

SYRINGE WITH ROLLING DIAPHRAGM

CROSS-REFERENCE TO APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/984,386, entitled "Syringe With Rolling Diaphragm" and filed on April 25, 2014, and U.S. Provisional Patent Application No. 61/987,086, entitled "Syringe With Rolling Diaphragm" and filed on May 1, 2014, the disclosures of which are incorporated by reference herein in their entirety.

BACKGROUND OF THE DISCLOSURE

Field of the Disclosure

[0002] The present disclosure is related to syringes for use in the medical field and, more particularly, to syringes used in the medical field where the syringe includes a rolling diaphragm for selectively filling the syringe with a fluid and discharging the fluid from the syringe.

Description of Related Art

[0003] In many medical diagnostic and therapeutic procedures, a medical practitioner, such as a physician, injects a patient with one or more medical fluids. In recent years, a number of injector-actuated syringes and fluid injectors for pressurized injection of medical fluids, such as a contrast solution (often referred to simply as "contrast"), a flushing agent, such as saline, and other medical fluids, have been developed for use in procedures such as angiography, computed tomography (CT), ultrasound, magnetic resonance imaging (MRI), positron emission tomography (PET), and other molecular imaging procedures. In general, these fluid injectors are designed to deliver a preset amount of fluid at a preset pressure and/or flow rate.

[0004] In some injection procedures, the medical practitioner places a catheter or a needle connected to tubing, or other fluid delivery connection into a vein or artery of the patient. The catheter or the tubing is connected to either a manual or to an automatic fluid injection mechanism. Automatic fluid injection mechanisms typically include at least one syringe connected to at least one fluid injector having, for example, at least one powered linear piston. The at least one syringe includes, for example, a source of contrast and/or a source of flushing fluid. The medical practitioner enters settings into an electronic control system of the fluid injector for a fixed volume of contrast and/or saline and a fixed rate of injection for each.

[0005] The injected contrast and/or saline are delivered to a patient's vasculature through the catheter or needle inserted into the patient's body, such as the patient's arm or groin area. A dose of contrast is referred to as a bolus. Once the bolus of contrast is delivered to the desired site, that area is imaged using a conventional imaging technique, such as angiography imaging or scanning, CT, ultrasound, MRI, PET, and other molecular imaging procedures. The presence of the contrast becomes clearly visible against the background of the surrounding tissue.

[0006] A number of injector-actuated syringes and powered injectors for use in medical procedures have been developed. Typically, injectors have drive members, such as pistons, that connect to a syringe plunger. The syringe generally includes a rigid barrel with the syringe plunger being slidably disposed within the barrel. The drive members drive the plungers in a proximal and/or distal direction relative to a longitudinal axis of the barrel to aspirate a fluid into the syringe barrel or deliver the fluid from the syringe barrel.

[0007] It is well known that syringes used in the medical field are typically disposable and are discarded after one use. Although disposable syringes are typically made by mass production methods such as injection molding, such disposable syringes are relatively expensive due to the materials and precision involved in their manufacture. Accordingly, it remains desirable to develop improved designs of syringes to facilitate injection procedures.

SUMMARY OF THE DISCLOSURE

[0008] The present disclosure generally relates to syringe assemblies and to methods of forming syringe assemblies. The syringe assemblies may be useful in fluid delivery applications.

[0009] In one aspect, a rolling diaphragm for receiving a medical fluid therein may have a proximal end having an end wall for engagement with a plunger and a distal end received within a throughbore of a pressure jacket, the distal end having a nozzle. The rolling diaphragm may further include a sidewall extending between the proximal end and the distal end along a longitudinal axis. At least a portion of at least one of the sidewall and the end wall having non-uniform thickness. At least a portion of the sidewall may be flexible and rolls upon itself when acted upon by the plunger such that an outer surface of the sidewall at a folding region is folded in a radially inward direction as the plunger is advanced from the proximal end to the distal end and such that the outer surface of the sidewall at the folding region is unfolded in a radially outward direction as the plunger is retracted from the proximal end to the distal end.

[0010] In another aspect, the end wall may have a radiused folding edge that transitions into a distally extending ramp having continuously increasing thickness. The end wall may have a plunger engagement portion protruding proximally from a central region of the ramp. The end wall may have one or more ribs protruding radially outward from the plunger engagement portion toward the radiused folding edge. The rolling diaphragm may have a conical shape that narrows from the proximal end toward the distal end. The conical shape may narrow continuously or discontinuously from the proximal end toward the distal end. The proximal end may be inverted from a first convex configuration to a second concave configuration upon engagement with the plunger. The outer surface of the sidewall may have one or more grooves recessed radially inward into the sidewall. The outer surface of the sidewall may have one or more projections protruding radially outward from the sidewall. In some aspects, the rolling diaphragm may have a spherical shape or an ellipsoid shape. The rolling diaphragm may have an elliptical cross-section having a major axis extending along the longitudinal axis and a minor axis extending perpendicular to the longitudinal axis.

[0011] In accordance with another aspect, the rolling diaphragm may have a first portion extending from an approximate longitudinal midpoint of the rolling diaphragm to the distal end and a second portion that is complementary in shape to the first portion and extending from the first portion to the proximal end. The rolling diaphragm may further have a pressure sleeve surrounding at least a portion of an outer portion of the sidewall. The pressure sleeve may have one or more openings extending through the sidewall of the pressure sleeve. The one or more openings may be connected to a vacuum source. A first portion distal of an approximate midpoint of the rolling diaphragm may have a first inner diameter, and a second portion proximal of the approximate midpoint of the rolling diaphragm may have a second inner diameter. The first inner diameter may be larger than the second inner diameter. A first portion of the sidewall distal of an approximate midpoint of the rolling diaphragm may have a first thickness, wherein a second portion of the sidewall proximal of the approximate midpoint of the rolling diaphragm may have a second thickness. The first thickness may be larger than the second thickness. The proximal end may have a rigid plunger monolithically formed with the proximal end. The plunger may be overmolded with the proximal end. The outer surface of the sidewall may be in contact with a rigid outer shell. The sidewall of the rolling diaphragm may separate from the rigid outer shell as the sidewall rolls upon itself during advancement of the plunger from the

proximal end to the distal end. At least a portion of the outer surface of the sidewall of the rolling diaphragm is adhered to the rigid outer shell by an adhesive. The adhesive may be a pressure-activated adhesive. At least a portion of the outer surface of the sidewall may have an adhesive that adheres the outer surface of the sidewall with the plunger during advancement of the plunger from the proximal end to the distal end.

[0012] In accordance with another aspect, the sidewall may have a non-uniform thickness between the proximal end and the distal end. A proximal portion of the sidewall may have a thicker sidewall thickness than the distal portion of the sidewall. A proximal portion of the sidewall may have a thinner sidewall thickness than the distal portion of the sidewall. A heat-shrinkable layer may surround at least a portion of the outer surface of the sidewall. The folding region may initiate rolling of the sidewall as the plunger is advanced from the proximal end to the distal end of the rolling diaphragm. The outer surface of the sidewall may have a plurality of tabs, each tab having a first end connected to the outer surface of the sidewall and a second end protruding radially outward relative to the first end. Each of the plurality of tabs may be radially deflectable. The sidewall of the rolling diaphragm may have one or more indicia for indicating a presence of a liquid within an interior volume of the rolling diaphragm. An interior of the rolling diaphragm may be pre-filled with a medical fluid to be delivered to a patient. An interior of the rolling diaphragm may be filled with a medical fluid from a fluid source for delivery to a patient.

[0013] In accordance with another aspect, a fluid delivery system may include a fluid injector having at least one reciprocally operable piston, a plunger operably connectable to the piston, a pressure jacket releasably connectable to the fluid injector, and a rolling diaphragm disposed within the throughbore of a pressure jacket. The rolling diaphragm may have a proximal end with an end wall for engagement with a plunger, a distal end configured to be received at the distal end of the pressure jacket, and a sidewall extending between the proximal end and the distal end of the rolling diaphragm along a longitudinal axis. At least one of the end wall and at least a portion of the sidewall having a non-uniform thickness. The sidewall of the rolling diaphragm may be flexible and configured to roll upon itself such that an outer surface of the sidewall at a folding region is folded in a radially inward direction as the plunger is advanced from the proximal end to the distal end of the rolling diaphragm and such that the outer surface of the sidewall at the folding region is unfolded in a radially outward direction as the plunger is retracted from the proximal end to the distal end of the rolling diaphragm.

[0014] In accordance with another aspect, the plunger may have a skirt extending radially around a body of the plunger. An outer diameter of the skirt may be dimensioned such that the skirt is compressed against the sidewall of the rolling diaphragm to discharge fluid from the interior of the rolling diaphragm as the plunger is advanced in a distal direction. The plunger may have a fluid-filled cavity with a reciprocally movable piston extending into at least a portion of the fluid-filled cavity. The plunger may be monolithically formed with the proximal end of the rolling diaphragm. The plunger may have a groove shaped in a distal end of the plunger. The proximal end of the rolling diaphragm may have a projection configured for being inserted into and retained within the groove of the plunger. The groove may be T-shaped. The plunger may have a connection interface for releasably connecting to a piston of the fluid injector such that the plunger is reciprocally driven by the piston. The plunger may have a first threaded member and the proximal end of the rolling diaphragm may have a second threaded member. The first threaded member of the plunger may be releasably connectable with the second threaded member of the rolling diaphragm.

[0015] In another aspect, the distal end of the plunger may have one or more radially-expandable ribs. The distal end of the plunger may have one or more rotatable elements such that rotation of the one or more rotatable elements in a first direction causes an expansion of the radially-expandable ribs and rotation of the one or more rotatable elements in a second direction causes a retraction of the radially-expandable ribs. The distal end of the plunger may have a slot configured for receiving a projection on the proximal end of the rolling diaphragm. The plunger may be rotated after the projection on the proximal end of the rolling diaphragm is inserted into the slot to lock the plunger with the rolling diaphragm. The plunger may have a plurality of concentric elements arranged in a telescoping orientation relative to one another. Each of the plurality of concentric elements may be movable independently in a proximal or a distal direction. The plunger may be co-molded with the proximal end of the rolling diaphragm. The plunger may have a first element and a second annular element surrounding the first element. The first element may be movable relative to the second element between a first position and a second position. In the first position, the second element may engage the sidewall of the rolling diaphragm, and, in the second position, the second element may disengage the sidewall of the rolling diaphragm.

[0016] In another aspect, the plunger may be compressible by the piston such that the plunger expands radially outward to engage the sidewall of the rolling diaphragm when the piston moves in a distal direction. The plunger may have a first inner element and a second outer element, such that the first inner element may be movable relative to the second element between a first position and a second position. In the first position, the second outer element may be expanded radially outward to engage the sidewall of the rolling diaphragm. In the second position, the second outer element may be retracted radially inward to disengage the sidewall of the rolling diaphragm. The plunger may have an inner element, an elastic element wrapped around at least a portion of the inner element, and an expandable outer element surrounding the inner element and the elastic element. Upon rotation of the elastic element around the inner element in a first direction, the expandable outer element may be expanded radially outward. Upon rotation of the elastic element around the inner element in a second direction opposite the first direction, the expandable outer element may be contracted radially inward. An outer surface of the expandable outer element may be textured. The expandable outer element may have a slit extending in a longitudinal direction between a proximal end of the expandable outer element and the distal end of the expandable outer element.

[0017] In accordance with another aspect, the rolling diaphragm may have a radial lip that is inverted from a radially outward position to a radially inward position upon engagement by the plunger such that at least a portion of the plunger is retained between the proximal end of the rolling diaphragm and the radial lip. The plunger may have a central opening configured to receive a plunger engagement portion, such as a tab, protruding from the proximal end of the rolling diaphragm. The tab may be permanently secured within at least a portion of the central opening. At least a portion of the tab may be expanded radially outward after it is inserted into the central opening to retain the tab within the central opening. The tab may be adhesively secured within at least a portion of the central opening. The plunger may have a cylindrical plunger body having one or more projections protruding radially outward from an outer surface of the cylindrical plunger body. The one or more projections may be configured for engaging the sidewall of the rolling diaphragm. At least one of the one or more projections may be angled in a proximal direction from the proximal end to the distal end of the plunger. An outer surface of the plunger may have a first threaded portion and an inner surface of the sidewall of the rolling diaphragm has a second threaded portion. At least one of the first threaded portion and

the second threaded portion may be discontinuous. The proximal end of the rolling diaphragm may have a proximally-extending connection element with a radial tab.

[0018] In another aspect, the piston may have a locking arrangement for releasably receiving the connection element. The locking arrangement may have an annular recess configured to receive at least a portion of the connection element and the radial tab, and a locking element selectively movable between a first position where the radial tab of the connection element is locked within the annular recess and a second position where the radial tab of the connection element is removable from the annular recess. The locking element may be slidable from the first position to the second position. The locking element may be rotatable from the first position to the second position. The sidewall of the rolling diaphragm may have one or more radially-protruding gripping elements that are inverted from a radially-outward facing position to a radially-inward facing position when the plunger engages the proximal end of the rolling diaphragm. The plunger may have one or more gripping elements that correspond to the gripping elements on the sidewall of the rolling diaphragm.

