment. The flow oscillator **2420***b* comprises a proportional solenoid **2546**. The tubing set **2464***b* comprises an inflow tube **2548** and an outflow tube **2550**. The inflow tube **2548**, is between the injector syringe mechanism **1152** and the flow oscillator **2420***b*, and hydraulically coupled to each. The outflow tube **2550** is between the flow oscillator **2420***b* and the aspiration catheter **2402**, and hydraulically coupled to each. For example, a distal end **2552** of the inflow tube **2548** is bonded within a counterbore **2554** of a base **2556** of the flow oscillator **2420***b*. A proximal end **2558** of the outflow tube **2550** is bonded within a counterbore **2560** of the base **2556** of the flow

oscillator **2420***b*. The ends **2552**, **2558** of the tubes **2548**, **2550** can be adhesively or epoxy bonded, or can be secured over barb fittings, or other equivalents. The base **2556** of the flow oscillator **2420***b* comprises a first main flow passageway **2562***a* extending from a proximal end **2564** to a central portion **2566** of the base **2556**, and a second main flow passageway **2562***b* extending from the central portion **2566** to a distal end **2568** of the base **2556**. Normal injection flow is configured to pass through a lumen **2570** of the inflow tube, through the first main flow passageway **2562***a* of the base **2556** of the flow oscillator **2420***b*, through the central portion **2566**, and through a lumen **2572** of the outflow tube **2550**. The central portion **2566** comprises a first transverse passage **2574**, a second transverse passage **2576**, and a connecting space **2578**.

[0364] A side projection **2580** includes a transverse cavity **2582** in which a solenoid valve **2584** is slidably contained. The solenoid valve **2584** is connected to a linearly actuatable shaft **2586** that is electromagnetically actuated by a solenoid **2588**. A stop **2590** in the central portion **2566** represents the fully closed position at which the sealing end **2592** of the solenoid valve **2584** stops and fully seals off the first main flow passageway **2562***a* from the second main flow passageway **2562***b*. FIG. **79** illustrates the proportional solenoid **2546** in the fully closed (sealed) position. In this position there is no flow proceeding from the first transverse passage **2574** to the second transverse passage **2576**, because the connecting space **2578** is completely blocked by the sealing end **2592** of the solenoid valve **2584**. FIG. **80** illustrates the proportional solenoid **2546** in the partially close position. In this position, there is flow from the first transverse passage **2574** to the second transverse passage **2576**, but there is some flow resistance at the connecting space **2578**, due to its decreased space height. FIG. **81** illustrates the proportional solenoid **2546** in the fully open position. In this position, there is flow from the first transverse passage **2574** to the second transverse passage **2576**, with the least amount of resistance, because the connecting space **2578** is at its maximum space height.

[0365] The controller **2484** is configured to apply a variable (e.g., sinusoidal) voltage/current at the proportional solenoid **2546**, causing the solenoid valve **2584** to slide up and down in a variable manner with the changes in voltage/current, opening and closing the connecting space **2578**. In other configurations, the controller **2484** causes a variable operation of the proportional solenoid **2546** between the configuration of FIG. **80** and the configuration of FIG. **81**, avoid the fully closed configuration of FIG. **79**. In some embodiments, the controller **2484** causes a variable operation of the proportional solenoid **2546** between a first partially open configuration and a second partially open configurations. The resulting variable or oscillatory flow rate, flow velocity, and/or pressure delivers a variable jet in the aspiration catheter **2402**. The flow path is from the lumen **2570**, through the first main flow passageway **2562***a*, through the first transverse passage **2574**, through the connecting space **2578**, through the second transverse passage **2576**, through the second main flow passageway **2562***b*, and through the lumen **2572**. Then, the fluid is injected through the high pressure injection lumen **2410**, where its exits as a jet into the aspiration lumen **2404** of the aspiration catheter **2402**. The controller **2484** can be configured to receive a signal from the pressure transducer **2415**, or any pressure transducer that is hydraulically coupled to the system, for example to the lumen of the tubing set **2464***b*.

[0366] The proportional solenoid **2546** can be configured to electrically adjust at a controlled frequency. The oscillation of the pressure and the resulting flow through the high pressure injection lumen **2410** can be adjusted by a user such that it has a frequency that is effective in optimizing an aspiration (e.g., thrombectomy) procedure. In some embodiments, this comprises a 3-8 Hz oscillation. In some embodiments, this comprises a 4-7 Hz oscillation. In some embodiments, this comprises a 5-6 Hz oscillation. In some embodiments, this comprises a 5 Hz oscillation.

[0367] FIG. **82** illustrates a block diagram of the injector syringe mechanism **1152** and flow oscillator **2420***b*/tubing set **2464***b* of FIGS. **76** and **79-81**. In this embodiment, the flow oscillator **2420***b* comprises an iQ Valve, proportional solenoid **2546** (Melbourne, Florida, USA). A microvalve **2594** is coupled to the iQ Valve **2546** to control a leak rate (e.g., into the atmosphere

2595). This in turn determines the actual pressure drop in the system. A pressure transducer **2415** and catheter **2402** are also illustrated.

[0368] FIGS. **83-84** illustrate a flow oscillator **2420***c* on a tubing set **2464***c*, according to a third embodiment. The flow oscillator **2420***c* comprises a tubing pincher **2600** or compressor. The tubing set **2464***c* comprises compressible tubing **2602**, at least at the portion that extends through the tubing pincher **2600**. The tubing **2602**, is between the injector syringe mechanism **1152** and the aspiration catheter **2402**, and hydraulically coupled to each. The pincher **2600** comprises a first pinch rod **2604** and a second pinch rod **2606**. The pinch rods **2604**, **2606** each extend transversely to a pincher body **2608**. The tubing **2602** of the tubing set **2646***c* is configured to be placed between the first pinch rod **2604** and the second pinch rod **2606**. At least the first pinch rod **2604** is configured to be moveable by and internal motor or other mechanism **2610** to be moved along a y-axis in a positive and negative direction. The controller **2484** is configured to cause the first pinch rod **2604** to move sinusoidally back-and-forth, in a positive Y and negative Y direction. The rods **2604**, **2606** are attached to connectors **2612**, **2614** that are coupled to the body **2608**. FIG. **83** illustrates the tubing **2602** in place between the pinch rods **2604**, **2606** in the open, uncompressed position. The first pinch rod **2604** and its connector **2612** are moveably coupled to the body **2608** (upper arrow in FIG. **84**). In some embodiments the second pinch rod **2606** is attached statically to the body **2608** (as in FIG. **84**), and in other embodiments can also be moveable in relation to the body **2608** (alternative double arrow in FIG. **84**). FIG. **84** illustrates the first pinch rod **2604** after having been moved by the motor/mechanism **2610** to a position that almost occludes the tubing **2602**, but does not completely occlude the tubing. Thus, below a particular threshold fluid viscosity, the oscillation between the position of FIG. **83** and the position of FIG. **84** produces a non-clipped pressure wave to the fluid injected by the injector syringe mechanism **1152**. In other embodiments, a clipped (on the high end) pressure wave can instead be created. In some embodiments, the oscillation comprises a 3-8 Hz oscillation. In some embodiments, it comprises a 4-7 Hz oscillation. In some embodiments, it comprises a 5-6 Hz oscillation. In some embodiments, it comprises a 5 Hz oscillation

[0369] In some embodiments, the hand switch **2411**, or the foot pedal **2451**, or any other switch coupled to the pump **2421**/syringe **2466** an be configured to change the effect of the injection of fluid from an oscillating manner to a non-oscillating manner. In some embodiments, the foot pedal **2451**, or any other switch coupled to the pump **2421**/syringe **2466**, can be configured to change the effect of the injection of fluid from a non-oscillating manner to an oscillating manner. In some embodiments, the foot pedal **2451**, or any other switch coupled to the pump **2421**/syringe **2466** can be configured to change the effect of the injection of fluid from an oscillating manner to a damped oscillating manner, e.g., having damped or pseudo-damped oscillation. A pseudo-damped oscillation can be constructed and simulated by maintaining the frequency of the change in screw direction (counter-clockwise to clockwise and vice versa), but slowly decreasing the total number of turns of the screw in each direction while also decreasing the average and maximum rotational speed of the screw in each direction. The effect is a pressure wave that has an unchanged frequency, but a lower pressure differential amplitude. In some embodiments, the oscillation of the injection of the pump **2421**/syringe **2466** comprises a 3-8 Hz oscillation. In some embodiments, it comprises a 4-7 Hz oscillation. In some embodiments, it comprises a 5-6 Hz oscillation. In some embodiments, it comprises a 5 Hz oscillation. In some embodiments, the oscillation is sinusoidal, but in others is can be “clipped” or “pinned” in shape.

[0370] Though not intended to be limiting, in some embodiments, the injection pressure of the pump **2421**/syringe **2466** can oscillate within a range that is between about 200 psi (13.6 atmospheres) and about 1500 psi (102.1 atmospheres). In some embodiments, the injection pressure of the pump **2421**/syringe **2466** can oscillate within a range that is between about 600 psi (40.8 atmospheres) and about 800 psi (54.4 atmospheres). In some embodiments, the injection pressure of the pump **2421**/syringe **2466** can oscillate within a range that is between about 600 psi

(40.8 atmospheres) and about 700 psi (47.6 atmospheres), or that is between about 700 psi (47.6 atmospheres) and about 800 psi (54.4 atmospheres). In some embodiments, the injector is configured to pressurize the liquid such that the flow rate varies between about 20 ml/min and about 45 ml/min, or about 31 ml/min.

[0371] The flow oscillator **2420***b* of FIGS. **79-81** and the flow oscillator **2420***c* of FIGS. **83-84** can be configured so that occlusion and/or compression can never reach a "completely closed" state. In the case of the flow oscillator **2420***b*, this can be achieved mechanically, by the abutment **2413** shown in FIG. **85**, that stops the solenoid valve **2584** from closing completely. The completely closed state can also be avoided by precision control of the controller **2484**. Similar mechanical and/or electronic (controller) control can be maintained on the flow oscillator **2420***c*. In other embodiments, the tubing **2602** can comprise a highly compliant portion upstream (between the flow oscillator **2420***c* and the pump **2421**), so that a temporary occlusion of the tubing **2602** caused by the pinch rods **2604**, **2406** causes a temporary increase in interior volume of the tubing **2602**, thus avoiding a catastrophic pressure increase.

[0372] FIG. **86** illustrates an aspiration system **2300** comprising an aspiration catheter **2302** comprising an elongate shaft **2301** including an aspiration lumen **2304** having an open distal end **2305** and a proximal end **2306** configured to couple to a peristaltic pump **2308**. The aspiration lumen **2304** is similar to the aspiration lumen **2404** of the aspiration catheter **2402** of FIG. **75**. The peristaltic pump **2308** is a roller pump having a base **2326**, a pressure shoe **2328** carried by the base **2326**, and a rotatable head **2330**, rotatably coupled to the base **2326**, and carrying two or more rollers, as shown in FIG. **75** (rollers **2432***a-d*). The rollers are arrayed around a perimeter of the rotatable head **2330**. The rotatable head **2330** is configured to be rotatable in at least a first rotational direction **2336** with respect to a rotational axis. The rotatable head **2330** can be rotated by a motor **2397**, either directly, or with a gear train. The peristaltic pump **2308** can be battery powered, and the battery (ies) can be rechargeable by wired or wireless means. The peristaltic pump **2308** can alternatively, or additionally be powered by a power cord **2393** configured to connect to a power supply **2332**. An extension tube **2338** having a distal end **2340** and a proximal end **2342**, and having a lumen **2344** extending therethrough, is hydraulically coupled to the proximal end **2306** of the aspiration lumen **2304** via a connector **2324**. The extension tube **2338** can be supplied (e.g., sterile) with the aspiration catheter **2302**, or can be packaged and supplied separately. In the embodiment shown in FIG. **86**, the extension tube **2338** comprises a sterile portion **2338***a* and a non-sterile portion **2338***b*. A proximal end of the sterile portion **2338***a* comprises a connector **2388** and a distal end of the non-sterile portion **2338***b* comprises a connector **2390**. Connector **2388** is configured to hydraulically couple to connector **2390**. In alternative embodiments, the connectors **2388**, **2390** can be replaced by a tube-to-barb connection. A Touhy-Borst seal **2346** is couplable and decouplable to the connector **2324** (e.g., via luer connections) and is configured to be loosened/opened to allow the insertion of a guidewire **2348** through the connector **2324** and the aspiration lumen **2304**. The aspiration lumen **2304** can thus be used to track the aspiration catheter **2302** over the guidewire **2348** through a subject's vasculature. The Touhy-Borst **2346** can be tightened to seal over the guidewire **2348**, to maintain hemostasis. Other types of seals can be incorporated in place of the Touhy Borst **2346**, including a spring-loaded, longitudinally compressible and actuatable seal. The distal end **2340** of the extension tube **2338** is slipped over a first barb fitting **2354** of a sideport **2352** of the connector **2324**. A second extension tube **2363** has a distal end **2361** that is slipped over a second barb fitting **2365** of the connector **2324** and a proximal end **2367**. The extension tube **2338** is configured to operate under negative pressure without collapsing, and can comprise standard suction tubing.