[0019] In another aspect, a syringe for a fluid delivery system may have a pressure jacket having a distal end, a proximal end, and a throughbore extending between the distal end and the proximal end. The syringe may further include a rolling diaphragm disposed within the throughbore of the pressure jacket. The rolling diaphragm may have a proximal end with an end wall configured for engagement with a plunger, a distal end configured to be received at the distal end of the pressure jacket, and a sidewall extending between the proximal end and the distal end of the rolling diaphragm along a longitudinal axis. At least one of the end wall and at least a portion of the sidewall having a non-uniform thickness. At least a portion of the sidewall of the rolling diaphragm may be flexible and configured to roll upon itself such that an outer surface of the sidewall at a folding region is folded in a radially inward direction as the plunger is advanced from the proximal end to the distal end of the rolling diaphragm and such that the outer surface of the sidewall at the folding region is unfolded in a radially outward direction as the plunger is retracted from the proximal end to the distal end of the rolling diaphragm.

[0020] In a further aspect, the pressure jacket may have a frusto-conical portion that terminates in an outlet portion configured to receive a nozzle of the rolling diaphragm. The proximal end of the pressure jacket may have a removable seal sealing the rolling diaphragm and a plunger prior to use. The pressure jacket may have a first portion and a second portion

pivotally connected together by a hinge. The first portion and the second portion may be lockable in a closed state. The pressure jacket may have a removable closure for enclosing at least a portion of the rolling diaphragm. The removable closure may have a threaded end for engaging corresponding threads on the distal end of the pressure jacket. The proximal end of the pressure jacket may have a connection interface configured for releasably connecting to a fluid injector. The proximal end of the pressure jacket may have a connection interface configured for releasably connecting to a fluid injector. The distal end of the pressure jacket may have a removable closure for enclosing at least a portion of the rolling diaphragm. The pressure jacket may have a shield protruding radially outward from the proximal end, the shield configured for engaging at least a portion of a housing of a fluid injector. The pressure jacket may have an annular flange slidably mounted to an outer portion of the sidewall of the pressure jacket. The annular flange may be slidable between a first position for locking the pressure jacket with the injector and a second position for unlocking the pressure jacket from the injector.

[0021] In some aspects, the pressure jacket may be reusable with an unused rolling diaphragm after a used rolling diaphragm is removed from the pressure jacket. The pressure jacket may be disposable with the rolling diaphragm. The pressure jacket may have a first removable cap enclosing the distal end of the pressure jacket and a second removable cap enclosing the proximal end of the pressure jacket. The distal end of the pressure jacket may be expandable radially outward relative to the proximal end of the pressure jacket for inserting or removing the rolling diaphragm from the throughbore of the pressure jacket. The pressure jacket may be permanently connected with a fluid injector. The pressure jacket may be releasably connected with a fluid injector. An adapter may be provided, the adapter having a first end for connecting to the fluid injector and a second end for releasably receiving the proximal end of the pressure jacket. The pressure jacket may have a flange protruding radially outward from an outer surface of the sidewall of the pressure jacket. The flange may have one or more openings extending through the flange in an axial direction. A flexible fluid container may be provided within an interior of the pressure jacket. The flexible fluid container may surround the rolling diaphragm. The flexible fluid container may be positioned proximally from the rolling diaphragm within an interior of the pressure jacket. The pressure jacket may have a heating element for heating the rolling diaphragm.

[0022] In another aspect, the rolling diaphragm may have a nozzle monolithically formed with the sidewall of the rolling diaphragm. The nozzle may have a connector configured for connecting to a fluid path set. The connector may be a luer connector. The nozzle may have a piercable seal configured to seal an interior of the rolling diaphragm. The nozzle may have a first seal between the nozzle and the sidewall of the rolling diaphragm and a second seal at an interface for connecting the nozzle to a fluid path set. The nozzle may have a removable cap. A fluid path set may be provided, the fluid path set having a puncture element and a seal. The seal may have a seal surface that corresponds to a shape of the piercable seal on the nozzle of the rolling diaphragm.

[0023] Further details and advantages of the various aspects described in detail herein will become clear upon reviewing the following detailed description of the various aspects in conjunction with the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] **FIG. 1** is a perspective view of a fluid injection system according to one aspect of the present disclosure.

[0025] **FIG. 2** is a perspective, cross-sectional view of a portion of the fluid injection system shown in **FIG. 1**.

[0026] **FIG. 3** is a side view of a rolling diaphragm in accordance with one aspect of the present disclosure.

[0027] **FIG. 4A** is a side view a rolling diaphragm in accordance with another aspect of the present disclosure, with the rolling diaphragm shown in an uncompressed state.

[0028] **FIG. 4B** is a side view the rolling diaphragm shown in **FIG. 4A** in a compressed state.

[0029] **FIG. 5A** is a side view a rolling diaphragm in accordance with another aspect of the present disclosure.

[0030] **FIG. 5B** is a cross-sectional side view the rolling diaphragm shown in **FIG. 5A** taken along line A-A.

[0031] **FIG. 6** is a cross-sectional side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0032] FIG. 7 is a cross-sectional side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0033] FIG. 8A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure where the plunger is shown in a first position.

[0034] FIG. 8B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 8A where the plunger is shown in a second position.

[0035] FIG. 9A is a partial cross-sectional side view of a rolling diaphragm in accordance with another aspect of the present disclosure where the rolling diaphragm is shown in a first state.

[0036] FIG. 9B is a partial cross-sectional side view of the rolling diaphragm shown in FIG. 9A with the rolling diaphragm shown in a second state after engagement with a plunger.

[0037] FIG. 10A is a side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0038] FIG. 10B is a partial side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0039] FIG. 11A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first state.

[0040] FIG. 11B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 11A, with the plunger shown in a second state.

[0041] FIG. 12A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first state.

[0042] FIG. 12B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 12A, with the plunger shown in a second state.

[0043] FIG. 13A is a cross-sectional side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0044] FIG. 13B is a cross-sectional side view of the rolling diaphragm shown in FIG. 12A, where the rolling diaphragm is engaged by a plunger.

[0045] FIG. 14A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0046] FIG. 14B is a cross-sectional side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0047] FIG. 15A is a perspective side view of a rolling diaphragm and an annular sleeve surrounding at least a portion of the rolling diaphragm in accordance with another aspect of the present disclosure.

[0048] FIG. 15B is a perspective side view of a rolling diaphragm and an annular shrink-wrap sleeve surrounding at least a portion of the rolling diaphragm in accordance with another aspect of the present disclosure.

[0049] FIG. 15C is a perspective side view of a rolling diaphragm and a heating element surrounding at least a portion of the rolling diaphragm in accordance with another aspect of the present disclosure.

[0050] FIG. 16A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0051] FIG. 16B is a cross-sectional side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0052] FIG. 17A is a perspective side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0053] FIG. 17B is a top view of the rolling diaphragm shown in FIG. 17A.

[0054] FIG. 18 is a side view of a rolling diaphragm in accordance with another aspect of the present disclosure.

[0055] FIG. 19 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0056] FIG. 20A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0057] FIG. 20B is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0058] FIG. 20C is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0059] FIG. 21A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0060] FIG. 21B is a perspective side view of a plunger in accordance with another aspect of the present disclosure.

[0061] FIG. 21C is a perspective side view of a rolling diaphragm and the plunger shown in FIG. 21B.

[0062] FIG. 22 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0063] FIG. 23 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0064] FIG. 24A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0065] FIG. 24B is a perspective view of a plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first, retracted state.

[0066] FIG. 24C is a perspective view of the plunger illustrated in FIG. 24B shown in a second, expanded state.

[0067] FIG. 25A is a perspective view of a plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first, retracted state.

[0068] FIG. 25B is a perspective view of the plunger illustrated in FIG. 25A shown in a second, expanded state.

[0069] FIG. 25C is a side view of a rolling diaphragm and the plunger shown in FIGS. 25A-25B.

[0070] FIG. 26A is a perspective view of a plunger in accordance with another aspect of the present disclosure.

[0071] FIG. 26B is a top view of the plunger shown in FIG. 26A.

[0072] FIG. 27 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0073] FIG. 28A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first axial position.

[0074] FIG. 28B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 28A, with the plunger shown in a second axial position.

[0075] FIG. 28C is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 28A, with the plunger shown in a third axial position.

[0076] FIG. 29 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0077] FIG. 30 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0078] FIG. 31 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0079] FIG. 32A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0080] FIG. 32B is a top view of the plunger shown in FIG. 32A.

[0081] FIG. 33A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first axial position.

[0082] FIG. 33B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 33A, with the plunger shown in a second axial position.

[0083] FIG. 34A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first axial position.

[0084] FIG. 34B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 34A, with the plunger shown in a second axial position.

[0085] FIG. 34C is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure

[0086] FIG. 35 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0087] FIG. 36A is a perspective view of a plunger in accordance with another aspect of the present disclosure.

[0088] FIG. 36B is a cross-sectional side view of the plunger shown in FIG. 36A and a rolling diaphragm.

[0089] FIG. 37 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0090] FIG. 38 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0091] FIG. 39A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first axial position.

[0092] FIG. 39B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 39A, with the plunger shown in a second axial position.

[0093] FIG. 40 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0094] FIG. 41A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first axial position.

[0095] FIG. 41B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 41A, with the plunger shown in a second axial position.

[0096] FIG. 41C is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 41A, with the plunger shown in a third axial position.

[0097] FIG. 42 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0098] FIG. 43 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[0099] FIG. 44 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[00100] FIG. 45 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure.

[00101] FIG. 46A is a cross-sectional side view of a plunger in accordance with another aspect of the present disclosure.

[00102] FIG. 46B is a cross-sectional side view of a rolling diaphragm and the plunger shown in FIG. 46A.

[00103] FIG. 47A is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure, with the plunger shown in a first axial position.

[00104] FIG. 47B is a cross-sectional side view of the rolling diaphragm and plunger shown in FIG. 47A, with the plunger shown in a second axial position.

[00105] FIG. 48A is a partially-exploded perspective view of a syringe having a pressure jacket, a rolling diaphragm, and plunger in accordance with another aspect of the present disclosure.

[00106] FIG. 48B is a cross-sectional side view of the syringe shown in FIG. 48A.

[00107] FIG. 49A is a partially-exploded perspective view of a syringe having a pressure jacket, a rolling diaphragm, and plunger in accordance with another aspect of the present disclosure.

[00108] FIG. 49B is a cross-sectional side view of the syringe shown in FIG. 49A.

[00109] FIG. 50A is a partially-exploded perspective view of a syringe having a pressure jacket, a rolling diaphragm, and plunger in accordance with another aspect of the present disclosure.

[00110] FIG. 50B is a perspective view of a pressure jacket for use with a syringe.

[00111] FIG. 51 is a cross-sectional side view of a syringe having a pressure jacket, a rolling diaphragm, and plunger in accordance with another aspect of the present disclosure.

[00112] FIG. 52A is a partially-exploded side cross-sectional view of a syringe having a pressure jacket, a rolling diaphragm, and plunger in accordance with another aspect of the present disclosure.

[00113] FIG. 52B is a partially-exploded side cross-sectional view of a syringe having a pressure jacket, a rolling diaphragm, and plunger in accordance with another aspect of the present disclosure.

[00114] FIG. 53 is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00115] FIG. 54 is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00116] FIG. 55A is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00117] FIG. 55B is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00118] FIG. 56A is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00119] FIG. 56B is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00120] FIG. 57 is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00121] FIG. 58A is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure.

[00122] FIG. 58B is a partial cross-sectional perspective view of a seal shown in FIG. 58A.

[00123] FIG. 59 is a side cross-sectional view of a syringe in accordance with another aspect of the present disclosure.

[00124] FIG. 60A is a side cross-sectional view of a seal for use with a syringe in accordance with another aspect of the present disclosure, with a seal piercing element shown in a first position.

[00125] FIG. 60B is a side cross-sectional view of the seal shown in FIG. 60B, with the seal piercing element shown in a second position.

[00126] FIG. 61 is a side cross-sectional view of a rolling diaphragm and a plunger in accordance with another aspect of the present disclosure.

[00127] FIG. 62 is a side cross-sectional view of a pressure jacket in accordance with another aspect of the present disclosure.

[00128] FIG. 63A is a perspective view of a syringe having a pressure jacket in accordance with another aspect of the present disclosure.

[00129] FIG. 63B is a cross-sectional side view of the syringe shown in FIG. 63A.

[00130] FIG. 63C is a perspective view of a rolling diaphragm for use with the pressure jacket shown in FIG. 63A.

[00131] FIG. 64A is a top perspective view of an alternative embodiment for a cap for use with the pressure jacket shown in FIG. 63A.