[0373] In use, a compressible portion **2337** of the extension tube **2338** is placed within the pressure shoe **2328** of the peristaltic pump **2308** such that rotation of the rotatable head **2330** in the rotational direction **2336** causes fluid to be forced through the lumen **2344** of the extension tube **2338** from the distal end **2340** to the proximal end **2342**, via compression of the compressible

portion **2337** by the rollers, in sequence. Optionally, a user interface **2356** on the peristaltic pump **2308** is configured to allow a user to input information or commands to the peristaltic pump **2308** or other components of the system **2300**. Otherwise, hardware or firmware can be pre-programmed with specific run parameters (motor speed, rotation speed, etc.). In some embodiments, there are only two rollers. In other embodiments, there are three rollers. In still other embodiments, as shown, there are four rollers. In other embodiments, the rollers can be replaced by bumps or protrusions. The compressible portion **2337** can comprise silicone tubing, polyurethane tubing, polyvinyl chloride tubing, or other compressible tubing. The compressible section **2337** can be a relatively short section that is attachable to and detachable from the peripheral ends of the extension tube **2338** (e.g., non-sterile portion **2338***b*), or in other embodiments, can comprise the entirety of the non-sterile portion **2338***b*, or even the entirety of the extension tube **2338** between the distal end **2340** and the proximal end **2342**. The proximal end **2342** of the extension tube **2338** is configured to be coupled to a hub **2357** of a canister **2358** having an interior **2360**, to allow fluid passing through the extension tube **2338** to pass into the interior **2360**. An additional hub **2362** in the canister **2358** can be left open (as shown) to allow the unfilled interior **2360** to match atmospheric pressure. Alternatively, the canister **2358** can be replaced by a bag, such as an empty infusion bag, configured for collecting aspirate therein. In some embodiments, a filter can be placed in line with the canister **2358**, to specifically maintain thrombus and collect it, if desired.

[0374] The aspiration catheter **2302** additionally has a high pressure injection lumen **2310** for injecting saline from a pump **2321** comprising a syringe **2366**, for example, via a high pressure pump **2312**. The high pressure injection lumen **2310** is similar to the high pressure injection lumen **2410** of the aspiration catheter **2402** of FIG. **75**. The high pressure pump **2312** comprises a power injector having an electric motor **2379** outputting rotation to a gearhead **2341** (e.g., gearbox), which is configured to change a rotational speed (faster or slower) and/or to change a torque (lower or higher). The output of the gearhead **2341** is configured to indirectly drive a ball nut **2343** (FIGS. **87-88**) over a stationary (non-rotational) ball screw **2368** (e.g., via a belt drive configuration). The ball screw **2368** is shown within the ball nut **2343** by phantom lines, but the ball bearings are not shown. In other embodiments, the ball nut **2343** and the ball screw **2368** can be replaced by a standard nut and leadscrew, or a half-nut and leadscrew. In the embodiment of FIGS. **87-88**, the motor **2379** is configured to drive the ball nut **2343** in a clockwise direction and in a counter-clockwise direction. In other embodiments, the ball nut **2343** can be driven in a single direction. The ball screw **2368** is statically coupled to a plunger **2389** that is sealingly carried within a barrel **2373** of the syringe **2366** and configured to be displaced along a longitudinal displacement path within the bore **2391** of the barrel **2373**. The barrel **2373** of the syringe **2366** has a large bore **2391**, having a large internal volume, and the motor **2379** is configured to enable large torques to generate high injection pressures within the syringe **2366**. In some embodiments, the pump **2321** and the peristaltic pump **2308** can be housed within a single enclosure. In some embodiments, the high pressure pump **2312** and the peristaltic pump **2308** (and the controller **2384**) can be housed within a single enclosure. In some embodiments, the high pressure pump **2312**, pump **2321**, and the peristaltic pump **2308** (and the controller **2384**) can be housed within a single enclosure. The aspiration catheter **2302** is configured to be placed through a guiding catheter, an introducer sheath, or through direct blood vessel puncture. The high pressure pump **2312** can be battery powered, and the battery (ies) can be rechargeable by wired or wireless means. The high pressure pump **2312** can alternatively, or additionally be powered by a power cord **2398** configured to connect to a power supply **2399**.

[0375] A tubing set **2364** is coupled to the syringe **2366**. The high pressure pump **2312** is coupled to a controller **2384** that is configured to vary the speed of the motor **2379** or to turn the motor **2379** on and/or off. The controller **2384** can also be configured to control the motor **2397** of the peristaltic pump **2308** in the same manner (vary speed, turn on, turn off). The high pressure pump **2312** is configured to automatically inject in an oscillating or variable manner to force the saline

(flow) in an oscillating or variable manner through the injection lumen **2310** of the aspiration catheter **2302**. In some embodiments, a controller **2384** is configured to operate the motor **2379** at a first motor speed at an initiation of a first injection cycle and to then adjust the motor **2379** to a second motor speed at a time period within five seconds to two minutes from the initiation of the first injection cycle, the second motor speed lower than the first motor speed. Thus, a general performance target can be quickly reached, and then adjusted to be maintained. In some embodiments, the first motor speed is between 1.5 and 5 times greater than the second motor speed. In some embodiments, the first motor speed is between 3 and 4 times greater than the second motor speed. In some embodiments, the first motor speed is 3.5 times to 20 times greater than the second motor speed, or 8 times to 12 times greater, or 9 to 11 times greater. In some embodiments, the second motor speed is configured to act as the main motor speed throughout the first injection cycle. Thus, the initiation of injection at the first motor speed quickly brings the injection to the chosen performance parameters and/or primes the system, and the change to the second motor speed serves to maintain these parameters, and to minimize overshoot. In some embodiments, after the motor speed is brought to the second, lower speed, the oscillation of the flow can be initiated, or a significant amount of oscillation can be initiated or increased.

[0376] In use, injected saline is forced through the injection lumen **2310** by the high pressure pump **2312** and exits an orifice (e.g., similar to orifice **2474** of FIG. **75**) at a distal end (e.g., distal end **2476** of FIG. **75**) of the injection lumen **2310**. The injection lumen **2310** can extend within a separate tube (injection tube) that is substantially entirely within the shaft **2301**. In some embodiments, the tube is attached to the internal wall of the shaft **2301** only at a distal end portion. The injection tube **2349** can also be attached to the shaft **2301** at its proximal end. Thus, the free-floating nature of the remainder of the tube within the aspiration lumen **2304** or within the majority of the aspiration lumen **2304** increases the flexibility and trackability of the shaft **2301**. The high pressure saline is forced through the injection tube **2349** and out the orifice, causing a variable or oscillating (flow rate or flow velocity). The oscillation is created by a flow oscillator **2420***d* (FIGS. **87**-**88**). The jet is aimed within the aspiration lumen **2304**, just proximal the open distal end **2305** which can create a Venturi effect that forces blood or thrombus that is external and adjacent the open distal end **2305** into the aspiration lumen **2304**. The combination of the operation of the peristaltic pump **2308** and the jet created by the high pressure saline cause the maceration of thrombus, and the movement/flow of material (saline/blood/macerated thrombus/small pieces of thrombus) through the aspiration lumen **2304** from the open distal end **2305** to the proximal end **2306**, through the female luer **2352** of the connector **2324**, and through the lumen **2344** of the extension tube **2338** from its distal end **2340** to its proximal end **2342**, and finally into the interior **2360** of the canister **2358**. Thus, thrombus within a blood vessel of a subject can be macerated and removed by use of the system **2300**. Blood vessels can include peripheral blood vessels, coronary blood vessels, or blood vessels within the head or neck of the subject, including carotid arteries or cerebral arteries.

[0377] Variability in injection flow rate, flow velocity, and/or flow back pressure of the jet can provide a high maximum shear rate, to break up and macerate thrombus or other material, but without the injection of too high a volume of saline (or other fluid). Thus, the saline can be saved, and will not need to be changed as frequently, nor will the cost be as high. In some cases, a disrupted, non-laminar flow can be created by the variability and the higher maximum shear rate, and can serve to keep the lumens of the devices and tubing patent and flowing. Furthermore, larger pressure gradients can be achieved, allowing for a higher likelihood of the initiation of thrombus in a blood vessel to be pulled or forced into the open distal end **2305** of the aspiration lumen **2304** of the aspiration catheter **2302**.

[0378] An optional aspiration monitoring system **2314** comprising a pressure transducer **2316** is coupled, for example, proximal to the connector **2324** and/or proximal to the proximal end **2306** of the aspiration lumen **2304** of the aspiration catheter **2302**, such that the pressure transducer **2316** is

hydraulically coupled to the aspiration lumen **2304**. In the aspiration system **2300** of FIG. **86**, the aspiration monitoring system **2314** is carried on the connector **2324** with the pressure transducer **2316** within the interior of the connector **2324**. The aspiration monitoring system **2314** can include any of the features described in relation to the other aspiration monitoring systems **48**, **62**, **78**, **900**, **1216**, **1270**, **1414**, **2414** disclosed herein. Signals from the pressure transducer **2316** are carried on an electric cable **2380** to an input of the controller **2384**. The controller **2384** is configured to control the operation of the high pressure pump **2312**, including motor **2379**, via a cable **2381**, but the controller **2384** can also be configured to control the operation of the peristaltic pump **2308**, via a cable **2386**, or wirelessly. The controller **2384** can comprise a microcontroller. The controller **2384** can alternatively be located within the peristaltic pump **2308**, or can be located at another location. Control using signals of measured pressure from the pressure transducer **2316** adds an additional safety element to the system **2300**. Additionally, a non-functional device (because of a leak, incomplete connection, incomplete priming, rupture, blockage) can be quickly identified. Alternatively, a pressure sensor can be added to the high pressure pump **2312**, so that unallowably high pressures can also be quickly identified, protecting the motor **2379** of the high pressure pump **2312** from burnout or overheating danger. The integrity of the second extension tube **2363** and of the injection tube **2349** would thus also be protected, e.g., avoiding unnaturally high pressures that could lead to burst.

[0379] The in the aspiration catheter **2302**, the sideport **2352** is located distally on the connector **2324** from the second barb fitting **2365**. Thus, aspirated blood/thrombus/saline enters the sideport **2352** without ever having to contact interior irregularities (in geometry, shape) within the connector **2324**, that can otherwise cause flow resistance, or cause thrombus to catch (e.g., between the injection tube **2349** and the interior of the connector **2324**.