[00132] FIG. 64B is a bottom perspective view of the cap shown in FIG. 64A.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[00133] The illustrations generally show preferred and non-limiting aspects of the systems and methods of the present disclosure. While the description presents various aspects of the devices, it should not be interpreted in any way as limiting the disclosure. Furthermore, modifications, concepts, and applications of the disclosure's aspects are to be interpreted by those skilled in the art as being encompassed, but not limited to, the illustrations and descriptions herein.

[00134] The following description is provided to enable those skilled in the art to make and use the described aspects contemplated for carrying out the disclosure. Various modifications, equivalents, variations, and alternatives, however, will remain readily apparent to those skilled in the art. Any and all such modifications, variations, equivalents, and alternatives are intended to fall within the spirit and scope of the present disclosure.

[00135] For purposes of the description hereinafter, the terms “upper”, “lower”, “right”, “left”, “vertical”, “horizontal”, “top”, “bottom”, “lateral”, “longitudinal”, and derivatives thereof shall relate to the disclosure as it is oriented in the drawing figures. When used in relation to a syringe, a pressure jacket, and/or a rolling diaphragm, the term “proximal” refers to a portion of a syringe, a pressure jacket, and/or a rolling diaphragm nearest to an injector when a syringe, a pressure jacket, and/or a rolling diaphragm is oriented for connecting to an injector. The term “distal” refers to a portion of a syringe, a pressure jacket, and/or a rolling diaphragm farthest away from an injector when a syringe, a pressure jacket, and/or a rolling diaphragm is oriented for connecting to an injector. The term “radial” refers to a direction in a cross-sectional plane normal to a longitudinal axis of a syringe, a pressure jacket, and/or a rolling diaphragm extending between proximal and distal ends. The term “circumferential” refers to a direction around an inner or outer surface of a sidewall of a syringe, a pressure jacket, and/or a rolling diaphragm. The term “axial” refers to a direction along a longitudinal axis of a syringe, a pressure jacket, and/or a rolling diaphragm extending between the proximal and distal ends. It is to be understood, however, that the disclosure may assume alternative variations and step sequences, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification, are simply exemplary embodiments of the disclosure. Hence, specific dimensions and other physical characteristics related to the embodiments (*i.e.*, aspects, variants, variations) disclosed herein are not to be considered as limiting.

[00136] Referring to the drawings in which like reference characters refer to like parts throughout the several views thereof, the present disclosure is generally directed to syringe configured as a rolling diaphragm.

[00137] With reference to **FIG. 1**, a fluid delivery system **100** may have a fluid injector **102**, such as an automated or powered fluid injector, adapted to interface with and actuate at least one rolling diaphragm **112** and pressure jacket **110**, as described herein, each of which may be independently filled with a medical fluid, such as contrast media, saline solution, or any desired medical fluid. The injector **102** may be used during a medical procedure to inject the medical fluid into the body of a patient by driving a plunger **144** of the at least one rolling diaphragm **112** with at least one piston. The injector **102** may be a multi-rolling diaphragm injector, wherein two or more rolling diaphragms **112** with corresponding pressure jackets **110** may be oriented in a side-by-side or other relationship and include corresponding plungers **144** separately actuated by respective pistons associated with the injector **102**. In embodiments with two rolling diaphragm/pressure jackets arranged in a side-by-side relationship and filled with two different medical fluids, the injector **102** may be configured to deliver fluid from one or both of the rolling diaphragms **112**.

[00138] The injector **102** may be enclosed within a housing **126** formed from a suitable structural material, such as plastic or metal. The housing **126** may be of various shapes and sizes depending on the desired application. For example, the injector **102** may be a free-standing structure configured to be placed on the floor or may be a smaller design for placement on a suitable table or support frame. The injector **102** includes at least one port for connecting the at least one rolling diaphragm **112** and pressure jacket **110** to respective piston elements.

[00139] At least one fluid path set **108** may be fluidly connected with a nozzle **130** of the at least one syringe **104** comprising a rolling diaphragm **112** and pressure jacket **110** for delivering medical fluid from the at least one rolling diaphragm **112** to a catheter, needle, or other fluid delivery connection (not shown) inserted into a patient at a vascular access site. Fluid flow from the at least one syringe **104** may be regulated by a fluid control module (not shown). The fluid control module may operate various pistons, valves, and/or flow regulating structures to regulate the delivery of the medical fluid, such as saline solution and contrast, to the patient based on user selected injection parameters, such as injection flow rate, duration, total injection volume, and/or ratio of contrast media and saline. One embodiment of a suitable front-loading fluid injector that

may be modified for use with the herein-described system including at least one rolling diaphragm and at least one interface for loading and releasable retaining of the at least one rolling diaphragm and pressure jacket with the fluid injector described herein with reference to **FIG. 1** is disclosed in United States Patent No. 5,383,858 to Reilly et al. which is incorporated by reference in its entirety. Another embodiment of relevant multi-fluid delivery systems that may be modified for use with the present system are found in United States Patent No. 7,553,294 to Lazzaro et al.; United States Patent No. 7,666,169 to Cowan et al.; International Patent Application No. PCT/US2012/037491 (published as WO 2012/155035); and United States Patent Application Publication No. 2014/0027009 to Riley et al.; all of which are assigned to the assignee of the present application, and the disclosures of which are incorporated herein by reference. Other embodiments may include new fluid injector systems designed to include various embodiments of the rolling diaphragm described herein.

[00140] **FIG. 2** is a perspective, cross-sectional view of a portion of the fluid injector **102** shown in **FIG. 1**. With reference to **FIG. 2**, the syringe **104** generally includes a cylindrical body or pressure jacket **110** and a rolling diaphragm **112** that interfaces with the pressure jacket **110**. As will be described hereinafter, the rolling diaphragm **112** defines an interior volume **114** for receiving a fluid therein. The rolling diaphragm **112** is configured for being inserted into at least a portion of the pressure jacket **110** and the pressure jacket **110** is configured for engagement with fluid injector **102**. The syringe **104** is adapted for use in CT, MRI, PET, and like procedures and operable at typical operating pressures of, for example, about 200-400 psi. In some aspects, the rolling diaphragm **112** may be a bladder syringe described in U.S. Patent Application No. 13/881,072, entitled “Bladder Syringe Fluid Delivery System”, or a syringe described in U.S. Patent Application No. 13/834,624, entitled “Bellows Syringe Fluid Delivery System”, the disclosures of which are incorporated herein by reference in their entirety.

[00141] The cylindrical body of pressure jacket **110** may be a unitary, typically cylindrical body having a distal end **116** and a proximal end **118** with a throughbore **T** extending between the distal end **116** and the proximal end **118**. The pressure jacket **110** is typically a reusable component, while the rolling diaphragm **112** is typically a single-use component. In another aspect, the rolling diaphragm **112** may be reusable such that the rolling diaphragm **112** is refillable with fluid. For example, the rolling diaphragm **112** can be pre-filled with fluid, or can be initially empty, and can be filled and/or refilled one or more times. In another aspect, both the

pressure jacket **110** and the rolling diaphragm **112** may be single-use components that are disposed of after each patient use. In this aspect, both the pressure jacket **110** and the rolling diaphragm **112** are disposed of after use and a new pressure jacket **110** and rolling diaphragm **112** are loaded into the fluid injector **102**. The pressure jacket **110** has a sidewall **120** that defines a throughbore between the distal and proximal ends **116**, **118**. The proximal end **118** is adapted to interface with the fluid injector **102** and includes one or more mounting structures **122** positioned to engage a locking mechanism at the front end or face plate **124** of the housing **126** of the fluid injector **102** to properly seat the pressure jacket **110** relative to the fluid injector **102**. As an example, two opposed bayonet attachment flanges may be provided on the proximal end **118** for interfacing with the fluid injector face plate **124** to secure the pressure jacket **110** to the fluid injector **102**. In some aspects, the pressure jacket **110** may have a connection interface to releasably secure the pressure jacket to the fluid injector **102** in the form of a connection interface described in U.S. Patent Application No. 14/526,294, entitled “Self-Orienting Syringe and Syringe Interface”, or in U.S. Patent Application No. 14/526,395, entitled “Self-Orienting Syringe and Syringe Interface”, the disclosures of which are incorporated herein by reference in their entirety. In another aspect, an adapter may be provided for connecting the pressure jacket **110** and rolling diaphragm **112** to the fluid injector **102**.

[00142] The distal end **116** of the pressure jacket **110** may include a substantially frusto-conical portion that terminates in an outlet port **128**. The pressure jacket **110** may be made of any suitable medical grade material, such as a medical grade plastic material, desirably a clear plastic material, such as, but not limited to, polycarbonate, acrylic, or polyester. In some aspects, the pressure jacket **110** may be releasably secured to the fluid injector **102**, for example but not limited to, by a retractable pin that extends through an opening of the pressure jacket **110** to prevent rotation of the pressure jacket **110** when it is loaded onto the fluid injector **102**. In other aspects, the pressure jacket **110** may have one or more legs that engage the housing of the fluid injector **102** to prevent rotation of the pressure jacket **110** when it is loaded onto the fluid injector **102**. In further aspects, a sliding collar may be provided around an outer circumference of the pressure jacket **110**. The sliding collar desirably engages an expandable ring to expand the ring against a corresponding locking feature of the fluid injector **102** to lock the pressure jacket **110** with the fluid injector **102**.

[00143] With reference to FIG. 3, and with continuing reference to FIG. 2, the rolling diaphragm 112 generally includes a hollow body that includes a forward or distal end 130, a rearward or proximal end 132, and a flexible sidewall 134 extending therebetween. The proximal end 132 defines a closed end wall 136. The closed end wall 136 may be shaped to interface directly with the piston head 138 and/or the plunger 144 of the fluid injector 102. For example, the closed end wall 136 may define a receiving end pocket for interfacing directly with a similarly-shaped piston head 138 and/or plunger 144. In particular, the piston head 138 and/or plunger 144 may be shaped to match the shape of the closed end wall 136 or pressure from the piston head 138 and/or plunger 144 may conform the end wall 136 to substantially match the shape of the piston head 138 and/or plunger 144. The closed end wall 136 may alternatively include an attached rigid base element for engaging with the piston head 138 or plunger 144 in a like manner. In one aspect, the proximal end 132 and/or the distal end 130 of the rolling diaphragm 112 may be more rigid relative to the sidewall 134. In yet another aspect, the rolling diaphragm 112 may be formed from a plurality of individual layers that are co-formed together into a single, unitary structure. At least one of the layers may peel away from the sidewall 134 as the sidewall 134 is rolled over during an injection procedure. At least one of the layers may be made from a heat-shrinkable material which is activated to shrink at a predetermined temperature. The predetermined temperature may be achieved, for example, during an autoclave process. In this aspect, the heat-shrinkable layer may serve as a pressure jacket. The sidewall 134 may have a smooth, substantially uniform structure, or it may have one or more ribs provided thereon to facilitate the rollover during an injection procedure. One or more indicia (not shown) may be formed on the sidewall 134. In another aspect, the sidewall 134 may have a non-uniform thickness along its longitudinal length to facilitate the rolling over of the sidewall 134. For example, the sidewall 134 at or near the proximal end 132 may be thinner than the sidewall 134 at or near the distal end 130 to facilitate rolling of the sidewall 134 from the proximal end 132 toward the distal end 130. The thicker sidewall 134 at or near the distal end 130 may function as the pressure jacket 110 and may not roll over. In specific embodiments, the sidewall 134 at or near the distal end 130 may be substantially rigid.

[00144] The rearward or proximal portion of the sidewall 134 connects to the closed end wall 136, and a forward or distal portion of the sidewall 134 defines a discharge neck 140 opposite the closed end wall 136. The closed end wall 136 may have a non-uniform thickness, for example in

a radial direction extending from a central longitudinal axis of the rolling diaphragm **112**. In certain embodiments, the end wall **136** may be thicker near the center and thinner near the connection with the sidewall **134**. The discharge neck **140** is adapted to be received in the interior portion of the distal end **116** of the pressure jacket **110** such that the discharge neck **140** is aligned with the outlet port **128** of the pressure jacket **110**. The distal end **130** of the rolling diaphragm **112** may be secured permanently within the interior of the pressure jacket **110**, adhesively secured therein, or be removably secured therein such as by a friction fit connection or other suitable mechanical connection, such as by securing at the distal end of the pressure jacket **110**. The discharge neck **140** terminates in a discharge port **142** that may have, according to one non-limiting aspect, a fracturable seal (discussed herein) for sterility purposes, such as piercable foil or an elastomeric seal.