[0380] A hand switch **2311** comprises an on/off button **2319** pushably carried on a housing **2323**. Signals (e.g., “on” or “off”) from the hand switch **2311** are carried by a cable **2331** to the controller **2384**, but can alternatively be carried wirelessly (e.g., to the controller **2384**). A main aspiration monitoring system **2800** comprises a pressure transducer **2801** (FIG. **95**) which is carried by the housing **2323** for fluid contact with the lumen **2344** is utilized to sense the pressure (e.g., negative pressure) within the lumen **2344**. In some embodiments, the pressure transducer **2801** is built into the hand switch **2311**. The pressure transducer **2801** extends through a hole **2803** in the wall **2804** of the sterile portion **2338***a* or the extension tube **2338**. The hole **2803** is in some embodiments sealingly filled with an adhesive, epoxy, or polymer **2806**. Signals from the pressure transducer **2801** are carried by conductive wires **2802** within the cable **2331** to the controller **2384**. However, the signals can alternatively by delivered wirelessly. Thus, control of the system **2300** is available to a user who is in proximity to the hand switch **2311**. The hand switch **2311** is carried on the sterile portion **2338***a*, and is also provided sterile. The user can thus include a user that has “scrubbed” for a procedure. The hand switch **2311** is secured around the extension tube **2338** with a sheath **2805** that is sealed around the exterior of the extension tube **2338**. In some embodiments, the sheath **2805** comprises shrink tubing. The hand switch **2311** can be configured to be located at different locations on and along the extension tube **2338** for the convenience of the user. The control of the system **2300** via the hand switch **2311** can be configured to include turning the high pressure pump **2312** (e.g., motor **2379**) on or off, turning the peristaltic pump **2308** (e.g., motor **2397**) on or off, increasing or decreasing the speed of either or both of the pumps **2312**, **2308**, or even controlling the flow oscillator **2420***d*. The button **2319** can in some embodiments comprise a plurality of buttons or other types of controls. Alternatively, or additionally to the hand switch **2311**, a foot pedal, similar to the foot pedal **2451** of FIG. **75**, can be utilized, having any or all of the structure and functionality of the foot pedal **2451**. The controller **2384** can include any or all of the structure and functionality of the controller **2484** of FIG. **75**. The pressure transducer **2801** is thus part of the main aspiration monitoring system **2800**, which can include any of the features described in relation to the other aspiration monitoring systems **48**, **62**, **78**, **900**, **1216**, **1270**, **1414**, **2414**, **2314**

disclosed herein. Control using signals of measured pressure from the pressure transducer **2801** adds an additional safety element to the system **2300**. Additionally, a non-functional device (because of a leak, incomplete connection, incomplete priming, rupture, blockage) can be quickly identified. The integrity of the second extension tube **2363** and of the injection tube **2349** is also protected, e.g., avoiding unnaturally high pressures that could lead to burst.

[0381] The high pressure pump **2312** comprises a base **2701** having vertical side walls **2702**, **2703**, connected to and extending from the base **2701**. The motor **2379** is mounted vertically onto the base **2701** via a motor mount **2704**, or in other embodiments Is coupled directly to the base **2701**. The gearhead **2341** extends upward from the motor **2379**, and the flow oscillator **2420***d* is coupled above the gearhead **2341**. A housing **2705** encloses the coupling of the flow oscillator **2420***d* and the syringe **2366**. The syringe **2366** injects through an output nozzle **2706**, and a connector **2707** hydraulically couples to the nozzle **2706** to the proximal end **2367** of the second extension tube **2363**, in a detachable manner.

[0382] The flow oscillator **2420***d* of the high pressure pump **2312** is shown in more detail in FIGS. **87**-**91**. The stationary ball screw **2368** is coupled to a bi-directionally vertically-moveable slide **2709**, via a horizontal pin **2710**. The slide **2709** is carried on the back wall **2708**. The back wall **2708** is connected to the base **2701**. A transverse through hole **2711** extends through the ball screw **2368**, and the horizontal pin **2710** engages the through hole **2711** to restrict rotation of the ball screw **2368**. Thus, as the nut **2343** is turned, the ball screw **2368** is driven and caused to move up and down in unison with the slidable portion **2807** of the slide **2709** (double-headed arrow, FIG. **88**). The nut **2343** is rotatably carried on the upper horizontal plate **2712** by a bearing **2715**. The upper horizontal plate **2712** comprises a vertical through hole **2713** adjacent with and aligned with the internal thread **2714** of the nut **2343**. Thus, as the motor **2379**/gear head **2341** drive rotation of the nut **2343** via a timing belt **2729**, the internal thread of the nut **2343** is engaged with and translates axially in relation to the external thread **2716** of the ball screw **2368**.

[0383] In addition to the up or down driven motion actuated by the interaction between the nut **2343** and the ball screw **2368**, the flow oscillator **2420***d* causes back-and-forth axial oscillation (e.g., up-and-down motion) via two circular bump plates or “ripple plates” **2717**, **2718** (disks) as their relative rotational orientation is changed with respect to each other, also by the driving of the motor **2379**. The general injection of the syringe **2366** is driven by the rotation of the nut **2343** with respect to the ball screw **2368**. As the ball screw **2368** is driven upward, the plunger **2389** injects by decreasing the volume of the barrel **2373** of the syringe **2366** and increasing its internal pressure, thus configured to inject liquid (e.g., saline) from the barrel **2373**. The output of the gearhead **2341** turns an output shaft **2719**. The flow oscillator **2420***d* comprises a first bump plate disk **2717** that is statically coupled to the output shaft **2719** and is configured to rotate therewith and move vertically therewith. The flow oscillator **2420***d* further comprises a second bump plate disk **2718** that is statically coupled to the upper horizontal plate **2712** and is not configured to rotate. The first bump plate disk **2717** and the second bump plate disk **2718** each comprise a central hole **2720**, **2721**, respectively, that allows clearance of the output shaft **2719**. The output shaft **2719** extends through the hole **2720** of the first bump plate disk **2717**, and the first bump plate disk **2717** is configured to rotate in unison with the output shaft **2719**. In some embodiments, the first bump plate disk **2717** is welded to the output shaft **2719**. In other embodiments, the first bump plate disk **2717** is secured to the output shaft **2719** by mechanical connectors, or adhesive or epoxy, or they are permanently screwed together or pinned together. The output shaft **2719** extends through the hole **2721** of the second bump plate disk **2718**, and the output shaft **2719** is configured to freely rotate within the hole **2721**. The output shaft **2719** is further secured to a first toothed pulley **2722** such that the output shaft **2719** and the first toothed pulley **2722** rotate in unison. The first toothed pulley **2722** comprises a cylindrical body **2723** having an axial hole **2724**. The output shaft **2719** is configured to insert into the hole **2724**. In some embodiments, the first toothed pulley **2722** is welded to the output shaft **2719**. In other embodiments, the first toothed pulley **2722** is secured to the output shaft

2719 by mechanical connectors, or adhesive or epoxy, or they are permanently screwed together or pinned together. The first toothed pulley **2722** further comprises circumferentially-arrayed teeth **2725**, for example four to 60 teeth, or six to 40 teeth, or 20 to 40 teeth, or four to ten teeth. A short pulley **2726** having circumferentially-arrayed teeth **2727** is secured to the upper end **2728** of the nut **2343**. In some embodiments, the short pulley **2726** is welded to the nut **2343**. In other embodiments, the short pulley **2726** is secured to the nut **2343** by mechanical connectors, or adhesive or epoxy, or they are permanently screwed together or pinned together. In some embodiments, the number of teeth **2727** of the short pulley **2226** can match the number of teeth **2725** of the first toothed pulley **2722**. In other embodiments, the number of teeth **2727** of the short pulley **2226** can be greater or less than the number of teeth **2725** of the first toothed pulley **2722** in order to deliver an increased torque to the nut **2343**, or to increase the rotational speed of the nut **2343**, respectively. However, the speeds can be controlled partially or solely by the gear ratio of the gearhead **2341**. The teeth **2725**, **2727** can in some embodiments be replaced by or can include therebetween holes or spaces configured to engage teeth of a timing belt **2729**. In an opposite alternative embodiment, the second bump plate disk **2718** is statically connected to the output shaft **2719** and configured to rotate in unison with it, and the first bump plate disk **2717** is statically connected to a stationary casing around the gearhead **2341**. Thus, the rotation of the second bump plate disk **2718** in relation to the non-rotational first bump plate disk **2717** induces the axial motion imparted by the flow oscillator **2420***d*.

[0384] Returning to the embodiment of FIGS. **86-91**, the timing belt **2729** is configured to engage with the teeth **2725**, **2727** (or hole, spaces). The timing belt **2729** comprises a continuous 360° pathway, and can be configured to take an oval, elliptical, circular, or other path shape as it is engaged for turning in unison with the first toothed pulley **2722** and the nut **2343**/short pulley **2226**, via the teeth **2725**, **2727** (or hole, spaces). In alternative embodiments, the timing belt **2729** is replaced by a continuous chain having a plurality of links, each link or some of the links configured to engage one of the teeth **2725**, **2727**.

[0385] A distal end **2730** of the ball screw **2368** comprises a transverse hole **2731**. The plunger **2389** of the syringe **2366** comprises a rubber material, a thermoplastic elastomer, or another substantially elastic material. The plunger **2389** is carried by a rigid base **2732** having a transverse hole **2733**. A pin **2734** is placed through the hole **2733** of the base **2732** and through the hole **2731** of the ball screw **2368**. The pin **2734** and the pin **2710** provide general securement of the ball screw **2368** while allowing for some freedom of movement, such that the relationship between the external thread **2716** of the ball screw **2368** and the internal thread **2714** of the nut **2343** is “sloppy” and is not over-constrained. Thus, galling between the threads **2716**, **2714** is lessened, minimized, or avoided. In alternative embodiments, the securement can be a set screw, instead of the pin **2734**.

[0386] Turning to FIGS. **89-91**, as the first bump plate disk **2717** is rotated in unison with the output shaft **2719** by the motor **2379**/gearhead **2341** in a first rotational direction **2735**, a first axial surface **2736** of the first bump plate disk **2717** is caused to circumferentially slide over a second axial surface **2737** of the second bump plate disk **2718**. In this embodiment, each of the surfaces **2736**, **2737** are substantially similar to each other. FIG. **90** illustrates the surfaces facing each other in a minimum axial displacement configuration between the two surfaces **2736**, **2737**. As the first bump plate disk **2717** in the first rotational direction **2735**, a maximum axial displacement configuration between the two surfaces **2736**, **2737** (FIG. **91**). Each of the two surfaces **2736**, **2737** has a circumferential sawtooth path **2738** having a series of deepest portions **2739**, in terms of an indentation into the disk **2717**, **2718**, and a series of maximum protrusion portions **2740**. The deepest portions **2740** (e.g., depressions) and the maximum protrusion portions **2740** are interspersed between each other and are circumferentially arrayed. In the minimum axial displacement configuration of FIG. **90**, the deepest portions **2739** of the first disk **2717** do not necessarily exactly match the maximum protrusion portions **2740** of the second disk **2718** (and the deepest portions **2739** of the second disk **2718** in relation to the maximum protrusion portions **2740**

of the first disk **2717**), but they are very similar to each other in terms of each of their circumferential positions. In contrast, as the first bump plate disk **2717** is rotated in relation to the second bump plate disk **2718** toward the maximum axial displacement configuration of FIG. **91**, at the maximum axial displacement configuration the maximum protrusion portions **2740** of the first disk **2717** substantially match the maximum protrusion portions **2740** of the second disk **2718**, thus causing the maximum axial displacement DispMAX. In a particular embodiment, there are 36 maximum protrusion portions **2740** on the first disk **2717** and **36** maximum protrusion portions **2740** on the second disk **2718**. If the first disk **2717** is rotated at a rotational speed of 10 revolutions per minute (RPM) the complete back-and-forth cycles will occur at a frequency of six Hertz (Hz). In other words, there will be six slips between the maximum protrusion portions **2740** of the first disk **2717** and the maximum protrusion portions **2740** of the second disk **2718** each second. In some embodiments, the controller **2384** is configured to operate the system **2300** such that the back-and-forth cycles occur at a frequency of between about 0.5 Hz and about 10 Hz, or between about one Hz and about eight Hz. While these slips are occurring, the timing belt **2729** is driving the nut **2343** such that a continual axial displacement of the nut **2343** on the ball screw **2368** is also occurring. Thus, besides the injection of fluid (e.g., saline) from the syringe **2366**, there is also a cyclic variance in both pressure and flow rate from the syringe, caused by the cyclic slips between the two disk surfaces **2736**, **2737** (see time period C of graph in FIG. **94**). Besides the general injection via the plunger **2389** being caused by the upward driving of the ball screw **2368** by the rotating nut **2343**, there is the additional cyclic up-and-down motion of the nut **2343** itself, in unison with the upper horizontal plate **2712**, which is caused by the axial displacement changed from the reaction between the first bump plate disk **2717** and the second bump plate disk **2718**. In some embodiments, the upper horizontal plate **2712** is movably held on its periphery by one or more axial guides or slides **2771**, **2772**. The guides allow the up-and-down movement of the upper horizontal plate **2712**, but at least partially confine or constrain it from side-to-side movement.

[0387] The controller **2384** is configured to control the operation of the high pressure pump **2312** to cause the high pressure pump **2312** to inject pressurized fluid in a pulsatile manner, utilizing the cyclic or sinusoidal variation in the axial displacement between the two surfaces **2736**, **2737**. The high pressure jet is applied in a pulsatile fashion to optimize the cutting ability of the jet on a piece of thrombus. For example, a portion of thrombus that is aspirated into the open distal end **2305** of the aspiration lumen **2304** of the aspiration catheter **2302** can be more readily severed by a pulsating jet, much in the manner that a reciprocating saw. The controller **2384** is configured to operate the high pressure pump **2312** to pressurize fluid through the injection lumen such that the one or more jets are pulsatile. The controller **2384** is also configured to operate the peristaltic pump **2308** to further aid that that pressurized fluid injected through the injection lumen causes the one or more jets to be pulsatile. In some embodiments, the controller **2384** can vary the motor **2397** speed of the peristaltic pump **2308** so that it varies in a cyclic or sinusoidal manner. Or, that it produces a cyclic or sinusoidal variance in the negative pressure that is provided by the operation of the peristaltic pump **2308**.

[0388] An alternative aspiration system **2300**′ is illustrated in FIGS. **98-99**. The aspiration system **2300**′ is similar in most aspects to the aspiration system **2300** of FIGS. **86-91**, except that the cyclic up-and-down axial motion of the flow oscillator **2420***d* is provided by the nut **2343** alone, while the upper horizontal plate **2712** is maintained in a static state. The output of the gearhead **2775** is coupled to the output shaft **2719** by a weld **2775**. The upper horizontal plate **2712** is secured to the housing by attachments **2773**, **2774**. The disks **2717**, **2718** have a similar relative rotation and axial motion, but the disk **2717** is statically secured to an upper portion of the upper horizontal plate **2712**, and the disk **2718** is statically secured to the bottom of the nut **2343**.

[0389] An alternative aspiration system **2300**″ is illustrated in FIGS. **103-104**. The aspiration system **2300**″ is similar in most aspects to the aspiration system **2300** of FIGS. **86-91**, except that a static horizontal plate **2780** if rigidly coupled to the back wall **2708** or to any other static portion of

the enclosure. The motor **2379** and the gearhead **2341** are attached to the bottom **2781** of the static horizontal plate **2780** and hang downwardly, not requiring, thus, any attachment to the base **2701** (FIG. **86**). The stationary ball screw **2368**, as in the spiration system **2300**, is coupled to a bi-directionally vertically-moveable slide **2709**, via a horizontal pin **2710**. There is a hole **2782** in the static horizontal plate **2780** configured to clear the ball screw **2368** and allow up-and-down freedom of movement of the ball screw **2368** in relation to the static horizontal plate **2780**. The disk **2717** is rotationally coupled to and configured to rotate with the output shaft **2719**. Horizontal plate **2712** is now configured to be moved up and down by the axial displacement between the disks **2717**, **2718**. The first toothed pulley **2722** is rotationally coupled or keyed to the output shaft **2719**, but is configured to slide up and down in relation to the output shaft. In some embodiments, the output shaft **2719** has a hexagonal-shaped cross-section and there is a slightly larger hexagonal cavity (hole **2724**) extending axially in the first toothed pulley **2722**. As the horizontal plate **2712** carries both the first toothed pulley **2722** and the nut **2343**, both of them are move up and down equally in unison with the horizontal plate **2712**. The timing belt **2729** (or chain) is thus not required to flex or translate (other than rotationally), because the first toothed pulley **2722** and the nut **2343** hove up and down together.

[0390] Turning to FIG. **94**, in a first time period A, the controller **2384** initiates operation of the high pressure pump **2312** at point A**1** (e.g., t=0) to inject from the syringe **2366** through the second extension tube **2363** and the high pressure injection lumen **2310**, but does not yet initiate operation of the peristaltic pump **2308**. There is a noticeable pressure increase over this period. In some embodiments, first time period A is between about one second and about ten seconds, or between about one second and about five seconds, or about two or three seconds. At point A**2**, the controller **2384** then initiates operation of the peristaltic pump **2308**. The controller **2384** can be programmed or enabled to determine point A**2** based on a stored elapsed time after point A**1**. The controller can also be configured to recognize a proxy for internal pressure. The proxy in some embodiments comprises a measured current of the motor **2379**, which increases with increased resistance, which can occur as the pressure inside the barrel **2373** increases. The proxy in other embodiments comprises a measured torque on the motor **2379** or on the output shaft **2719**, for example via a torque sensor. Once a preset current or torque is achieved and is measured, the peristaltic pump **2308**, for example, is turned on by the controller **2384**. In alternative embodiments, the controller **2384** recognizes a measured injection pressure measured by a pressure sensor internal to the barrel **2373**, and compares it to a pressure that is stored in memory as a target pressure. In some embodiments, the target pressure is between about 300 psi (20.4 atmospheres) and about 600 psi (40.8 atmospheres), or between about 375 psi (25.5 atmospheres) and about 525 psi (35.7 atmospheres). When the controller **2384** recognizes the target injection pressure (at A**2**), or other proxy, or simply the target elapsed time between A**1** and A**2**, the controller **2384** then initiates operation of the peristaltic pump **2308**. In other alternative embodiments, the controller **2384** initiates operation of the peristaltic pump **2308** after recognition of a measured target flow rate or a measured target flow velocity (e.g., with input from the output of a Doppler sensor). In some embodiments, the controller **2384** initiates operation of the peristaltic pump **2384** based on one or more of the following target injection parameters: target catheter input pressure, target minimum catheter input pressure, target maximum catheter input pressure, target mean catheter input pressure, target flow rate, motor current (e.g., motor **2397**), motor speed (e.g., motor **2397**), torque, target minimum flow rate, target maximum flow rate, target mean flow rate, target flow velocity, target minimum flow velocity, target maximum flow velocity, and target mean flow velocity.

[0391] With both the high pressure pump **2312** and the peristaltic pump **2384** operating simultaneously over second time period B, the measured injection pressure continues to increase until point B**2**, at which the mean injection pressure reaches the desired amount and the pulsatile injection provided by the flow oscillator **2420***d* may become more pronounced, as shown in third time period C. During the third time period C, the pulsatile cyclic or sinusoidal injection pressure

(or flow rate, or flow velocity, etc.) can be visualized as valleys v. Pulsatility of injection may thus fully developed, but it is also possible that as aspiration from the peristaltic pump **2384** is added, there is additional time to fully develop the peak vacuum level. In some embodiments, a message to the use, or a light/LED, etc. indicates to the user when the injection pressure and the vacuum are both at desired levels. This curve can remain consistent, assuming that there are no significant events such as blockage due to clogging (e.g., from trapped thrombus inside the catheter aspiration lumen **2304**, or a catheter kink affecting the lumens **2304**, **2310**, etc.). The maintained pulsatility is aimed at maintaining a patent aspiration lumen **2304** that does not get clogged by aspirated portions of thrombus/clot. The jet from the orifice is configured to break up the thrombus into smaller pieces prior to the full aspiration. The initiation with the jet alone, during time period A, can serve to avoid a large initial piece of clot being sucked into the lumen and clogging it.

[0392] In alternative embodiments, instead of the first bump plate disk **2717** being configured to rotate in unison with the output shaft **2719**, a relationship between the first bump plate disk **2717** and the output shaft **2719** cam comprise coupling via planetary gears. Thus, the rotational speed of the output shaft **2719** can be greater or less than the rotational speed of the first bump plate disk **2717**.

[0393] In some embodiments, the second bump plate disk **2718**, instead of being configured to never rotate with respect to the upper horizontal plate **2712**, can instead be configured to rotate with respect to the upper horizontal plate **2712**, but only when a maximum torque is achieved. For example, a torque that is above a safety threshold. The second bump plate disk **2718** can be coupled to the upper horizontal plate **2712** by a bearing having a controlled amount of torque resistance that is configured to resist any torque below the upper safety threshold torque. Alternatively, a standard low-resistance bearing can be used, but a breakaway restraint can secure the bearing, such that it will break away at or above the upper safety threshold torque.

[0394] The flow oscillator **2420***d* of FIGS. **86-91** is configured for rotation in the first rotational direction **2735** during injection. After the procedure, or during a filling or refilling interval, the motor **2379** is operated (e.g., by the controller **2384**) to cause the output shaft **2719** and nut **2343** to operate in an opposite rotational direction, that causes the ball screw **2368** to move downward, and the plunger **2389** to retract. This would be done, for example, to refill the interior of the barrel **2373** with saline. The shape of the first axial surface **2736** and the second axial surface **2737** are configured such that relative rotation and slipping between the two disks **2736**, **2737** in the injection direction causes the pulsatile flow, as described; however, in the opposite relative direction, the slipping is controlled (due to the non-similar path) such that there is little or no pulsatile flow (e.g., as the barrel **2373** is filled). The plunger **2389** can also be loaded (pulled back) into the barrel **2373** in this manner, without significant pulsing.

[0395] FIGS. **92-93** illustrate a portion of an alternative flow oscillator **2420***e* comprising a first bump plate disk **2741** and a second bump plate disk **2742**. The first bump plate disk **2741** and the second bump plate disk **2742** have axial surfaces **2743**, **2744**, respectively, that are not substantially similar to each other. The second surface **2744** comprises circumferentially-arrayed relatively flat valleys **2745** interspersed between substantially symmetric protrusions **2746**. The first surface **2743** comprises a surface that is similar to the surface **2736** of the first disk **2717** in FIGS. **87-91**. However, the maximum protrusion portion **2747** is radiused or filleted even more than the first axial surface **2736** and the second axial surface **2737** shown in FIGS. **89-91**. The first disk **2741** is configured to be rotated in a first rotational direction **2748** in relation to the second disk **2742**, and in a second, opposite rotational direction **2749** in relation to the second disk **2742**. In some embodiments, as shown in FIGS. **92-93**, there are the same number of maximum protrusion portions **2747** on the first surface **2743** as there are valleys **2745** on the second surface **2744**. In alternative embodiments, there are fewer maximum protrusion portions **2747** on the first surface **2743** than there are valleys **2745**, on the second surface **2744**. For example, in some embodiments, there are only three maximum protrusion portions **2747** on the first surface **2743** (e.g., separated by

less than 180°, or located every) 120°, or six maximum protrusion portions **2747** (less than 90°, or located every) 60°, or between three and 36 maximum protrusion portions **2747**, or between six and 24 maximum protrusion portions **2747**, or between twelve and 36 maximum protrusion portions **2747**.

[0396] Either by the relative rotation between disks **2717**, **2718** or disks **2741**, **2742**, the return of the second disk **2718**, **2742** axially back toward the first disk **2717**, **2741** comprises a recoil or a slip. With this recoil the plunger **2389** in turn recoils, thus producing the valleys v. The total amount of axial height in the protrusions (in relation to the valleys), or the total axial variation in the surface contours can be controlled in fabricating the disks **2717**, **2718**, **2741**, **2742**, to produce a desired pressure variation or flow (rate, velocity, etc.) variation, such as that shown in third time period C in FIG. **94**. In some embodiments, the total axial range (variation of the contour in the axial direction) is between about 0.2 mm and about 5 mm, or between about 0.3 mm and about 3 mm, or between about 0.3 mm and about 2 mm, or between about 0.3 mm and about 1 mm. By providing these predetermined dimensions on the disks **2717**, **2718**, **2741**, **2742**, a predetermined amount of axial movement is produced during operation.