[00145] The sidewall **134** of the rolling diaphragm **112** defines a soft, pliable or flexible, yet self-supporting body that is configured to roll upon itself under the action of the piston head **138** and/or plunger **144**. In particular, as shown in **FIG. 2**, the sidewall **134** of the rolling diaphragm **112** is configured to roll such that its outer surface is folded and inverted in a radially inward direction as piston **138** and/or plunger **144** are moved in a distal direction and unroll and unfold in the opposite manner in a radially outward direction as piston **138** and/or plunger **144** are retracted in a proximal direction. With reference to **FIG. 3**, the closed end wall **136** may have a concave shape to facilitate the initiation of the inversion or rolling of the sidewall **134**. In another aspect, sidewall **134** of the rolling diaphragm **112** may be configured to be crushed under the action of the piston head **138** from a first, uncompressed state, as shown in **FIG. 4A**, to a second, compressed state, as shown in **FIG. 4B**, by folding over in a plurality of axial folds **112a**. One or more of the axial folds **112a** may be pre-formed at predetermined axial positions of the sidewall **134** of the rolling diaphragm **112**.

[00146] The rolling diaphragm **112** may be made of any suitable plastic material, desirably a clear plastic material, such as, but not limited to, polypropylene random copolymer, polypropylene impact copolymer, polypropylene homopolymer, polypropylene, polyethylene terephthalate, POM, ABS, HPDE, nylon, cyclic olefin copolymer, multilayer polypropylene, polycarbonate, ethylene vinyl acetate, polyethylene, and the like. The material of the rolling diaphragm **112** is desirably selected to meet the required tensile and planar stress requirements, water vapor transmission, and chemical/biological compatibility. In some aspects, the rolling

diaphragm **112** may have at least one electro-active polymer layer that expands or contracts in response to an application of an electrical voltage. The electro-active polymer layer may be activated to expand or contract the sidewall **134** of the rolling diaphragm **112** to disengage or engage the plunger **144**. In some aspects, the electro-active polymer layer may be made from a NAFIONTM or FLEMIONTM materials. In various embodiments, the clear plastic material may withstand sterilization procedures, such as exposure to ethylene oxide or electromagnetic radiation sterilization procedures.

[00147] The rolling diaphragm **112** according to various embodiments herein may be made by a blowing-filling-capping (BFC) technique, also referred to in the relevant field of endeavor as a blow-mold-seal (BFS) technique, wherein the rolling diaphragm **112** is blow-molded, filled with the desired medical fluid, such as saline or contrast media, and aseptically sealed by sealing the discharge port **142** with an integrally formed/molded rupture-ready seal, as will be described hereinafter. The BFC technique permits the rolling diaphragm **112** to be formed, filled, and sealed typically in one machine or apparatus. These steps may be accomplished under sterility maintained conditions, limiting the possibility of introducing contaminants in the formed, filled, and sealed rolling diaphragm **112**. The entire assembly may be autoclaved or otherwise treated for sterilization. The rupture-ready seal is formed as part of the molding process at the conclusion of the filling of the rolling diaphragm **112**. A sterility-enhanced preformed and prefilled rolling diaphragm **112** results from the BFC process. The rupture-ready seal may be designed for external removal or puncture by a user, or may be designed to reliably burst when a preset internal pressure is reached in the rolling diaphragm **112** as the piston head **138** moves distally or forward in the rolling diaphragm **112**. In another aspect, the rolling diaphragm **112** may be ruptured by a piercing element provided on the pressure jacket **110**. In another aspect, the rolling diaphragm **112** may be encased in a protective cover (not shown) to increase its rigidity and prevent contamination. The protective cover may or may not be removed from the rolling diaphragm **112** prior to installation on the injector **102**. The rolling diaphragm **112** may be formed to have a variety of shapes. For example, the rolling diaphragm **112** may be cylindrical, conical, spherical, ellipsoidal, egg-shaped, etc. Furthermore, the rolling diaphragm **112** may have different width to length ratios. For example, the rolling diaphragm **112** may be formed to have a diameter that is substantially smaller or larger compared to its longitudinal length. One of ordinary skill in the art will understand that the injector **102** may be desirably

programmed to control the movement of the plunger **144** in order to deliver a substantially constant and predictable flow rate of fluid from the rolling diaphragm **112**.

[00148] The outer diameter of the rolling diaphragm **112** may be dimensioned such that the rolling diaphragm **112** fits within the interior space defined by the throughbore and inner surface of the pressure jacket **110**. In one aspect, the rolling diaphragm **112** fits snugly within the pressure jacket **110** such that the outer surface of the rolling diaphragm **112** abuts the inner surface of the walls of the pressure jacket **110**. In another aspect, the rolling diaphragm **112** fits loosely within the pressure jacket **110** such that there is a gap between at least a portion of the outer surface of the rolling diaphragm **112** and the inner surface of the pressure jacket **110**. The rolling diaphragm **112** may be expanded under pressure during an injection procedure such that the outer surface of the rolling diaphragm **112** abuts the inner surface of the pressure jacket **110**.

[00149] **FIGS. 5A-5B** show a rolling diaphragm **112** in accordance with another aspect of the present disclosure. **FIG. 5B** is a cross-sectional side view the rolling diaphragm shown in **FIG. 5A** taken along line A-A. The components of rolling diaphragm **112** shown in **FIGS. 5A-5B** are substantially similar to the components of the rolling diaphragm **112** described herein with reference to **FIGS. 2-3**. Reference numerals in **FIGS. 5A-5B** are used to illustrate identical components as the corresponding reference numerals in **FIGS. 2-3**. As the previous discussion regarding the rolling diaphragm **112** generally shown in **FIGS. 2-3** is applicable to the aspect shown in **FIGS. 5A-5B**, only the relevant differences between these systems are discussed hereinafter.

[00150] Referring initially to **FIG. 5A**, the distal end **130** of the rolling diaphragm **112** has an open-ended discharge neck **140** having a connection interface **140a** for connecting to a corresponding connection interface which may connect to a fluid path set (not shown). In some aspects, the connection interface **140a** is a threaded interface having one or more threads **140b** for mating with corresponding threads on the connection interface to the fluid path set. In certain aspects the connection interface to the fluid path may have a connection configured to connect to the fluid path, such as a luer connection.

[00151] With reference to **FIG. 5B**, the discharge neck **140** has a first sidewall thickness T_1 that is larger than a thickness T_2 of the sidewall **134**. Thickness T_1 is selected such that the discharge neck **140** may be sufficiently rigid to allow for connecting to a corresponding connection interface of a fluid path set (not shown) without substantially deforming the

discharge neck **140**. Thickness T_2 is selected such that the sidewall **134** of the rolling diaphragm **112** is flexible to allow for rolling over and unrolling of the sidewall **134** as described herein. The proximal end **132** of the rolling diaphragm **112**, such as the closed end wall **136**, may be reinforced to prevent deformation during rolling over of the sidewall **134**. In some aspects, the proximal end **132** of the rolling diaphragm **112** is configured for engagement with the plunger **144** (not shown). The proximal end **132** has a radiused folding edge **226** having a flexible sidewall to initiate the rolling over and in certain embodiments, unrolling of the sidewall **134** of the rolling diaphragm **112**. In this embodiment, the folding edge **226** may transition into a distally-extending ramp **272** having continuously increasing sidewall thickness T_3 to a distal portion **274** of the end wall **136**. The distal portion **274** may have a radiused central portion **276** extending distally from an upper surface of the distal portion **274** and a plunger engagement portion **244** extending proximally from a lower surface of the distal portion **274**. The plunger engagement portion **244** is configured for engagement with the plunger **144** (not shown), as described herein. The proximal end **132** of the rolling diaphragm **112** may have one or more ribs **278** protruding radially outward from the plunger engagement portion **244** along a lower surface of the ramp **272**.

[00152] FIG. 6 is a cross-sectional side view of a rolling diaphragm **112** in accordance with another aspect of the present disclosure. A first portion **112a** of the rolling diaphragm **112** has a first diameter D_1 and a second portion **112b** of the rolling diaphragm **112** has a second diameter D_2 that is different from the first diameter D_1 . In some aspects, the first portion **112a** may be an forward portion of the rolling diaphragm **112** extending from the distal end **130** to an approximate midpoint of the rolling diaphragm **112**, while the second portion **112b** may be a rearward portion of the rolling diaphragm **112** extending the approximate midpoint of the rolling diaphragm **112** to the proximal end **132**. The first diameter D_1 may be larger than the second diameter D_2 to allow the second portion **112b** to nest inside the first portion **112a** as the second portion **112b** is inverted about a folding edge **226**. Nesting of the second portion **112b** within the first portion **112a** minimizes hoop compression at the folding edge **226**. The folding edge **226** may have a thickened sidewall **134a** compared to the sidewall **134** of the first and second portions **112a**, **112b** of the rolling diaphragm **112**. In some aspects, the first portion **112a** may have a collar **228** surrounding or surrounded by the sidewall **134**, while the second portion **112b** may have a plunger support base **230** for reinforcing engagement with the plunger **144** (not

shown). **FIG. 40** shows a rolling diaphragm **112** with the plunger support base **230** and the collar **228** without the sidewall **134** having the varying diameter shown in **FIG. 6**.

[00153] **FIG. 7** is a cross-sectional side view of a rolling diaphragm **112** in accordance with another aspect of the present disclosure. A first portion **112a** of the rolling diaphragm **112** has a first sidewall **134a** and a second portion **112b** of the rolling diaphragm **112** has a second sidewall **134b** that has a different thickness from the first sidewall **134a**. An inner diameter of the rolling diaphragm **112** may be constant between the first portion **134a** and the second portion **134b**. In some aspects, the first portion **112a** may be an forward portion of the rolling diaphragm **112** extending from the distal end **130** to an approximate midpoint of the rolling diaphragm **112**, while the second portion **112b** may be a rearward portion of the rolling diaphragm **112** extending the approximate midpoint of the rolling diaphragm **112** to the proximal end **132**. The first sidewall **134a** may be thicker than the second sidewall **134b** such that the first portion **112a** of the rolling diaphragm **112** is more rigid relative to the second portion **112b** of the rolling diaphragm **112**. The second portion **112b** nests inside the first portion **112a** as the second portion **112b** is inverted about a folding edge **226**. An exterior portion of the second sidewall **134b** may be supported circumferentially by a collar **228**. In some aspects, the first and second portions **134a**, **134b** may have a substantially identical wall thickness, while an approximate midpoint between the first portion **134a** and the second portion **134b** has a portion with a thinner sidewall thickness relative to the sidewall of the first and second portions **134a**, **134b** to define a folding edge or an inversion front and prevent buckling of the sidewall as the second portion **134b** is inverted upon itself.

[00154] **FIG. 8A** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure where the plunger **144** is shown in a first position. **FIG. 8B** is a cross-sectional side view of the rolling diaphragm **112** and plunger **144** shown in **FIG. 8A** where the plunger **144** is shown in a second position. In some aspects, the sidewall **134** of the rolling diaphragm **112** is tapered such that it narrows and the diameter decreases from the proximal end **132** toward the distal end **130** to correspond substantially to a tapered shape of the plunger **144**. The sidewall **134** may be folded such that there is contact between a folded portion **170** and an unfolded portion **172** of the sidewall **134** to minimize residual volume after the plunger **144** is advanced to its maximum distal position. The radius **R** at which the sidewall **134** is rolled over is desirably minimized to reduce localized stress at the

folded portion. With reference to **FIG. 8B**, in another aspect the sidewall **134** may be folded such that there is no contact between a folded portion **170** and an unfolded portion **172** of the sidewall **134** as the plunger **144** is advanced to its maximum distal position. In this aspect, the radius **R'** is larger than the radius **R** in **FIG. 8A**.

[00155] **FIG. 9A** is a partial cross-sectional side view of a rolling diaphragm **112** in accordance with another aspect of the present disclosure where the rolling diaphragm **112** is shown in a first state. **FIG. 9B** is a partial cross-sectional side view of the rolling diaphragm **112** shown in **FIG. 9A** with the rolling diaphragm **112** shown in a second state after engagement with a plunger **144**. The proximal end **132** of the rolling diaphragm **112** may be initially formed in a convex shape, such that a portion of the proximal end **132** extends convexly outwardly in a proximal direction. When the plunger **144** engages the proximal end **132**, such as shown in **FIG. 9B**, the convex shape of the proximal end **132** is inverted toward the distal end **146** such that the proximal end **132** is substantially concave as the plunger **144** is advanced in the distal direction. The proximal end **132** may have a pre-formed rolling radius **R** that facilitates rollover of the rolling diaphragm **112** once it is engaged by the plunger **144**. In some aspects, the proximal end **132** may have one or more pre-defined folding portions **132a** that facilitate an inversion of the proximal end **132** from the initial convex shape to a concave shape upon engagement with the plunger **144**. The folding portions **132a** may have thinner sidewalls relative to a thickness of the sidewall **134** of the rolling diaphragm **112**.

[00156] **FIG. 10A** is a side view of a rolling diaphragm **112** in accordance with another aspect of the present disclosure. The rolling diaphragm **112** has one or more recessed elements **182a** that are formed to extend in a radially inward direction. In some aspects, the one or more recessed elements **182a** may be formed such that the sidewall **134** has a substantially uniform thickness over at least a portion of an area where the one or more recessed elements **182a** is formed. In other aspects, the one or more recessed elements **182a** may be formed such that the sidewall **134** has a thinner or thicker sidewall thickness at the location where the one or more recessed elements **182a** is formed. The one or more recessed elements **182a** may be spaced apart equally or unequally around an outer circumference of the rolling diaphragm **112** to facilitate rollover of the sidewall **134**. The plunger **144** (not shown) may be configured to engage one or more of the plurality of recessed elements **182a** as the plunger **144** is advanced in a distal

direction. In some aspects, the plunger **144** may be shaped to correspond to a shape of the rolling diaphragm **112** having one or more recessed elements **182a**.