[0397] A method for catheter-based aspiration includes providing a catheter having a distal portion configured for insertion within a blood vessel of a subject, the catheter including a first lumen having a distal opening at the distal portion of the catheter, a second lumen having a distal end at the distal portion of the catheter, and an orifice located at or near the distal end of the second lumen, the orifice configured to direct liquid into the first lumen at or near the distal opening of the first lumen, and further includes actuating an injector in a non-uniform manner to cause a pulsatile pressure of a liquid in the second lumen as the liquid is injected through the second lumen. In some embodiments, actuating the injector in a non-uniform manner includes repeatedly displacing a plunger in an interior of a barrel in a first direction along a longitudinal displacement axis by an increment, followed by movement of the barrel in a second direction, opposite the first direction. In some embodiments, movement of the barrel in the second direction corresponds to recoil of the injector following displacement thereof. In some embodiments, the recoil is a controlled recoil corresponding to a predetermined amount of movement in the second direction. In some embodiments, movement of the barrel in the second direction corresponds to controlled mechanical slip within an actuator. In some embodiments, repeatedly displacing the plunger includes displacing the plunger at a frequency of between 1 Hz and 8 Hz. In some embodiments, the method further includes reducing a pressure of the liquid in the second lumen to bring or maintain the pressure of the liquid below an injection pressure threshold. In some embodiments, reducing the pressure of the liquid in the second lumen includes actuating a valve in pressure communication with the second lumen. In some embodiments, the method further includes utilizing a mechanical oscillator coupled to the injector to at least partially cause the pulsatile pressure of the liquid, the mechanical oscillator including a first member and a second member axially arrayed with respect to each other and configured such that changes in a relative rotational orientation between the first member and the second member cause reciprocal relative axial displacement between the first member and the second member, and wherein the first member is coupled to the plunger and configured to transfer motive force thereto along the longitudinal displacement axis. In some embodiments, the method further includes coupling a negative pressure source to a proximal portion of the first lumen of the catheter. In some embodiments, the negative pressure source includes a peristaltic pump. In some embodiments, the method further includes utilizing a controller to initiate operation of the injector prior to initiating operation of the peristaltic pump. In some embodiments, initiating operation of the injector prior to initiating operation of the peristaltic pump further includes initiating operation of the peristaltic pump only after the injector reaches a target injection parameter. In some embodiments, the target injection parameter includes one or more parameter selected from the list consisting of: a target catheter input pressure, a target minimum catheter input pressure, a target maximum catheter input pressure, a target mean catheter

input pressure, a target flow rate, a target minimum flow rate, a target maximum flow rate, a target mean flow rate, a target flow velocity, a target minimum flow velocity, a target maximum flow velocity, and a target mean flow velocity.

[0398] FIGS. **96-97** illustrate an aspiration system **2900** that integrates together a high pressure pump **2902** (e.g., power injector), a peristaltic pump **2903**, and control circuit board **2905**, into a single enclosure **2901**. The enclosure **2901** comprises a bottom plate **2906**, a top plate **2907**, a front plate **2908**, a back plate **2909**, a left plate **2910**, and a right plate **2911**. The enclosure **2901** is carried on a vertical pole **2912** that is coupled to a base **2913** having wheels **2914**. In some embodiments, the pole height can be adjustable by a user (not shown). The pole **2912** is optional. In other embodiments, the enclosure **2901** can be configured to by placed on a table or stacked on other equipment. The peristaltic pump **2903** is a roller pump having a base **2915**, a pressure shoe **2916** carried by the base **2915**, and a rotatable head **2917**, rotatably coupled to the base **2915**, and carrying two or more rollers, as shown in FIG. **75** (rollers **2432***a-d*). The rollers are arrayed around a perimeter of the rotatable head **2917**. The rotatable head **2917** is configured to be rotatable in at least a first rotational direction with respect to a rotational axis. The rotatable head **2917** is configured to be rotated by a motor **2918**. The peristaltic pump **2903** is configured to connect to a power supply. As shown in FIG. **96**, as assembled, the peristaltic pump **2903** is accessible to a user outside of the right plate **2911**.

[0399] An aspiration catheter, such as the aspiration catheter **2402** of FIG. **75**, is configured to be coupled to the peristaltic pump **2903** and to the high pressure pump **2902**. The high pressure pump **2902** comprises a power injector having an electric motor **2919** outputting rotation to a gearhead **2920** (e.g., gearbox), which is configured to change a rotational speed (faster or slower) and/or to change a torque (lower or higher). The output of the gearhead **2920** is configured to indirectly drive a ball nut within a ball nut assembly **2921** over a stationary ball screw **2922** (e.g., via a belt drive configuration or chain drive configuration). The gearhead **2920** is mounted to a mounting plate **2942**. The motor **2919** is configured to drive the ball nut in a clockwise direction and in a counter-clockwise direction. The ball screw **2922** is statically coupled to a plunger (similar to plunger **2389**) that is sealingly carried within a barrel **2923** of a syringe **2924** and configured to be displaced along a longitudinal displacement path within the bore of the barrel **2923**. The barrel **2923** of the syringe **2924** has a large bore, having a large internal volume, and the motor **2919** is configured to enable large torques to generate high injection pressures within the syringe **2924**. The syringe **2924** includes a nozzle **2946** having an exit orifice **2947**. The aspiration catheter **2402** is configured to be placed through a guiding catheter, an introducer sheath, or through direct blood vessel puncture. In some embodiments, the aspiration catheter **2402** can be a microcatheter. In other embodiments, the aspiration catheter **2402** can be configured to be utilized with a separate microcatheter and/or a guidewire. The pump **2902** is configured to connect to a power supply. A DC/DC power converter **2941** can provide the desired voltage to run different components, for example 24 Volts for the peristaltic pump **2903** and 48V for the high pressure pump **2902**. The DC/DC power converter **2941** can be configured to protect against harsh, mobile use to stop or minimize over-temperature, overload, short-circuit, overvoltage and input under-voltage lock-out.

[0400] A syringe holder **2925** is coupled to a door **2926**. Together, the syringe holder **2925** and the door **2926** are configured to slide in a path parallel to the left plate **2910** and the right plate **2911** that moves toward and away from the back plate **2909**. A push button latch **2943** is coupled to the door **2926** to allow “push-to-open” and “push-to-lock” capability. In other embodiments, the door **2926** is configured to open in a pivoting manner, like a standard house front door. In other embodiments, the door **2926** is not required. The bottom end **2927** of the syringe **2924** is configured to couple to a circular opening **2928** in the syringe holder **2925**. In use, after then bottom end **2927** of the syringe **2924** has been engaged with the opening **2928**, the syringe holder **2925** and the door **2926** are slid into place (in a direction toward the back plate **2909**). The barrel **2923** of the syringe **2924** now extends upwardly through a notch **2929** in the top plate **2907**. The

top plate **2907** includes an edge **2930** that acts as a stop against an upper edge **2931** of a flange **2932** of the syringe **2924**. The syringe holder **2925** includes an edge **2933** that acts as a bottom stop against a lower edge **2934** of the syringe **2924**. In other embodiments, the syringe **2924** comprises a lower male thread and the opening **2928** in the syringe holder **2925** comprises a female thread, wherein the male thread can be removably screwed into the female thread. An aligner **2945** aligns the base of the plunger to guide its movement through the barrel **2923** of the syringe **2924**. If the syringe **2924** is loaded with the plunger (alone) sealingly inserted within the interior of the barrel **2923**, the motor **2919** is then operated to drive the ball screw **2922** upward vertically to engage the ball screw **2922** or an end thereof into a proximal orifice in the plunger. If the syringe **2924** is loaded without the plunger, the motor **2919** is then operated to drive the ball screw **2922** upward vertically to engage the plunger into the interior of the barrel **2923**.

[0401] The ball screw **2922** is pinned (as in FIGS. **86**-**88**) to a carriage **2937** that is slidably coupled to an elongate guide rail **2938**. The ball screw **2922** is thus configured to move upwardly and downwardly, as it is driven by the rotating ball nut, while the ball screw **2922** is maintained in a non-rotatable state. A main aspiration monitoring system (e.g., main aspiration monitoring system **2800** of FIGS. **86** and **95**) comprising a pressure transducer (e.g., pressure transducer **2801**) is configured such that its cable **2331** includes a RJ-45 compatible connector, configured to detachably connect to an RJ-45 jack **2935** which is accessible through a square hole **2936** in the front plate **2908**. This allows signals to be transmitted from the pressure transducer **2801** to the control circuit board **2905**. A holding bracket **2944** is configured to hang a canister (e.g., canister **2358** of FIG. **86**) used for the collection of aspirated thrombus or blood. The control circuit board **2905** is also configured to control a motor controller **2904** for the peristaltic pump **2903**.

[0402] A display **2939** is carried on the front plate **2908** and is viewable to a user through a rectangular opening **2940** in the front plate **2908**. The display **2939** is LCD, and includes resistive touch-screen control capability. Alternatively, other types of display can be utilized, and other types of touch-screen (e.g., capacitive). The aspiration system **2900** is compatible with the extension tubing **2338**, **2363** of FIG. **86** and is configured to perform in a similar manner. As shown in FIG. **96**, integrating the majority of the components into a single enclosure **2901**, and carried on a mobile base **2913** via a pole **2912**, allows rapid implementation into an emergent or a scheduled procedure, while using a small amount of space. It is also adaptable to a changing scenario during the procedure. For example, it is relatively easy to move the entire system **2900** from one side of a procedure table to the other, or to change rooms with the patient.

[0403] Any of the aspiration systems **1400**, **1400′**, **1400″**, **400**, **600**, **2100**, **2400**, **2300**, **2900** utilizing the peristaltic pump **1408**, **408**, **608**, **2102**/**2108**, **2408**, **2308**, **2903** or the centrifugal pump **1409** together with an aspiration catheter **1402**, **1402′**, **402**, **602**, **2402**, **2302** having both an aspiration lumen and an injection lumen can alternatively also be used with an aspiration catheter **202** having an aspiration lumen **204** and no injection lumen, or with an aspiration catheter **1402**, **1402′**, **402**, **602**, **2402**, **2302** without injecting through the injection lumen. The peristaltic pump **1408**, **408**, **608**, **2102**/**2108**, **2408**, **2308**, **2903** or the centrifugal pump **1409** alone can be used for the aspiration of thrombus. Any element configured to cause a particular pressure or injection pattern of the injectate can be considered a “drive unit.” Thus, a motor, or a solenoid, can be considered two different drive units. Additionally, if configured to work together, a motor and solenoid can be considered a single (compound) drive unit.

[0404] Using any of the aspiration systems described herein, a distal blood pressure can be measured in a diseased coronary artery, peripheral artery, or other artery by the open distal end of the aspiration lumen **1404** of the aspiration catheter **1402**, with the pumps **1408**, **1412** turned off or uncoupled, in order to determine a value for Fractional Flow Reserve (FFR), as disclosed in U.S. Pat. No. 6,565,514, Method and System for Determining Physiological Variables, to Svanerudh et al., which is incorporated herein by reference in its entirety for all purposes. The pressure sensor **1416** can be used to measure the pressure in the aspiration lumen **1404**. For example, in a first step,

the user assures that the pump **1412** is not actively pumping saline through the injection lumen **1410** and assures that the peristaltic pump **1408** is not actively aspirating through the aspiration lumen **1404**. In a second step, the user places the open distal end **1405** of the aspiration lumen **1404** distal to an atherosclerotic lesion, stenosis, or partial blockage of interest in an artery, or a partial blockage or stenosis caused significantly by thrombus, or by a combination of atherosclerosis and thrombus. The user then in a third step measures a pressure at the open distal end **1405** of the aspiration lumen **1404** using the aspiration monitoring system **1414** while also measuring a pressure proximal to the lesion, for example, with a pressure transducer coupled to a guiding catheter. In a fourth step, the user obtains or calculates the Fractional Flow Reserve (FFR), to help determine the significance of the stenosis of partial blockage.

[0405] In an alternative embodiment, the first disk comprises a first circumferentially-poled magnetic disk and the second disk comprises a second circumferentially-poled magnetic disk, such that relative rotational movement of the first disk with respect to the second disk at least partially serves to generate the reciprocal relative axial displacement, wherein the first disk and the second disk each comprise paired poling configurations, such that when same poles are overlayed, the first disk and the second disk are axially moved apart by one or more repulsive force, and when opposite poles are overlayed, the first disk and the second disk are axially moved closer to each other by one or more attractive force. In some embodiments, the system further comprise(s) a non-magnetic buffer layer between the first disk and the second disk, the buffer layer configured to minimize direct frictional contact between the first disk and the second disk.

[0406] FIGS. **100**-**101** illustrate a surgical aspiration probe **2950** configured to be used with any of the aspiration systems **1400**, **1400′**, **1400″**, **400**, **600**, **2100**, **2400**, **2300**, **2900** disclosed herein. Instead of a catheter shaft, the surgical aspiration probe **2950** comprises a handle **2951** and a hypodermic tubular shaft **2952**. The shaft **2952** comprises stainless steel. In other embodiments, the shaft **2952** comprises other relatively stiff biocompatible metals or polymers. As shown in FIG. **102**, the shaft **2952** is configured to be placed through an introducer sheath **2953** that has been inserted into a burr hole **2954** in the cranium **2955** of a patient **2956**. The shaft **2952** is also configured to be inserted through an endoscope. In some cases, the endoscope is inserted through the burr hole, and the shaft **2952** is inserted through the endoscope lumen.

[0407] The handle **2951** comprises a first half **2957** and a second half **2958**, which are connected to each other with screws **2959***a*-*d*, closing the halves **2957**, **2958** over the shaft **2952**. The screws **2959***a*-*d* are placed through holes **2960** in the second half **2958** and threadingly engage with female threaded holes **2961** in the first half **2957** to secure the first half **2957** and the second half **2958** together. In alternative embodiments, instead of using screws **2959***a*-*d*, the first half **2957** and the second half **2958** are bonded (adhesive, epoxy, hot melt) or welded (ultrasonically) together. A high pressure injection tube **2962** is inserted into an aspiration lumen **2963** of the shaft **2952** and is bonded to the inside wall of the aspiration lumen **2963** with an adhesive or epoxy At a distal end of the shaft **2952**, continuously along the length of the shaft **2952**, or at several different locations along shaft **2952**. The high pressure injection tube **2962** can comprise polyimide, and comprises a lumen **2964** extending therethrough. The lumen **2964** is blocked at a distal end **2965** of the injection tube **2962** by a blocking material **2966**, which can comprise an epoxy, an adhesive, a hot melt, and/or a friction plug. Immediately proximal to the blocking material **2966**, is an orifice **2967** in the wall **2968** of the injection tube **2962**. Thus, high pressure liquid, such as saline, can be injected from a proximal end **2969** of the lumen **2964**, such that is travels down the lumen **2964** and exits out the orifice **2967**, into the aspiration lumen **2963** of the shaft **2952**.

[0408] Thus, a negative pressure is created to force material that is external and adjacent the open distal end **2970** into the aspiration lumen **2963**. The tip configuration of any of the aspiration catheters of any of the aspiration systems **1400**, **1400′**, **1400″**, **400**, **600**, **2100**, **2400**, **2300**, **2900** of this disclosure can be utilized to tailor the desired effect. A peristaltic pump **1408**, **408**, **608**, **2102**/**2108**, **2408**, **2308**, **2903** or the centrifugal pump **1409** can be additionally used to provide a

negative pressure at a proximal end **2971** of the aspiration lumen **2963**. A y-connector **2972** comprises a first luer **2973** that is hydraulically coupled to the lumen **2964** of the injection tube **2962**, and a second luer **2974** that is hydraulically coupled to the aspiration lumen **2963**. Each of the halves **2957**, **2958** of the handle **2951** includes a proximal semi-circular hole **2975**, **2976** configured to be closed around the first luer **2973** and an angle side semi-circular hole **2977**, **2978** configured to be closed around the second luer **2974**, as shown in FIG. **100**. A hole **2979** on the top **2980** of the first half **2957** is configured to contain a push button **2981**, which comprises a push button element **2982**, a base **2983**, and a dome seal **2984**. Two screws **2985***a-b* insert through holes in the base **2983** to secure the push button element **2982** in place within the first half **2957**, and seal the dome seal **2984** against an underside of the first half **2957**, surrounding the hole **2979**.

[0409] A pressure transducer **2986** is coupled to the distal end of the y-connector **2972**, which is hydraulically coupled to the aspiration lumen **2963**, to measure a pressure (e.g., negative pressure) therein. A signal from the pressure transducer **2986** is carried by insulated conductors **2987** which pass through two semi-circular holes **2988**, **2989** in the halves **2957**, **2958**, which close around the insulated conductors **2987**. Alternatively, the signal can be transmitted wirelessly. In addition, a signal from the push button element **2982** is carried by insulated conductors **2990**, which also pass through the holes **2988**, **2989**. The signals from the push button element **2982**, carried by the conductors **2990**, can be configured to communicate with a controller of any of the aspiration systems **1400**, **1400′**, **1400″**, **400**, **600**, **2100**, **2400**, **2300**, **2900**. For example, the push button **2981** can be utilized by a user to then the system **2950** on or off. Pressing the push button **2981** to turn the system on can initiate the controller such that the controller first begins the injection through the lumen **2964** of the injection tube **2962**, and then begins the aspiration through the aspiration lumen **2963**.

[0410] Turning to FIG. **102**, a burr hole **2954** is made in the cranium **2955** of a patient **2956**. A peel away sheath **2953** (or a standard non-peel-away sheath) is placed through the burr hole **2954** and inserted until its distal end **2991** is located at a desired position **2994** in or adjacent a hemorrhage **2992** (or tumor, or other undesirable element) within the brain **2993** of the patient **2956**. The hemorrhage **2992** may have been the result of a ruptured artery that has bled into the brain **2993**. Again, the shaft **2952** is also configured to be inserted through an endoscope. The distal end **2995** of the shaft **2952** is moved out from a distal opening **2996** of the sheath **2953**, and moved back, to aspirate the contents of the hemorrhage **2992** (and/or other material) at different locations, and to more completely aspiration the hemorrhage **2992**. When the aspiration is complete, the sheath **2953** can be split in half (peeled away) and removed, the shaft **2952** can be retracted from the burr hole **2954**, and the burr hold 2954 can be closed up with bone wax. In some cases, a craniotomy is used, to expose a larger amount of area, for example, in the case of a large hemorrhage **2992**. In addition to or instead of removal of hemorrhage **2992**, the surgical aspiration probe **2950** can be utilized to remove clot/thrombus from the brain.

[0411] FIGS. **105**A-**108** illustrate an alternative high-pressure pump **3002** for the aspiration system **2900** of FIGS. **96-97**. The high-pressure pump **3002** comprises a power injector having an electric motor **3019** outputting rotation to a gearhead **3020** (e.g., gearbox), which is configured to change a rotational speed (faster or slower) and/or to change a torque (lower or higher). The motor **3019** is connected to a power supply and controller (not shown) via cables **3025** and one or more connectors **3026**. The output of the gearhead **3020** is configured to indirectly drive a ball nut **3098** within a ball nut assembly **3021** over a stationary (non-rotational) ball screw **3022** via chain **3099** (or alternatively, a belt). The gearhead **3020** is mounted to a mounting plate **3042** via screws **3038**. The motor **3019** is configured to drive the ball nut **3098** in a clockwise direction and in a counter-clockwise direction. The ball screw **3022** is statically coupled to a plunger (similar to plunger **2389**) that is sealingly carried within a barrel **2923** of a syringe **2924** and configured to be displaced along a longitudinal displacement path within the bore of the barrel **2923** (FIG. **97**). The pump **3002** is configured to connect to a power supply.

[0412] A housing **3023** is attached to the mounting plate **3042** by several screws **3024**. Alternatively, the housing **3023** can be coupled to the mounting plate **3042** by welding, brazing, adhesive, epoxy, hot melt, or other joining materials and methods. Turning to FIGS. **106**-**108**, an output shaft **3027** from the gearhead **3020** is coupled to a drive sprocket **3028**. The drive sprocket **3028** is rotatably held within a circular cavity **3029** of the housing **3023** by a ball bearing **3030**. The drive sprocket **3028** turns within the same longitudinal axis LA**1** as the output shaft **3027**. A driven sprocket **3031** is rotatably coupled to the ball nut **3098** and both turn within the same longitudinal axis LA**2** as each other. A continuous 360° extending chain **3099** is configured to engage with teeth **3032**, **3033** of the sprockets **3028**, **3031**, so that the drive sprocket **3028** is able to drive the driven sprocket **3031**. In some embodiments, the drive sprocket **3028** and the driven sprocket **3031** have the same number of teeth as each other. In some embodiments, the drive sprocket **3028** and the driven sprocket **3031** have the diameter as each other. In the embodiment of FIGS. **105**A-**108**, the drive sprocket **3028** has a smaller diameter than the driven sprocket **3031** and has fewer teeth, and thus is configured to drive the driven sprocket **3031** (and thus the ball nut **3098**) at a slower rotational speed, but with an increased torque. The gear ratio of the drive sprocket **3028** and driven sprocket **3031** can in some embodiments be between 1.5 to 2.5.

[0413] The ball nut **3098** drives the ball screw **3022** in a longitudinal direction, and the ball screw **3022** passes through a sleeve bearing **3034** which maintains its straight movement, without adding large amounts of frictional resistance. The sleeve bearing **3034** can comprise a lubricious material or can be a lubricated component. A flow oscillator **3035** causes back-and-forth axial oscillation (e.g., up-and-down motion) via two circular bump plates or "ripple plates" **3036**, **3037** (disks) as their relative rotational orientation is changed with respect to each other, also by the driving of the motor **3019**/gearhead **3020**/output shaft **3027**. Thus, as the drive sprocket **3028** is turned about longitudinal axis LA**1**, it generally maintains its longitudinal position. Whereas, when the ball nut **3098** is turned about the longitudinal axis LA**2**, it is caused to move back and forth longitudinally, due to the axial displacement caused by the ripple plate **3036** and ripple plate **3037** rotationally slipping against each other. In some embodiments, wherein the driven sprocket **3031** and the ball nut **3098** are rigidly coupled together, the chain **3099** is able to slightly flex or curve in order to allow the driven sprocket **3031** to move axially (in both directions) along with the ball nut **3098**. In other embodiments, the driven sprocket **3031** and the ball nut **3098** are keyed together to allow for some axial slippage between the two, but to maintain one-to-one rotation. For example, the ball nut **3098** can comprise an external square, hex or other non-circular shape extending on the side toward the driven sprocket **3031** such that it freely passes through a similarly-shaped but slightly larger hole in the driven sprocket **3031**. Thus, as the ball nut **3098** moves back-and-forth axially, the driven sprocket **3031** generally maintains its longitudinal position, and the chain **3099** does not need to flex or curve. A second sleeve bearing **3039** (see FIG. **107**), comprising a lubricious or lubricated material, surrounds the ripple plates **3036**, **3037** to help stabilize their rotation and orientation, without adding large amounts of frictional resistance.

[0414] In alternative embodiments, any of the embodiments presented herein utilizing a ball screw **2368**, **2922**, **3022** can instead utilize a screw that is turned by the motor/gearhead/output shaft, configured to threadingly engage with a non-rotating nut coupled to the housing. The distal end of the screw can be coupled to the plunger with a rotatable connection (rotational coupling). Thus, the screw longitudinally displaces and rotates while the plunger longitudinally displaces with the screw, but does not rotate.