[00157] **FIG. 10B** is a partial side view of a rolling diaphragm in accordance with another aspect of the present disclosure. The rolling diaphragm **112** has one or more ribs **182b** that are formed to extend in a radially outward direction. In some aspects, the one or more ribs **182b** may be formed such that the sidewall **134** has a substantially uniform thickness over at least a portion of an area where the one or more ribs **182b** is formed. In other aspects, the one or more ribs **182b** may be formed such that the sidewall **134** has a thinner or thicker sidewall thickness at the location where the one or more ribs **182b** is formed. The one or more ribs **182b** may be shaped such that a first portion of the one or more ribs **182b** extends radially outward further compared to a second portion of the ribs **182b**. For example, the one or more ribs **182b** may be shaped such that the ribs **182b** extend radially outward further at or near the proximal and distal ends compared to a central portion of the one or more ribs **182b**. The one or more ribs **182b** may be spaced apart equally or unequally around an outer circumference of the rolling diaphragm **112** to facilitate rollover of the sidewall **134**. The plunger **144** (not shown) may be configured to engage one or more of the plurality of ribs **182b** as the plunger **144** is advanced in a distal direction. In some aspects, the plunger **144** may be shaped to correspond to a shape of the rolling diaphragm **112** having one or more ribs **182b**.

[00158] **FIG. 11A** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first state. **FIG. 11B** is a cross-sectional side view of the rolling diaphragm **112** and plunger **144** shown in **FIG. 11A**, with the plunger **144** shown in a second state. The rolling diaphragm **112** may be initially formed such that the proximal end wall **136** is inverted inwardly toward the distal end **130** such that internal volume **114** of the rolling diaphragm **112** is empty of fluid. In order to withdraw the proximal end wall **136** of the rolling diaphragm **112** in the proximal direction and fill the interior volume of the rolling diaphragm **112** with fluid, the plunger **144** engages at least a portion of the proximal end wall **136** to “grab” the proximal end wall **136** before withdrawing in the proximal direction. In some aspects, an external diameter of the plunger **144** may be slightly smaller than an internal diameter of the rolling diaphragm **112** in an inverted state shown in **FIG. 11A**. In order to facilitate connection of the proximal end wall **136** of the rolling diaphragm **112** with the plunger **144**, an expandable material **214**, such as

expandable foam, may be provided. The expandable material **214** may be in an unexpanded state prior to engagement of the plunger **144** with the proximal end wall **136** of the rolling diaphragm **112**. For example, the expandable material **214** may be contained in a container that is pierced by the plunger **144** as the plunger **144** is advanced toward the proximal end wall **136** of the rolling diaphragm **112**. The expandable material **214** may be expandable when exposed to air such that the expandable material **214** expands and engages the sidewall **134** of the rolling diaphragm **112** at the proximal end wall **136** and the plunger **144**. The expandable material **214** may harden after a predetermined amount of time to permanently or releasably connect the plunger **144** to the proximal end wall **136** of the rolling diaphragm **112** and allow the rolling diaphragm **112** to be withdrawn in the proximal direction due to movement of the plunger **144**. One or more gripping elements **246** may be provided on a folded portion of the sidewall **134** and/or on at least a portion of the outer circumference of the distal portion of the plunger **144** to provide an engagement between the surface for the expandable material **214** and the proximal end wall **136** and/or the inwardly facing outer wall proximate the proximal end wall **136**.

[00159] FIG. 12A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first state. FIG. 12B is a cross-sectional side view of the rolling diaphragm **112** and plunger **144** shown in FIG. 12A, with the plunger **144** shown in a second state. The rolling diaphragm **112** may be initially formed such that the proximal end wall **136** is inverted inwardly toward the distal end **130** such that an interior volume of the rolling diaphragm **112** is empty of fluid. In order to withdraw the proximal end wall **136** of the rolling diaphragm **112** in the proximal direction and fill the interior volume of the rolling diaphragm **112** with fluid, the plunger **144** engages at least a portion of the proximal end wall **136** to “grab” the proximal end wall **136** before withdrawing in the proximal direction. In some aspects, an external diameter of the plunger **144** may be slightly smaller than an internal diameter of the rolling diaphragm **112** in an inverted state shown in FIG. 12A. In order to facilitate connection of the proximal end wall **136** of the rolling diaphragm **112** with the plunger **144**, a distal portion of the plunger **144** may have an expandable balloon **216**. The balloon **216** may be expanded from a deflated state, such as shown in FIG. 12A, to an inflated state, such as shown in FIG. 12B, by introducing an operating fluid, such as fluid or pressurized gas, into an interior of the balloon **216**. Expansion of the balloon **216** from the deflated state to an inflated state causes the balloon **216** to engage the

sidewall **134** of the rolling diaphragm **112** at the proximal end wall **136**. The rolling diaphragm **112** may then be withdrawn in the proximal direction when urged by the plunger **144**.

[00160] FIG. **13A** is a cross-sectional side view of a rolling diaphragm **112** in accordance with another aspect of the present disclosure. FIG. **13B** is a cross-sectional side view of the rolling diaphragm **112** shown in FIG. **13A**, where the rolling diaphragm **112** is engaged by a plunger **144**. In some aspects, the proximal end **132** of the rolling diaphragm **112** may be connected to the distal end **116**, rather than the proximal end **118**, of the pressure jacket **110**, such that the rolling diaphragm **112** is inverted relative to the rolling diaphragm **112** shown in FIG. **2**. In particular, the sidewall **134** of the rolling diaphragm **112** is initially inverted into the interior of the pressure jacket **110** such that the distal end **130** of the rolling diaphragm **112** is positioned toward the proximal end **118** of the pressure jacket **110**. The plunger **144** is provided at the distal end **130** of the rolling diaphragm **112**. With reference to FIG. **13B**, the rolling diaphragm **112** may be co-molded with the plunger **144**. After co-molding, the rolling diaphragm **112** may be expanded to its final form by a blow molding technique. For example, the rolling diaphragm **112** may be expanded by a stretch blow molding technique. Alternatively, the rolling diaphragm **112** may be molded to its final, expanded shape and the plunger **144** may be co-molded with the rolling diaphragm **112**.

[00161] FIG. **14A** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The rolling diaphragm **112** has a substantially spherical shape. The proximal end **132** of the rolling diaphragm **112** may have an engagement member **218a** for engagement with a corresponding engagement member **218b** formed on the plunger **144**. The proximal end **132** is inverted from a first convex configuration to a second concave configuration upon engagement with the plunger **144**. The distal end **130** of the rolling diaphragm **112** may have a support element **220** for engaging the plunger **144** at the end of the stroke of the plunger **144** in the distal direction. The support element **220** may be provided inside an interior volume of the rolling diaphragm **112**. Alternatively, the support element **220** may engage an exterior sidewall at the distal end **130** of the rolling diaphragm **112**. The plunger **144** is desirably shaped to expel substantially all fluid from the interior volume of the rolling diaphragm **112**.

[00162] FIG. **14B** is a cross-sectional side view of a rolling diaphragm in accordance with another aspect of the present disclosure. Similar to the substantially spherical shape of the

rolling diaphragm **112** shown in **FIG. 14A**, the rolling diaphragm **112** in **FIG. 14B** has a substantially ellipsoid shape. The rolling diaphragm **112** has an elliptical cross-section having a major axis **A₁** extending along the longitudinal direction of the rolling diaphragm **112** and a minor axis **A₂** extending perpendicular to the longitudinal direction, where the major axis **A₁** is longer than the minor axis **A₂**. In this manner, the rolling diaphragm **112** has a first portion extending from an approximate longitudinal midpoint of the rolling diaphragm **112** to the distal end **130** and a second portion that is complementary in shape to the first portion and extending from the first portion to the proximal end **132**. The fluid injector **102** (shown in **FIG. 1**) may have a controller with a built-in algorithm to provide a constant fluid flow regardless of the shape of the rolling diaphragm **112**. For example, the controller may control the speed of the piston **138** (shown in **FIG. 2**) to increase or decrease the speed of the piston **138** at various longitudinal points to compensate for any fluid flow rate changes due to changes in a cross-sectional area of the rolling diaphragm **112** at such longitudinal points.

[00163] **FIG. 15A** is a perspective side view of a rolling diaphragm **112** and an annular sleeve **222** surrounding at least a portion of the rolling diaphragm **112** in accordance with another aspect of the present disclosure. The annular sleeve **222** may have one or more openings **224** extending through a sidewall of the annular sleeve **222**. In some aspects, the pressure jacket **110** may have a vacuum means for pulling the rolling diaphragm **112** against the inner sidewall **120** of the pressure jacket **110** or the annular sleeve **222**. In yet another aspect, the pressure jacket **110** may have a pressure means for releasing the rolling diaphragm **112** from the pressure jacket **110** after use by introducing pressurized air through the one or more openings **224** of the annular sleeve **222**. The inner sidewall of the annular sleeve **222** may be textured to prevent the outer surface of the rolling diaphragm **112** from sticking to the inner surface of the annular sleeve **222** and to facilitate the removal of the rolling diaphragm **112** from the annular sleeve **222** after use.

[00164] With reference to **FIG. 15B**, the rolling diaphragm **112** has an annular shrink-wrap sleeve **222a** surrounding at least a portion of the rolling diaphragm **112**. The shrink-wrap sleeve **222a** may be heat activated such that it shrinks radially inward to compress against an outside sidewall **134** of the rolling diaphragm **112**. The shrink-wrap sleeve **222a** may be disposed between the pressure jacket **110** (not shown) and the rolling diaphragm **112**.

[00165] With reference to **FIG. 15C**, a heating element **223** may be provided around at least a portion of the rolling diaphragm **112**. The heating element **223** may be disposed on the pressure

jacket **110**, such as an interior or exterior sidewall of the pressure jacket **110**. In some aspects, the heating element **223** may be configured for pre-heating the sidewall **134** of the rolling diaphragm **112**, for example to raise its pliability and facilitate inversion of the rolling diaphragm **112** when acted upon by the plunger **144** (not shown). The heating element may apply heat to the shrink-wrap sleeve shown in **FIG. 15B**.

[00166] **FIG. 16A** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. According to this aspect, the rolling diaphragm **112** is initially in a collapsed or empty state. An adhesive layer **232** is disposed between at least a portion of the rolling diaphragm **112** and the plunger **144**. The adhesive layer **232** may be adhered to at least a portion of the rolling diaphragm **112** and at least a portion of the plunger **144**. The adhesive layer **232** may be releasable from one or both of the rolling diaphragm **112** and the plunger **144** upon movement of the plunger **144** in a proximal direction. In some aspects, the adhesive layer **232** may be provided on an outer portion of the sidewall **134** of the rolling diaphragm **112** before the sidewall **134** is rolled upon itself. The adhesive layer **232** may assist in preventing the buckling of the sidewall **134** when the inverted portion of sidewall **134** is engaged by the plunger **144**. The internal volume **114** of the rolling diaphragm **112** may be initially empty. In order to withdraw the proximal end **132** of the rolling diaphragm **112** from the distal end **130** and fill the internal volume **114** with fluid, the plunger **144** engages the end wall and/or the sidewall **134** of an inverted portion of the rolling diaphragm **112**. The adhesive layer **232** may be a pressure activated adhesive that applies an adhesive force on the inverted portion of sidewall **134** of the rolling diaphragm **112** as the plunger **144** is retracted in a proximal direction. The adhesive layer **232** may peel away from the sidewall **134** at the folding edge **226**, or it may remain adhered to the sidewall **134** of the rolling diaphragm **112**. The adhesive layer **232** may be an adhesive coating. The plunger **144** may have one or more piston engagement elements **234** configured for releasable engagement with a piston of an injector to allow for reciprocal movement of the plunger **144**. In some aspects, the internal volume **114** of the rolling diaphragm **112** may have a vacuum that assists in drawing fluid into the rolling diaphragm **112** when the plunger **144** (not shown) is retracted in the proximal direction. In **FIG. 16B**, the adhesive layer **232**, such as an adhesive coating, is disposed between the sidewall **134** of the rolling diaphragm **112** and the pressure jacket **110**. In some aspects, the rolling diaphragm **112** peels away from the inner sidewall of the pressure jacket **110** as the plunger (not shown)

urges the proximal end **132** of the rolling diaphragm **112** toward the distal end **130**. A release layer (not shown) may be provided at the adhesion interface between the rolling diaphragm **112** and the pressure jacket **110**.