[0415] The following clauses include examples of apparatus of the disclosure:

[0416] Clause 1: In one example, a system for catheter-based aspiration includes an aspiration catheter having an aspiration lumen and an injection lumen, the injection lumen having a distal orifice configured for directing liquid into a distal portion of the aspiration lumen, and an injector configured to pressurize the liquid in an oscillating manner within the injection lumen, such that liquid exits the distal orifice and enters the distal portion of the aspiration lumen with a variable

flow rate and/or variable flow velocity, wherein the injector includes a barrel having an interior, a plunger configured to sealingly change an effective volume of the interior of the barrel, and a controller configured to control movement of the plunger within the interior of the barrel.
[0417] Clause 2: In some examples, the system of clause 1 further includes wherein the controller is configured to operate a drive unit, the drive unit configured to change the relationship between the plunger and the barrel.
[0418] Clause 3: In some examples, the system of clause 2 further includes wherein the drive unit includes a screw.
[0419] Clause 4: In some examples, the system of clause 3 further includes wherein the drive unit is configured to turn the screw in a clockwise direction and to turn the screw in a counter-clockwise direction.
[0420] Clause 5: In some examples, the system of any one of clauses 2-4 further includes wherein the drive unit includes a motor.
[0421] Clause 6: In some examples, the system of clause 5 further includes wherein the controller is configured to operate the motor at a first motor speed at an initiation of a first injection cycle and to adjust to a second motor speed at a time within five seconds to two minutes from the initiation of the first injection cycle, the second motor speed lower than the first motor speed.
[0422] Clause 7: In some examples, the system of clause 6 further includes wherein the first motor speed is between 1.5 times and 3.5 times greater than the second motor speed.
[0423] Clause 8: In some examples, the system of clause 6 further includes wherein the first motor speed is between 2 times and 3 times greater than the second motor speed.
[0424] Clause 9: In some examples, the system of either one of clauses 7-8 further includes wherein the second motor speed is configured to be the main motor speed throughout the first injection cycle.
[0425] Clause 10: In some examples, the system of any one of claims **1**-**5** further includes wherein the injector includes a relief valve.
[0426] Clause 11: In some examples, the system of clause 10 further includes wherein the relief valve is configured to mechanically establish a maximum injection pressure.
[0427] Clause 12: In some examples, the system of any one of clauses 1-11 further includes a peristaltic pump configured for driving fluid from the distal portion of the aspiration lumen to a proximal portion of the aspiration lumen.
[0428] Clause 13: In some examples, the system of clause 12 further includes a compressible tube configured to be hydraulically coupled to the aspiration lumen and configured to be engaged with the peristaltic pump.
[0429] Clause 14: In some examples, the system of any one of clauses 1-13 further includes a switch configured to change the effect of the injection of fluid by the injector from the oscillating manner to a non-oscillating manner.
[0430] Clause 15: In some examples, the system of any one of clauses 1-13 further includes a switch configured to change the effect of the injection of fluid by the injector from the oscillating manner to a damped oscillating manner.
[0431] Clause 16: In some examples, the system of any one of clauses 5-9 further includes a transducer configured to monitor electrical current of the motor.
[0432] Clause 17: In some examples, the system of clause 16 further includes wherein the controller is configured to calculate an injection pressure of the injector based at least in part on the measured electrical current.
[0433] Clause 18: In some examples, the system of any one of clauses 1-17 further includes wherein the oscillating manner includes a 3-8 Hz oscillation.
[0434] Clause 19: In some examples, the system of any one of clauses 1-17 further includes wherein the oscillating manner includes a 4-7 Hz oscillation.
[0435] Clause 20: In some examples, the system of any one of clauses 1-17 further includes

wherein the oscillating manner includes a 5-6 Hz oscillation.
[0436] Clause 21: In another example, a system for catheter-based aspiration includes an aspiration catheter having an aspiration lumen and an injection lumen, the injection lumen having a distal orifice configured for directing liquid into a distal portion of the aspiration lumen, and an injector configured to pressurize the liquid in an oscillating manner within a range of between about 200 psi and about 1500 psi at a proximal portion of the injection lumen, such that liquid exits the distal orifice and enters the distal portion of the aspiration lumen with a variable flow rate and/or variable flow velocity.
[0437] Clause 22: In some examples, the system of clause 21 further includes wherein the injector is configured to pressurize the liquid in an oscillating manner between about 600 psi and about 700 psi at the proximal portion of the injection lumen.
[0438] Clause 23: In some examples, the system of clause 21 further includes wherein the injector is configured to pressurize the liquid such that the flow rate varies between values that include 31 ml/min.
[0439] Clause 24: In some examples, the system of clause 21 further includes wherein the injector is configured to pressurize the liquid such that the flow rate varies between about 20 ml/min and about 45 ml/min.
[0440] Clause 25: In some examples, the system of any one of clauses 21-24 further includes wherein injector includes a drive unit configured to power the injection and a controller configured to control the drive unit.
[0441] Clause 26: In some examples, the system of clause 25 further includes wherein the drive unit includes a solenoid.
[0442] Clause 27: In some examples, the system of clause 26 further includes wherein the drive unit further includes a valve coupled to the solenoid.
[0443] Clause 28: In some examples, the system of clause 27 further includes wherein the drive unit includes a motor.
[0444] Clause 29: In some examples, the system of any one of clauses 21-25 further includes a compressible tube configured to be hydraulically coupled to the injection lumen, wherein oscillatory changes in the internal cross-sectional space at a first location of the compressible tube at least partially promotes the oscillating manner.
[0445] Clause 30: In some examples, the system of clause 29 further includes a variable pincher configured to engage an external portion of the compressible tube at the first location and to variably change the internal cross-sectional space by variable external compression.
[0446] Clause 31: In some examples, the system of clause 30 further includes wherein the variable external compression is sinusoidal.
[0447] Clause 32: In some examples, the system of any one of clauses 21-31 further includes a peristaltic pump configured for driving fluid from the distal portion of the aspiration lumen to a proximal portion of the aspiration lumen.
[0448] Clause 33: In some examples, the system of clause 32 further includes an additional compressible tube configured to be hydraulically coupled to the aspiration lumen and configured to be engaged with the peristaltic pump.
[0449] Clause 34: In some examples, the system of any one of clauses 21-33 further includes wherein the oscillating manner includes a 3-8 Hz oscillation.
[0450] Clause 35: In some examples, the system of any one of clauses 21-33 further includes wherein the oscillating manner includes a 4-7 Hz oscillation.
[0451] Clause 36: In some examples, the system of any one of clauses 21-33 further includes wherein the oscillating manner includes a 5-6 Hz oscillation.
[0452] Clause 37: In yet another example, a system for catheter-based aspiration includes an injection tube including an injection lumen having a distal orifice, and an injector configured to pressurize the liquid in an oscillating manner within the injection lumen, such that liquid exits the

distal orifice with a variable flow rate and/or variable flow velocity, wherein the injector includes a barrel having an interior, a plunger configured to sealingly change an effective volume of the interior of the barrel, and a controller configured to control movement of the plunger within the interior of the barrel.

[0453] Clause 38: In some examples, the system of clause 37 further includes wherein the controller is configured to operate a drive unit, the drive unit configured to change the relationship between the plunger and the barrel.

[0454] Clause 39: In some examples, the system of clause 38 further includes wherein the drive unit includes a screw.

[0455] Clause 40: In some examples, the system of clause 39 further includes wherein the drive unit is configured to turn the screw in a clockwise direction and to turn the screw in a counter-clockwise direction.

[0456] Clause 41: In some examples, the system of any one of clauses 38-40 further includes wherein the drive unit includes a motor.

[0457] Clause 42: In some examples, the system of clause 41 further includes wherein the controller is configured to operate the motor at a first motor speed at an initiation of a first injection cycle and to adjust to a second motor speed at a time within five seconds to two minutes from the initiation of the first injection cycle, the second motor speed lower than the first motor speed.

[0458] Clause 43: In some examples, the system of clause 42 further includes wherein the first motor speed is between 1.5 times and 3.5 times greater than the second motor speed.

[0459] Clause 44: In some examples, the system of clause 42 further includes wherein the first motor speed is between 2 times and 3 times greater than the second motor speed.

[0460] Clause 45: In some examples, the system of any one of clauses 43-44 further includes wherein the second motor speed is configured to be the main motor speed throughout the first injection cycle.

[0461] Clause 46: In some examples, the system of any one of clauses 37-41 further includes wherein the injector includes a relief valve.

[0462] Clause 47: In some examples, the system of clause 46 further includes wherein the relief valve is configured to mechanically establish a maximum injection pressure.

[0463] Clause 48: In some examples, the system of any one of clauses 37-47 further includes a switch configured to change the effect of the injection of fluid by the injector from the oscillating manner to a non-oscillating manner.

[0464] Clause 49: In some examples, the system of any one of clauses 37-47 further includes a switch configured to change the effect of the injection of fluid by the injector from the oscillating manner to a damped oscillating manner.

[0465] Clause 50: In some examples, the system of any one of clauses 41-45 further includes a transducer configured to monitor electrical current of the motor.

[0466] Clause 51: In some examples, the system of clause 50 further includes wherein the controller is configured to calculate an injection pressure of the injector based at least in part on the measured electrical current.

[0467] Clause 52: In some examples, the system of any one of clauses 37-51 further includes wherein the oscillating manner includes a 3-8 Hz oscillation.

[0468] Clause 53: In some examples, the system of any one of clauses 37-51 further includes wherein the oscillating manner includes a 4-7 Hz oscillation.

[0469] Clause 54: In some examples, the system of any one of clauses 37-51 further includes wherein the oscillating manner includes a 5-6 Hz oscillation.

[0470] Clause 55: In still another example, a system for catheter-based aspiration includes an aspiration catheter having an aspiration lumen and an injection lumen, the injection lumen having an orifice located at or near a distal end thereof, the orifice configured for directing liquid into a distal portion of the aspiration lumen, an injector configured to pressurize the liquid within the

injection lumen, such that liquid exits the orifice and enters the distal portion of the aspiration lumen, and a flow oscillator configured to cause a variable flow rate and/or variable flow velocity of the liquid that enters the distal portion of the aspiration lumen.
[0471] Clause 56: In some examples, the system of clause 55 further includes wherein the flow oscillator includes a relief valve.
[0472] Clause 57: In some examples, the system of clause 56 further includes wherein the relief valve is configured to mechanically establish a maximum injection pressure.
[0473] Clause 58: In some examples, the system of clause 55 further includes a controller configured to operate the flow oscillator.
[0474] Clause 59: In some examples, the system of any one of clauses 55 or 58 further includes wherein the flow oscillator includes a drive unit.
[0475] Clause 60: In some examples, the system of clause 59 further includes wherein the drive unit includes a screw.
[0476] Clause 61: In some examples, the system of clause 60 further includes wherein the drive unit is configured to turn the screw in a clockwise direction and to turn the screw in a counter-clockwise direction.
[0477] Clause 62: In some examples, the system of any one of clauses 59-61 further includes wherein the drive unit includes a motor.
[0478] Clause 63: In some examples, the system of clause 58 further includes wherein the flow oscillator includes a drive unit including a motor, and wherein the controller is configured to operate the motor at a first motor speed at an initiation of a first injection cycle and to adjust to a second motor speed at a time within five seconds to two minutes from the initiation of the first injection cycle, the second motor speed lower than the first motor speed.
[0479] Clause 64: In some examples, the system of clause 63 further includes wherein the first motor speed is between 1.5 times and 3.5 times greater than the second motor speed.
[0480] Clause 65: In some examples, the system of clause 63 further includes wherein the first motor speed is between 2 times and 3 times greater than the second motor speed.
[0481] Clause 66: In some examples, the system of any one of clauses 64-65 further includes wherein the second motor speed is configured to be the main motor speed throughout the first injection cycle.
[0482] Clause 67: In some examples, the system of any one of clauses 55-66 further includes a peristaltic pump configured for driving fluid from the distal portion of the aspiration lumen to a proximal portion of the aspiration lumen.
[0483] Clause 68: In some examples, the system of clause 67 further includes a compressible tube configured to be hydraulically coupled to the aspiration lumen and configured to be engaged with the peristaltic pump.
[0484] Clause 69: In some examples, the system of any one of clauses 55-68 further includes a switch configured to change the effect of the flow oscillator from an oscillating manner to a non-oscillating manner.
[0485] Clause 70: In some examples, the system of any one of clauses 55-68 further includes a switch configured to change the effect of the flow oscillator from an oscillating manner to a damped oscillating manner.
[0486] Clause 71: In some examples, the system of any one of clauses 55-68 further includes a switch configured to change the effect of the flow oscillator from a variable manner to a non-variable manner.
[0487] Clause 72: In some examples, the system of any one of clauses 63-66 further includes a transducer configured to monitor electrical current of the motor.
[0488] Clause 73: In some examples, the system of clause 72 further includes wherein the controller is configured to calculate an injection pressure of the injector based at least in part on the measured electrical current.