[00167] FIG. 17A is a perspective side view of a rolling diaphragm **112** in accordance with another aspect of the present disclosure. FIG. 17B is a top view of the rolling diaphragm **112** shown in FIG. 17A. The rolling diaphragm **112** has a plurality of foldable tabs **236** around an outer circumference of the sidewall **134**. A first end of each foldable tab **236** may be connected to the outer portion of the sidewall **134** while a second end is foldable relative to the first end in a circumferential direction of the outer portion of the sidewall **134**. In a folded configuration, such as when all of the foldable tabs **236** are folded against the outer portion of the sidewall **134**, the foldable tabs **236** may be aligned such that indicia **238**, such as a label identifying the contents of the rolling diaphragm **112** may be identified.

[00168] FIG. 18 is a side view of a rolling diaphragm in accordance with another aspect of the present disclosure. The sidewall **134** of the rolling diaphragm **112** may have one or more fluid presence indicators **240** to indicate whether the internal volume **114** of the rolling diaphragm **112** is filled with fluid. The one or more fluid presence indicators **240** may be integrally formed with the sidewall **134** of the rolling diaphragm **112**.

[00169] FIG. 19 is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has a skirt **174** that extends radially outward from the distal end of the plunger **144**. The skirt **174** is compressed against the sidewall **134** of the rolling diaphragm **112** such that it forces the fluid in a distal direction within the interior volume **114** forward as the plunger **144** is advanced in the distal direction. The skirt **174** minimizes or eliminates the residual volume of fluid in the fold **176**.

[00170] FIG. 20A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has a piston **178** at its distal end, such that the piston **178** is reciprocally moveable within a fluid- or elastomer-filled cavity **180** formed at the distal end of the plunger **144**. As the plunger **144** is advanced in a distal direction, such as during fluid delivery from the interior volume **114** of the rolling diaphragm **112**, the piston **178** is driven into the cavity **180**, thereby increasing the pressure of the fluid or elastomer within the cavity **180**. The cavity **180** is desirably flexible such that the increase in fluid or elastomer pressure causes the cavity **180** to expand against the sidewall **134** of the rolling

diaphragm **112**. The cavity **180** is compressed against the sidewall **134** of the rolling diaphragm **112** such that it forces the fluid within the interior volume **114** forward as the plunger **144** is advanced in the distal direction. The expansion of the cavity **180** minimizes or eliminates the residual volume of fluid in the fold **176**. Upon retraction of the plunger **144** in the proximal direction, the piston **178** is also retracted from the cavity **180** to reduce the pressure therein and allow the plunger **144** to be retracted from the rolling diaphragm **112**. In some aspects, the cavity **180** may be filled with an elastomer.

[00171] FIG. **20B** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. Similar to the rolling diaphragm **112** shown in FIG. **20A**, the plunger **144** has a piston **178** at its distal end, such that the piston **178** is reciprocally moveable within a fluid-filled cavity **180** formed at the distal end of the plunger **144**. In some aspects, the cavity **180** may be filled with an elastomer. As the plunger **144** is withdrawn in a proximal direction, such as during filling of the rolling diaphragm **112**, initially in a compressed or empty configuration, with fluid, the piston **178** may be independently moved in a proximal direction relative to the plunger **144**, thereby increasing the pressure of the fluid within the cavity **180**. The cavity **180** is desirably flexible such that the increase in fluid pressure causes the cavity **180** to expand against the sidewall **134** of the rolling diaphragm **112**. The cavity **180** is compressed against the sidewall **134** of the rolling diaphragm **112** such that it contacts the sidewall **134** to increase the gripping force between the plunger **144** and the sidewall **134** as the plunger **144** is withdrawn in the proximal direction.

[00172] FIG. **20C** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. Similar to the rolling diaphragm **112** shown in FIG. **20A**, the plunger **144** has a piston **178** at its distal end, such that the piston **178** is reciprocally moveable within a fluid-filled cavity **180** formed at the distal end of the plunger **144**. In some aspects, the cavity **180** may be filled with an elastomer. The cavity **180** has a first distal portion **180a** and a second proximal portion **180b** in fluid communication with the first distal portion **180a** via a fluid line **180c**. As the plunger **144** is withdrawn in a proximal direction, such as during filling of the rolling diaphragm **112** with fluid, the piston **178** may be independently moved in a proximal direction relative to the plunger **144**, thereby forcing the fluid from the second proximal portion **180b** into the first distal portion **180a** through the fluid line **180c** to increase the pressure of the fluid within the cavity **180**. The outer diameter of the piston **178**

may be smaller than an outer diameter of the second first distal portion **180** to increase a mechanical fluid advantage of the piston **178** in increasing the pressure in the first distal cavity **180a**. The cavity **180** is desirably flexible such that the increase in fluid pressure causes the first distal portion **180a** to expand against the sidewall **134** of the rolling diaphragm **112**. The first distal portion **180a** is compressed against the sidewall **134** of the rolling diaphragm **112** such that it contacts the sidewall **134** to increase the gripping force on the sidewall **134** as the plunger **144** is withdrawn in the proximal direction.

[00173] FIG. 21A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The rolling diaphragm **112** has a built-in plunger **144**. In some aspects, the plunger **144** is disposed within the interior volume **114** of the rolling diaphragm **112**. Alternatively, the plunger **144** may be formed, such as by molding or by adhesion, at the proximal end **132** of the rolling diaphragm **112**. Prior to use, the proximal end **132** of the rolling diaphragm **112** is sealed with a seal **150** to prevent removal of the plunger **144**.

[00174] FIG. 21B is a perspective side view of a plunger **144** in accordance with another aspect of the present disclosure. FIG. 21C is a perspective side view of a rolling diaphragm **112** and the plunger **144** shown in FIG. 21B. The plunger **144** has a groove **206** shaped into the distal end of the plunger **144**. In operation, the groove **206** captures at least a portion of the sidewall **134** or the end wall at the proximal end **132** of the rolling diaphragm **112** to facilitate the rollover of the sidewall **134**. As shown in FIG. 21C, the groove **206** may be shaped to receive a projection **208** formed at the proximal end **132** of the rolling diaphragm **112**. The groove **206** may have a T-shaped configuration that corresponds to the shape of the projection **208**. A variety of other shapes, including, but not limited to, oval, rectangular, triangular, etc. are also contemplated. In a further aspect, such as shown in FIGS. 26A-26B, the groove **206** is in the form of a slot shaped to receive the projection **208**. The groove **206** is arranged on one of the plunger **144** and the rolling diaphragm **112**, while the projection **208** is arranged on the other of the plunger **144** and the rolling diaphragm **112**. The groove **206** is shaped such that the projection **208** can be inserted in one direction only. Once inserted into the groove **206**, the projection **208** may be rotated relative to the groove **206** in order to lock the plunger **144** relative to the rolling diaphragm **112**. To remove the projection **208** from the groove **206**, the projection **208** is desirably rotated such that it is aligned with the groove **206** in a direction corresponding to

the insertion direction. In yet another aspect, such as shown in **FIGS. 23-24**, the plunger **144** is connected to the rolling diaphragm **112** by a threaded member **210** having a male thread feature on one of the plunger **144** and the rolling diaphragm **112** that threadably engage a female threaded feature on the other of the plunger **144** and the rolling diaphragm **112**. An embodiment where the position of the male and female threaded features are reversed is also contemplated.

[00175] **FIG. 22** is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure. The distal end of the plunger **144** has a projection **211** that extends radially outward from the plunger **144** to engage the sidewall **134** of the rolling diaphragm **112**. The projection **211** may engage the folding edge **226** of the rolling diaphragm **112** to facilitate rolling over of the folding edge **226** as the plunger **144** is advanced in a distal direction.

[00176] **FIG. 23-24A** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** is connected to the rolling diaphragm **112** by a threaded member **210** having a male threaded feature on the plunger **144** that threadably engages a female threaded feature on the rolling diaphragm **112**. In some aspects, the threaded member **210** has a female threaded feature on the plunger **144** that threadably engages a male threaded feature on the rolling diaphragm **112**.

[00177] **FIG. 24B** is a perspective view of a plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first, retracted state. **FIG. 24C** is a perspective view of the plunger **144** illustrated in **FIG. 24C** shown in a second, expanded state. The plunger **144** has one or more expandable ribs **213** at the distal end that are expandable radially outward from a first, retracted state (shown in **FIG. 24B**) to a second, expanded state (**FIG. 24C**). The one or more expandable ribs **213** may be automatically expandable and retractable depending on the distal or proximal movement of the plunger **144**. In some aspects, the one or more expandable ribs **213** may expand radially outward to engage the sidewall **134** of the rolling diaphragm **112** (not shown) when the plunger **144** is advanced in the distal direction to expel fluid from the rolling diaphragm **112**. In other aspects, the one or more expandable ribs **213** may expand radially outward to engage the sidewall **134** of the rolling diaphragm **112** (not shown) when the rolling diaphragm **112** is in the empty, collapsed stated and the plunger **144** is retracted in the proximal direction to fill the rolling diaphragm **112** with fluid. **FIGS. 25A-25C** show the plunger **144** with one or more rollers **215** on a non-expandable portion of the plunger

144. The rollers **215** engage the sidewall **134** of the rolling diaphragm **112** (shown in **FIG. 25C**) and may be freely rotatable in a direction of plunger movement.

[00178] **FIGS. 27-28C** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with other aspects of the present disclosure. The plunger **144** has a plurality of concentric portions **144a-144d** arranged in a telescoping orientation relative to each other. Each of the concentric portions **144a-144d** may be advanced in a proximal or distal direction independently of the remaining concentric portions **144a-144d**. In one aspect, outer concentric portions may support the proximal end **132** of the rolling diaphragm **112** while the inner concentric portions are advanced to deliver the fluid from the rolling diaphragm **112**. Controlling the movement of individual concentric portions **144a-144d** allows for a more uniform compression of the rolling diaphragm **112** and a complete expulsion of fluid from the rolling diaphragm **112**. In addition, by selectively withdrawing individual concentric portions **144a-144d** in a proximal direction, the rolling diaphragm **112** can be more easily removed from the plunger **144** after compression.

[00179] **FIG. 29** is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure. The rolling diaphragm **112** may be formed as a flexible container with or without a defined outlet port at the distal end **130**. The rolling diaphragm **112** may be retained within a pressure jacket **110** and acted upon by a plunger **144** at the proximal end **132** of the rolling diaphragm **112**. Movement of the plunger **144** in the distal direction compresses the rolling diaphragm **112** against a distal sidewall **262** of the pressure jacket **110**. A piercing element **264** having a seal **266** is provided at the distal sidewall **262** of the pressure jacket **110**. As the plunger **144** compresses the rolling diaphragm **112** against the distal sidewall **262** of the pressure jacket **110**, the piercing element **264** pierces through the sidewall **134** of the rolling diaphragm **112** to bring the fluid path set **108** in fluid communication with the internal volume **114** of the rolling diaphragm **112**. The seal **266** seals around the pierced portion of the sidewall **134** to prevent fluid from leaking into the pressure jacket **110**.

[00180] **FIG. 30** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The rolling diaphragm **112** is co-molded with the plunger **144**. In some aspects, the plunger **144** may be a rigid, substantially non-deformable plunger, while the rolling diaphragm **112** may have a flexible sidewall **134** that

may be rolled over on itself to allow the internal volume **114** of the rolling diaphragm **112** to expand or contract. Initially, the rolling diaphragm **112p** may be in a pre-formed configuration which is co-molded with the plunger **144**. After co-molding the rolling diaphragm pre-form **112p** with the plunger **144**, the rolling diaphragm pre-form **112p** may be expanded to its final form by a blow molding technique in a mold **M**. For example, the rolling diaphragm pre-form **112p** may be expanded by a stretch blow molding technique. The plunger **144** may be fixed in the mold **M** while at least a portion of the rolling diaphragm pre-form **112p** is expanded by blow molding. In some aspects, a first portion of the rolling diaphragm **112** is fixed in the mold **M**, while a second portion of the rolling diaphragm **112** is expanded, during which expansion the plunger **144** may move within the mold **M**. Alternatively, the rolling diaphragm **112** may be molded to its final, expanded shape and the plunger **144** may be co-molded with the rolling diaphragm **112**. In some aspects, a first portion of the rolling diaphragm **112**, such as the proximal or the distal end, may be pre-formed, while a second portion of the rolling diaphragm **112** may be expanded, such as by a stretch blow molding technique.

[00181] FIG. 31 is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has an inner element **268** and an outer element **270** surrounding the inner element **268** and movable relative to the outer element **270**. The outer element **270** has one or more gripping elements **246** protruding radially outward from an outer circumference of the outer element **270**. The one or more gripping elements **246** of the outer element **270** engage the sidewall **134** of the rolling diaphragm **112** at the folding edge **226**. The one or more gripping elements **246** may be retractable when engaged by at least a portion of the inner element **268** or the outer element **270**. The plunger **144** reciprocally moves the inner element **268** relative to the outer element **270** in a series of incremental strokes. Each stroke has a distal component and a proximal component, with the proximal component being longer than the distal component. In this manner, the plunger **144** has a net movement in the proximal direction. With each distal movement of the plunger **144**, the inner element **268** moves distally relative to the outer element **270**, which releases a radial loading on the outer element **270** and reduces the grip of the gripping elements **246** (such as by withdrawing the gripping elements **246** into the outer element **270**) from the sidewall **134** of the rolling diaphragm **112**. The outer element **270** can then be advanced distally to engage the sidewall **134** distally of the folding edge **226**. With each proximal movement of the plunger

144, the inner element **268** moves proximally relative to the outer element **270**, which increases the radial loading on the outer element **270** and engages the gripping elements **246** with the sidewall **134** of the rolling diaphragm **112**. The outer element **270** draws the sidewall **134** of the rolling diaphragm **112** in the proximal direction until it reaches the folding edge **226**, after which the plunger movement is repeated. In this manner, the internal volume **114** of the rolling diaphragm **112** can be filled with fluid. Fluid can be discharged from the rolling diaphragm **112** in a manner described herein. In some aspects, the outer element **270** may be an expandable element that has a resiliently deflectable element, such as a spring, that expands radially outward to contact the sidewall **134** of the rolling diaphragm **112** upon engagement of the plunger **144** with the outer element **270**.

[00182] FIG. 32A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. FIG. 32B is a top view of the plunger **144** shown in FIG. 32A. The plunger **144** has a central portion **145** and a plurality of radially extendable elements **147** operatively connected to the central portion **145**. The central portion **145** has a first ramp surface **145'** that defines a substantially conical distal portion of the central portion **145**. Each of the radially extendable elements **147** has a second ramp surface **147'** that corresponds to the first ramp surface **145'** on the central portion **145**. The plunger **144** is initially inserted in an inverted rolling diaphragm **112**. Movement of the central portion **145** in a proximal direction causes the first ramp surface **145'** of the central portion **145** to engage the second ramp surface **147'** on at least one of the plurality of radially extendable elements **147**. Due to a slope of the first and second ramp surfaces **145'**, **147'**, a radial movement component is imparted on at least one of the radially extendable elements **147** as a result of proximal movement of the central portion **145**. Such radial movement of at least one of the radially extendable elements **147** causes a gripping surface **147''** of at least one of the radially extendable elements **147** to engage the folded portion of the sidewall **134** of the rolling diaphragm **112** as plunger **144** is retracted.

[00183] FIG. 33A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first axial position. FIG. 33B is a cross-sectional side view of the rolling diaphragm **112** and plunger **144** shown in FIG. 33A, with the plunger **144** shown in a second axial position. The proximal end **132** of the rolling diaphragm **112** has a plunger engagement portion **254** formed as a ring

that protrudes radially outward relative to the sidewall **134** at the proximal end **132** of the rolling diaphragm **112**. The plunger engagement portion **254** may extend continuously or discontinuously around the circumference of the proximal end **132** of the rolling diaphragm **112**. The plunger **144** has a radially inwardly recessed portion **256** that is configured to coact with the plunger engagement portion **254** of the rolling diaphragm **112** upon movement of the plunger **144** in a distal direction. In some aspects, the plunger engagement portion **254**, which initially protrudes in a radially outward direction on the rolling diaphragm **112** that is uncompressed, as shown in **FIG. 33A**, is inverted to protrude radially inward, as shown in **FIG. 33B**, when the sidewall **134** of the rolling diaphragm **112** folds over due to movement of the plunger **144** in the distal direction. When the plunger engagement portion **254** is folded over in a radially inward direction, the recessed portion **256** of the plunger **144** receives the plunger engagement portion **254** such that the plunger engagement portion **254** is retained axially between a collar **258** at a distal end of the recessed portion **256** and a plunger base **260** at a proximal end of the recessed portion **256**. The collar **258** of the plunger **144** may be retractable radially inward to allow the plunger **144** to be released from the plunger engagement portion **254** of the rolling diaphragm **112**.

[00184] **FIG. 34A** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first axial position. **FIG. 34B** is a cross-sectional side view of the rolling diaphragm **112** and plunger **144** shown in **FIG. 34A**, with the plunger **144** shown in a second axial position. The rolling diaphragm **112** has a first engagement portion **244a** formed at the proximal end **132** of the rolling diaphragm **112**. The first engagement portion **244a** is configured for engagement with the plunger **144**. In some aspects, the first engagement portion **244a** is formed as a tab extending proximally from a central portion of the proximal end **132**. The first engagement portion **244a** may be non-deformable or deformable, such as by heating. The first engagement portion **244a** is connectable to a second engagement portion **244b** formed on the plunger **144**. The second engagement portion **244b** may be formed as a recess configured to receive the tab of the first engagement portion **244a**. In some aspects, the first engagement portion **244a** may be releasably or non-releasably connected to the second engagement portion **244a**. For example, at least a portion of the first engagement portion **244a** may be permanently and non-releasably coupled with the second engagement portion **244b** by fusing or adhering at least a portion of the first

engagement portion **244a** with the second engagement portion **244b**, such as by heating at least a portion of the first engagement portion **244a**. In some aspects, at least a portion of the first engagement portion **244a** may be releasably coupled with the second engagement portion **244b** via a snap-fit connection, or via a threaded connection. Once connected, the first engagement portion **244a** and the second engagement portion **244b** allow the plunger **144** to reciprocally move to allow filling or discharging the rolling diaphragm **112**.

[00185] In some aspects, the first engagement portion **244a** is formed as a tab **244c** extending proximally from a central portion of the proximal end **132** with a lip **244d** protruding radially outward from a proximal end of the tab **244c**. The first engagement portion **244a** is connectable to a second engagement portion **244d** formed on the plunger **144**. The second engagement portion **244b** may have a pair of radially deflectable fingers **244e** configured to engage the lip **244d** of the first engagement portion **244a**. The radially deflectable fingers **244e** may be deflectable from a first position to a second position to clear the lip **244d** as the plunger **144** is advanced distally to lock the second engagement portion **244b** with the first engagement portion **244a**. Once locked, a radial deflection of the fingers **244e** may be prevented by a collar that extends around at least a portion of the fingers **244e**. In some aspects, the fingers **244e** may be locked against the pressure jacket **110** (shown in FIG. 2) to prevent disengagement of the fingers **244e** from the first engagement portion **244a** during withdrawal of the plunger **144** in a proximal direction, such as during filling of the rolling diaphragm **112**.

[00186] FIG. 35 is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has a first end **144a** and a second end **144b** where the first end **144a** is movable axially relative to the second end **144b**. The first and second ends **144a**, **144b** are connected together by webbing **144c** extending obliquely to a longitudinal axis of the plunger **144**. Upon movement of the first end **144a** toward the second end **144b**, the webbing **144c** expands radially outwardly to engage the sidewall **134** of the rolling diaphragm **112** allowing retraction of the inwardly facing wall of the empty rolling diaphragm **112**. Upon movement of the first end **144a** away from the second end **144b**, the webbing **144c** contracts radially inwardly to disengage from the sidewall **134** of the rolling diaphragm **112**.

[00187] FIG. 36A is a perspective view of a plunger **144** in accordance with another aspect of the present disclosure. FIG. 36B is a cross-sectional side view of the plunger **144** shown in FIG.

36A and a rolling diaphragm **112**. The plunger **144** has one or more first gripping elements **246a** protruding radially outward relative to a body of the plunger **144**. In some aspects, the one or more first gripping elements **246a** may have a first end connected to the body of the plunger **144** and a second end protruding radially outward relative to the first end. At least one of the one or more first gripping elements **246a** may be configured for engaging a smooth sidewall **134** of the rolling diaphragm **112** (not shown). In other aspects shown in **FIG. 36B**, at least one of the one or more first gripping elements **246a** on the plunger **144** may be configured for engaging corresponding second gripping elements **246b** formed on the sidewall **134** of the rolling diaphragm **112**. The interaction between the first gripping elements **246a** and the second gripping elements **246b** increases the gripping force at the interface between the plunger **144** and the sidewall **134** of the rolling diaphragm **112**. The one or more gripping elements may be active gripping elements that are engaged (by radial extension) or disengaged (by radial retraction) relative to the body of the plunger **144**, such as shown in **FIG. 43**. In some aspects, at least one of the first gripping elements **246a** and the second gripping elements **246b** may be angled relative to a longitudinal axis of the plunger **144** and the rolling diaphragm **112** to prevent unintended disengagement during proximal movement of the plunger **144**.

[00188] **FIG. 37** is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has a first threaded portion **240a**, while an inwardly facing outer portion of the sidewall **134** of the rolling diaphragm **112** has a second threaded portion **240b** that can be threadably engaged with the first threaded portion **240a** of the plunger **144**. In some aspects, the plunger **144** may be rotated about its longitudinal axis and move linearly along the longitudinal axis to allow the first threaded portion **240a** to engage with the second threaded portion **240b**. Once engaged, the plunger **144** can be moved withdrawn axially without rotation. The threaded engagement between the first threaded portion **240a** and the second threaded portion **240b** assists in increasing the gripping force of the plunger **144** against the sidewall **134** of the rolling diaphragm **112** as the rolling diaphragm **112** is drawn from a collapsed configuration in a proximal direction to fill the interior volume **114** of the rolling diaphragm **112** with fluid. In some aspects, at least one of first threaded portion **240a** and the second threaded portion **240b** may be discontinuous around at least a portion of the circumference of the piston **144** and sidewall **134** of the rolling diaphragm **112**, respectively. In other aspects, the first threaded portion **240a** and the second threaded portion **240b** may extend

helically about the longitudinal axis of the plunger **144** and the rolling diaphragm **112**, respectively. In further aspects, the first threaded portion **240a** and the second threaded portion **240b** may be formed as a plurality of circular ridges on one of the plunger **144** and the rolling diaphragm **112** and corresponding circular grooves on the other of the plunger **144** and the rolling diaphragm **112**.

[00189] FIG. 38 is a cross-sectional side view of a rolling diaphragm and plunger in accordance with another aspect of the present disclosure. An annular member **242** may be disposed between a folded inwardly facing portion of the sidewall **134** of the rolling diaphragm **112** and the plunger **144**. The annular member **242** may be pressurized to expand against the sidewall **134** of the rolling diaphragm **112** to prevent bending and buckling of the sidewall **134** when the plunger **144** is withdrawn in a proximal direction. In certain embodiments, the annular member **242** can roll upon itself in a manner similar to the rolling of the rolling diaphragm **112** described herein.

[00190] FIG. 39A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first axial position. FIG. 39B is a cross-sectional side view of the rolling diaphragm **112** and plunger **144** shown in FIG. 39A, with the plunger **144** shown in a second axial position. The rolling diaphragm **112** has a first engagement portion **244a** formed at the proximal end **132** of the rolling diaphragm **112**. The first engagement portion **244a** is configured for engagement with the plunger **144**. In some aspects, the first engagement portion **244a** is formed as one or more legs **244c** extending proximally from a central portion of the proximal end **132**. Each of the legs **244c** has a radially-extending ledge **244d** at a proximal end thereof. The first engagement portion **244a** is connectable to a second engagement portion **244b** formed on the plunger **144**. The second engagement portion **244b** may be formed as a recess configured to receive the leg **244c** and the ledge **244d** of the first engagement portion **244a**. In some aspects, the first engagement portion **244a** may be releasably connected to the second engagement portion **244b**. For example, the second engagement portion **244b** on the plunger **144** may have a movable locking element **244e** that is movable to selectively lock the first engagement portion **244a** of the rolling diaphragm **112**. In some aspects, the locking element **244e** may be movable linearly in a radial direction to allow the leg **244c** and the ledge **244d** to be withdrawn from the recess of the second engagement portion **244b**. In other aspects, the locking element **244e** may be pivotable about a

pivot point between a locked position, in which the leg **244c** and the ledge **244d** are locked within the recess of the second engagement portion **244b**, and an unlocked position, in which the leg **244c** and the ledge **244d** can be withdrawn from the recess of the second engagement portion **244b**. Once connected, the first engagement portion **244a** and the second engagement portion **244b** allow the plunger **144** to reciprocally move to allow filling or discharging the rolling diaphragm **112**. In some aspects, the first engagement portion **244a** and the second engagement portion **244b** may be connected by way of a bayonet connection by rotating one of the first engagement portion **244a** and the second engagement portion **244b** relative to the other of the first engagement portion **244a** and the second engagement portion **244b**.

[00191] FIG. 41A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first axial position. FIGS. 41B-42C are cross-sectional side views of the rolling diaphragm **112** and plunger **144** shown in FIG. 41A, with the plunger **144** shown in second and third axial positions, respectively. The rolling diaphragm **112** is disposed within a pressure jacket **110** that has an inner diameter that is larger than an outer diameter of an uncompressed rolling diaphragm **112** such that a space **S** is created between the inner sidewall of the pressure jacket **110** and the outer portion of the sidewall **134** of the rolling diaphragm **112**. As the plunger **144** is advanced toward the distal end **130** of the rolling diaphragm **112**, the sidewall **134** of the rolling diaphragm **112** is compressed, causing the sidewall **134** to expand radially outward and engage the inner sidewall of the pressure jacket **110**. Desirably, the rolling diaphragm **112** is used with a high crack-pressure valve that prevents fluid from being delivered from the interior volume **114** of the rolling diaphragm **112** until a predetermined pressure is reached at the outlet of the rolling diaphragm **112** or within a tubing set (not shown). Further movement of the plunger **144** in the distal direction further compresses the sidewall **134** of the rolling diaphragm **112** to increase the total strain on the sidewall **134** while remaining within its elastic limits.