[0489] Clause 74: In some examples, the system of any one of clauses 55-73 further includes wherein the variable flow rate and/or variable flow velocity includes a 3-8 Hz oscillation.
[0490] Clause 75: In some examples, the system of any one of clauses 55-73 further includes wherein the variable flow rate and/or variable flow velocity includes a 4-7 Hz oscillation.
[0491] Clause 76: In some examples, the system of any one of clauses 55-73 further includes wherein the variable flow rate and/or variable flow velocity includes a 5-6 Hz oscillation.
[0492] Clause 77: In still another example, a system for catheter-based aspiration includes an aspiration catheter having an aspiration lumen and an injection lumen, the injection lumen having an orifice located at or near a distal end thereof, the orifice configured for directing liquid into a distal portion of the aspiration lumen, an injector configured to pressurize the liquid within the injection lumen, such that liquid exits the orifice and enters the distal portion of the aspiration lumen, and a flow oscillator configured to cause an oscillating pressure of the liquid that within the injection lumen.
[0493] Clause 78: In some examples, the system of clause 77 further includes wherein the flow oscillator includes a relief valve.
[0494] Clause 79: In some examples, the system of clause 78 further includes wherein the relief valve is configured to mechanically establish a maximum injection pressure.
[0495] Clause 80: In some examples, the system of clause 77 further includes a controller configured to operate the flow oscillator.
[0496] Clause 81: In some examples, the system of either one of clauses 77 or 80 further includes wherein the flow oscillator includes a drive unit.
[0497] Clause 82: In some examples, the system of clause 81 further includes wherein the drive unit includes a screw.
[0498] Clause 83: In some examples, the system of clause 82 further includes wherein the drive unit is configured to turn the screw in a clockwise direction and to turn the screw in a counter-clockwise direction.
[0499] Clause 84: In some examples, the system of any one of clauses 81-83 further includes wherein the drive unit includes a motor.
[0500] Clause 85: In some examples, the system of clause 80 further includes wherein the flow oscillator includes a drive unit including a motor, and wherein the controller is configured to operate the motor at a first motor speed at an initiation of a first injection cycle and to adjust to a second motor speed at a time within five seconds to two minutes from the initiation of the first injection cycle, the second motor speed lower than the first motor speed.
[0501] Clause 86: In some examples, the system of clause 85 further includes wherein the first motor speed is between 1.5 times and 3.5 times greater than the second motor speed.
[0502] Clause 87: In some examples, the system of clause 85 further includes wherein the first motor speed is between 2 times and 3 times greater than the second motor speed.
[0503] Clause 88: In some examples, the system of any one of clauses 86-87 further includes wherein the second motor speed is configured to be the main motor speed throughout the first injection cycle.
[0504] Clause 89: In some examples, the system of any one of clauses 77-88 further includes a peristaltic pump configured for driving fluid from the distal portion of the aspiration lumen to a proximal portion of the aspiration lumen.
[0505] Clause 90: In some examples, the system of clause 89 further includes a compressible tube configured to be hydraulically coupled to the aspiration lumen and configured to be engaged with the peristaltic pump.
[0506] Clause 91: In some examples, the system of any one of clauses 77-90 further includes a switch configured to change the effect of the flow oscillator from an oscillating manner to a non-oscillating manner.
[0507] Clause 92: In some examples, the system of any one of clauses 77-90 further includes a

switch configured to change the effect of the flow oscillator from an oscillating manner to a damped oscillating manner a switch configured to change the effect of the flow oscillator from an oscillating manner to a damped oscillating manner.
[0508] Clause 93: In some examples, the system of any one of clauses 77-90 further includes a switch configured to change the effect of the flow oscillator from a variable manner to a non-variable manner.
[0509] Clause 94: In some examples, the system of any one of clauses 85-88 further includes a transducer configured to monitor electrical current of the motor.
[0510] Clause 95: In some examples, the system of clause 94 further includes wherein the controller is configured to calculate an injection pressure of the injector based at least in part on the measured electrical current.
[0511] Clause 96: In some examples, the system of any one of clauses 77-95 further includes wherein variable pressure includes a pressure oscillation within the range of 200 pounds per square inch to 1500 pounds per square inch.
[0512] Clause 97: In some examples, the system of any one of clauses 1-11, 21-31, or 77-88 further includes a negative pressure source.
[0513] Clause 98: In some examples, the system of clause 97 further includes wherein the negative pressure source includes a variable negative pressure source.
[0514] Clause 99: In some examples, the system of clause 98 further includes wherein the variable negative pressure source is configured to deliver a variable negative pressure at a frequency of between 3 Hz and 8 Hz.
[0515] Clause 100: In still another example, a system for catheter-based aspiration includes an aspiration catheter having a distal portion configured for insertion within a blood vessel of a subject, the aspiration catheter including an aspiration lumen having a distal opening at the distal portion of the aspiration catheter, an injection lumen having a distal end at the distal portion of the aspiration catheter, and an orifice located at or near the distal end of the injection lumen, the orifice configured to direct liquid into the aspiration lumen at or near the distal opening of the aspiration lumen, the system further including an injector configured to pressurize the liquid within the injection lumen, such that liquid exits the orifice and enters the aspiration lumen, and a mechanical oscillator coupled to the injector and configured to cause a pulsatile pressure of the liquid as it is injected through the injection lumen, wherein the injector includes a barrel and a plunger, the plunger sealingly displaceable within an interior of the barrel along a longitudinal displacement axis, wherein the mechanical oscillator includes a first disk and a second disk axially arrayed with respect to each other and configured such that changes based upon relative rotational orientation between the first disk and the second disk cause reciprocal relative axial displacement between the first disk and the second disk, and wherein the first disk is coupled to the plunger and configured to transfer motive force thereto along the longitudinal displacement axis, wherein a first one of the first disk or second disk includes a first side, and the other of the first disk or second disk includes a second side, the first side facing the second side, the first side having series of circumferentially-arrayed axial dimensional variations, and the second side including a first protrusion that extends less than 180° on the second side, the first protrusion configured to physically engage with the first side such that relative rotational movement of the first protrusion with respect to the series of circumferentially-arrayed axial dimensional variations at least partially generates the reciprocal relative axial displacement, and wherein the circumferentially-arrayed axial dimensional variations include a series of radially-extending projections, and wherein the circumferentially-arrayed axial dimensional variations further include a series of radially-extending depressions, interspersed between the radially-extending projections.
[0516] Clause 101: In some examples, the system of clause 100 further includes wherein a first one of the first disk or second disk includes a ceramic, and the other of the first disk or second disk includes a metal.

[0517] Clause 102: In some examples, the system of clause 100 further includes a screw configured to drive the plunger.
[0518] Clause 103: In some examples, the system of clause 102 further includes a chain coupled between the first disk and the screw.
[0519] Clause 104: In some examples, the system of clause 102 further includes a belt coupled between the first disk and the screw.
[0520] Clause 105: In still another example, a system for catheter-based aspiration includes an aspiration catheter having a distal portion configured for insertion within a blood vessel of a subject, the aspiration catheter including an aspiration lumen having a distal opening at the distal portion of the aspiration catheter, an injection lumen having a distal end at the distal portion of the aspiration catheter, and an orifice located at or near the distal end of the injection lumen, the orifice configured to direct liquid into the aspiration lumen at or near the distal opening of the aspiration lumen, the system further including an injector configured to pressurize the liquid within the injection lumen, such that liquid exits the orifice and enters the aspiration lumen, a mechanical oscillator coupled to the injector and configured to cause a pulsatile pressure of the liquid as it is injected through the injection lumen, and a controller configured to control pulsatility of the liquid.
[0521] Clause 106: In some examples, the system of clause 105 further includes wherein the controller is configured to operate the mechanical oscillator and injector at an injection oscillation frequency of between about 1 Hz and about 8 Hz.
[0522] Clause 107: In yet another example, a system for catheter-based aspiration includes an aspiration catheter having a distal portion configured for insertion within a blood vessel of a subject, the aspiration catheter including an aspiration lumen having a distal opening at the distal portion of the aspiration catheter, an injection lumen having a distal end at the distal portion of the aspiration catheter, and an orifice located at or near the distal end of the injection lumen, the orifice configured to direct liquid into the aspiration lumen at or near the distal opening of the aspiration lumen, the system further including an injector configured to pressurize the liquid within the injection lumen, such that liquid exits the orifice and enters the aspiration lumen, a mechanical oscillator coupled to the injector and configured to cause a pulsatile pressure of the liquid as it is injected through the injection lumen, and a negative pressure source configured to couple to a proximal portion of the aspiration lumen of the aspiration catheter.
[0523] Clause 108: In some examples, the system of clause 107 further includes wherein the negative pressure source includes a peristaltic pump.
[0524] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments may be devised without departing from the basic scope thereof.
[0525] The ranges disclosed herein also encompass any and all overlap, sub-ranges, and combinations thereof. Language such as “up to,” “at least,” “greater than,” “less than,” “between,” and the like includes the number recited. Numbers preceded by a term such as “approximately”, “about”, and “substantially” as used herein include the recited numbers (e.g., about 10%=10%), and also represent an amount close to the stated amount that still performs a desired function or achieves a desired result. For example, the terms “approximately”, “about”, and “substantially” may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of the stated amount.
[0526] For purposes of the present disclosure and appended claims, the conjunction “or” is to be construed inclusively (e.g., “an apple or an orange” would be interpreted as “an apple, or an orange, or both”; e.g., “an apple, an orange, or an avocado” would be interpreted as “an apple, or an orange, or an avocado, or any two, or all three”), unless: (i) it is explicitly stated otherwise, e.g., by use of “either . . . or,” “only one of,” or similar language; or (ii) two or more of the listed alternatives are mutually exclusive within the particular context, in which case “or” would encompass only those combinations involving non-mutually-exclusive alternatives. For purposes of the present disclosure and appended claims, the words “comprising,” “including,” “having,” and

variants thereof, wherever they appear, shall be construed as open-ended terminology, with the same meaning as if the phrase “at least” were appended after each instance thereof.

Claims

1-15. (canceled)
16. (canceled)
17. A method for catheter-based aspiration, comprising: providing a catheter having a distal portion configured for insertion within a blood vessel of a subject, the catheter comprising: a first lumen having a distal opening at the distal portion of the catheter; a second lumen having a distal end at the distal portion of the catheter; and an orifice located at or near the distal end of the second lumen, the orifice configured to direct liquid into the first lumen at or near the distal opening of the first lumen; and actuating an injector in a non-uniform manner to cause a pulsatile pressure of a liquid in the second lumen as the liquid is injected through the second lumen, wherein actuating the injector in a non-uniform manner comprises repeatedly displacing a plunger in an interior of a barrel in a first direction along a longitudinal displacement axis by an increment, followed by movement of the barrel in a second direction, opposite the first direction.
18. The method of claim 17, wherein movement of the barrel in the second direction corresponds to recoil of the injector following displacement thereof.
19. The method of claim 18, wherein the recoil is a controlled recoil corresponding to a predetermined amount of movement in the second direction.
20. The method of claim 17, wherein movement of the barrel in the second direction corresponds to controlled mechanical slip within an actuator.
21. The method of claim 17, wherein repeatedly displacing the plunger comprises displacing the plunger at a frequency of between 1 Hz and 8 Hz.
22. The method of claim 17, further comprising reducing a pressure of the liquid in the second lumen to bring or maintain the pressure of the liquid below an injection pressure threshold.
23. The method of claim 22, wherein reducing the pressure of the liquid in the second lumen comprises actuating a valve in pressure communication with the second lumen.
24. The method of claim 17, further comprising utilizing a mechanical oscillator coupled to the injector to at least partially cause the pulsatile pressure of the liquid, the mechanical oscillator comprising a first member and a second member axially arrayed with respect to each other and configured such that changes in a relative rotational orientation between the first member and the second member cause reciprocal relative axial displacement between the first member and the second member, and wherein the first member is coupled to the plunger and configured to transfer motive force thereto along the longitudinal displacement axis.
25-30. (canceled)