[00192] FIG. 42 is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has an outer portion **143a** that is reciprocally movable to engage an inner portion of the sidewall **134** of the rolling diaphragm **112**, as described herein. The plunger **144** further has an inner portion **143b** that is independently movable relative to the outer portion **143a**. The outer portion **143a** is moved distally until the outer portion **143a** contacts the sidewall **134** of the rolling diaphragm **112**.

Subsequently, the inner portion **143b** is advanced distally to compress the sidewall **134** of the rolling diaphragm **112** to deliver fluid from the interior volume **114** of the rolling diaphragm **112**. The inner portion **143b** is then retracted proximally, while the outer portion **143a** is moved distally. The movement of the inner portion **143b** to expel fluid from the interior volume **114** of the rolling diaphragm **112** may be performed in a sequential manner. The plunger **144** has one or more first gripping elements **246a** protruding radially inward relative to the outer portion **143a**. At least one of the one or more first gripping elements **246a** on the plunger **144** may be configured for engaging corresponding second gripping elements **246b** formed on the sidewall **134** of the rolling diaphragm **112**. The interaction between the first gripping elements **246a** and the second gripping elements **246b** increases the gripping force at the interface between the plunger **144** and the sidewall **134** of the rolling diaphragm **112**.

[00193] FIG. 44 is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has a pair of pivotable elements **248** that are pivotable around a common pivot point **250**. By moving proximal ends **248a** of the pivotable elements **248** toward each other, the distal ends **248b** are moved away from each other and into engagement with the sidewall **134** of the rolling diaphragm **112**. Conversely, by moving the proximal ends **248a** of the pivotable elements **248** away from each other, the distal ends **248b** are moved toward each other and out of engagement with the sidewall **134** of the rolling diaphragm **112**. In FIG. 45, the pivotable elements **248** are pivotable about first and second pivot points **250a**, **250b**. The pivotable elements **248** are pivotable radially inward into engagement with an engagement portion **244** protruding from the proximal end **132** of the rolling diaphragm **112**. In certain embodiments, first and second pivot points **250a**, **250b** may be the same.

[00194] FIG. 46A is a cross-sectional side view of a plunger **144** in accordance with another aspect of the present disclosure. FIG. 46B is a cross-sectional side view of a rolling diaphragm **112** and the plunger **144** shown in FIG. 46A. The plunger **144** has a connection interface **254** configured for engagement with a piston **178** having connection features described in U.S. Patent Nos. 5,383,858 to Reilly et al.; 5,873,861 to Hitchins et al.; and 6,652,489 to Trocki et al., which are incorporated herein by reference in their entirety. The piston **178** has at least one attachment member adapted to releasably engage the plunger **144** regardless of the orientation of the plunger **144** about its longitudinal axis with respect to the piston **178**. In some aspects, the plunger **144**

has a cover **280** that covers at least a portion of the body of the plunger **144**. The cover **280** is retained with the body **282** by way of a lip **284** that engages a groove **286** on the body **282**. The body **282** further has an annular ridge **288** that receives one or more pins **290** that are reversibly extendable from the piston **178**. When the one or more pins **290** extend radially outward from the piston **178**, at least one of the pins **290** is received inside the annular ridge **288**. In this manner, proximal or distal movement of the piston **178** results in a corresponding movement of the plunger **144** as a result of engagement of at least one of the pins **290** within the annular ridge **288**. Retracting the one or more pins **290** in a radially inward direction releases the one or more pins **290** from the annular ridge **288** to allow the piston **178** to be released from the plunger **144**.

[00195] FIG. 47A is a cross-sectional side view of a rolling diaphragm **112** and plunger **144** in accordance with another aspect of the present disclosure, with the plunger **144** shown in a first axial position. FIG. 47B is a cross-sectional side view of the rolling diaphragm **112** and plunger **144** shown in FIG. 47A, with the plunger **144** shown in a second axial position. The rolling diaphragm **112** has a conical shape that extends radially outward from the proximal end **132** toward the distal end **130**. An outer circumference of the sidewall **134** has an elastic element **252**, such as a spring, coiled around the sidewall **134** and extending between the proximal end **132** and the distal end **130**. The elastic element **252** is configured to roll upon itself in a manner similar to the rolling over of the sidewall **134** of the rolling diaphragm **112** upon engagement with the plunger **144**. In some aspects, the elastic element **252** may be a reinforced elastomer spring, or a metal mesh.

[00196] FIG. 48A is a partially-exploded perspective view of a syringe having a pressure jacket **110**, a rolling diaphragm **112**, and plunger **144** in accordance with another aspect of the present disclosure. FIG. 48B is a cross-sectional side view of the syringe shown in FIG. 48A. The components of the syringe **104** shown in FIGS. 48A-48B are substantially similar to the components of the syringe **104** described above with reference to FIGS. 2-3. Reference numerals in FIGS. 48A-48B are used to illustrate identical components as the corresponding reference numerals in FIGS. 2-3. As the previous discussion regarding the syringe **104** generally shown in FIGS. 2-3 is applicable to the aspect shown in FIGS. 48A-48B, only the relevant differences between these systems are discussed hereinafter.

[00197] FIGS. 48A-48B illustrate a disposable, single-use syringe **104** that is prefilled with a fluid for delivery to a patient. The syringe **104** includes a disposable pressure jacket **110** that

interfaces with the injector **102**, as described above with reference to **FIG. 2**. The proximal end **118** of the pressure jacket **110** has a plunger **144** that engages the end wall **136** of the rolling diaphragm **112**. The plunger **144** has a distal end **146** that engages the end wall **136** of the rolling diaphragm **112** and a proximal end **148** that is shaped to engage the piston head **138** of the injector **102**. The proximal end **118** of the pressure jacket **110** is provided with a seal **150**. The seal **150** seals the proximal end **118** of the pressure jacket **110** prior to use with the injector **102** (not shown in **FIGS. 48A-48B**). Additionally, the seal **150** provides a vapor barrier. Desirably, the seal **150** is removed prior to connecting the syringe **104** to the injector **102**. The syringe **104** further includes a cap **152** provided at the distal end **130** of the rolling diaphragm **112**. The cap **152** may be molded, adhered, screwed, or otherwise mechanically coupled to the distal end **130** of the rolling diaphragm **112**. Desirably, the connection between the cap **152** and the distal end **130** of the rolling diaphragm **112** is formed to withstand typical injection pressures. The cap **152** has a connector **154**, such as a luer-type connector, for connecting to a fluid path set (not shown). In one aspect, the fluid path set includes a corresponding connector for coupling to the connector **154** on the cap **152**. A piercing needle **156** is provided, for example, on the fluid path set to allow piercing of the cap **152** and the discharge port **142** of the rolling diaphragm **112** to fluidly connect the interior volume **114** of the rolling diaphragm **112** with the fluid path set. Desirably, the fluid path set is disposed with the rolling diaphragm **112** after use.

[00198] **FIG. 49A** is a partially-exploded perspective view of a syringe **104** having a pressure jacket **110**, a rolling diaphragm **112**, and plunger **144** in accordance with another aspect of the present disclosure. **FIG. 49B** is a cross-sectional side view of the syringe **104** shown in **FIG. 49A**.

[00199] The components of the syringe **104** shown in **FIGS. 49A-49B** are substantially similar to the components of the syringe **104** described above with reference to **FIGS. 48A-48B**. Reference numerals in **FIGS. 49A-49B** are used to illustrate identical components as the corresponding reference numerals in **FIGS. 48A-48B**. As the previous discussion regarding the syringe **104** generally shown in **FIGS. 48A-48B** is applicable to the aspect shown in **FIGS. 49A-49B**, only the relevant differences between these systems are discussed hereinafter. The pressure jacket **110** may be a reusable pressure jacket **110** that may be used with different rolling diaphragms **112**. Desirably, the pressure jacket **110** is substantially conical and is removably connectable to the injector **102** to extend at least along a portion of the sidewall **134** of the rolling

diaphragm **112**. The rolling diaphragm **112** can be loaded from the distal end **116** of the pressure jacket **110**. The cap **152** is formed such that it extends from the distal end **130** of the rolling diaphragm **112** to at least a portion of the sidewall **134**. The cap **152** includes at least one locking tab **158** that extends radially outward from an outer surface of the cap **152**. The locking tab **158** is formed to engage a locking collar **160** provided on the injector **102**. The locking collar **160** is retractable such that it can be engaged with the locking tab **158** during use and disconnected therefrom when the rolling diaphragm **112** is to be removed from the pressure jacket **110**. The plunger **144** is reusable and expands radially with axial movement in a distal direction along the axis of the pressure jacket **110**. The plunger **144** may be spring-loaded against the piston head **138** by one or more springs **162**. Upon withdrawal of the piston head **138** in the proximal direction, the springs **162** push the plunger **144** apart from the piston head **138** to allow for the diameter of the plunger **144** to be reduced as it is withdrawn in the proximal direction. In one aspect, the used rolling diaphragm **112** may be removed from the pressure jacket **110** by a removal member, such as a burst of compressed air or an action of a mechanical piston that crushes the rolling diaphragm **112** to a compact size for easy disposal.

[00200] FIG. 50A is a partially-exploded perspective view of a syringe **104** having a pressure jacket **110**, a rolling diaphragm **112** (not shown, within pressure jacket **110**), and plunger **144** in accordance with another aspect of the present disclosure. In some aspects, the pressure jacket **110** is formed from two cylindrical halves **110a**, **110b** which are hingedly connected together. A hinge **166** may be provided substantially parallel with the longitudinal axis of the pressure jacket **110**, or a hinge **104** may be provided at the proximal end **118** or distal end **116** and substantially perpendicular relative to the longitudinal axis. The pressure jacket **110** may be opened by pivoting one of the cylindrical halves **110a**, **110b** relative to the other by action of the hinge to open pressure jacket **110** and allow for easier loading of the rolling diaphragm. Once loaded, the pressure jacket **110** may be closed before being connected to the injector **102**. With reference to FIG. 50B, a pressure jacket **110** is shown in accordance with another aspect. In this aspect, the pressure jacket **110** is formed from two cylindrical halves **110a**, **110b** which are joined together in a clam-shell configuration. A finger lock **194** is provided at the distal end **116** of the pressure jacket **110**. The pressure jacket **110** may be opened by swinging one of the cylindrical halves **110a**, **110b** relative to the other to allow for easier loading of the rolling diaphragm **112**. Once

loaded, the pressure jacket **110** may be closed before being connected to the injector **102** (not shown).

[00201] FIG. **51** is a cross-sectional side view of a syringe **104** having a pressure jacket **110**, a rolling diaphragm **112**, and plunger **144** in accordance with another aspect of the present disclosure. The pressure jacket **110** has a removable closure **196** for enclosing the distal end **116** of the pressure jacket **110**. The closure **196** may be removable from the distal end **116** of the pressure jacket **110** for loading the rolling diaphragm **112** into the pressure jacket **110**. Once the rolling diaphragm **112** is loaded, the distal end **116** of the pressure jacket **110** is closed by the closure **196**. For example, the closure **196** may have internal or external threads that engage the corresponding threads on the distal end **116** of the pressure jacket **110**. Alternatively, the closure **196** may be a bayonet-type closure having tabs or slots that engage with corresponding slots or tabs on the distal end **116** of pressure jacket **110**. The closure **196** may have a threaded fitting for connecting to the fluid path set (not shown).

[00202] FIGS. **52A-52B** are partially-exploded side cross-sectional views of a syringe **104** having a pressure jacket **110**, a rolling diaphragm **112**, and plunger **144** in accordance with another aspect of the present disclosure. The components of the syringe **104** shown in **52A-52B** are substantially similar to the components of the syringe **104** described above with reference to FIGS. **48A-48B**. Reference numerals in **52A-52B** are used to illustrate identical components as the corresponding reference numerals in FIGS. **48A-48B**. As the previous discussion regarding the syringe **104** generally shown in FIGS. **48A-48B** is applicable to the aspect shown in **52A-52B**, only the relevant differences between these systems are discussed hereinafter. FIG. **52a** illustrates a syringe **104** having a substantially cylindrical pressure jacket **110**. According to various embodiments, the cap **152** has a closure member **168** that is removably connected to the cap **152**. The closure member **168** may optionally be formed integrally with the cap **152** while still being removably connected to the cap **152**. Prior to use, the closure member **168** engages the cap **152** to seal the cap **152** and prevent contamination thereof. The closure member **168** is then removed to allow the cap **152** to be pierced by piercing member **156** and connected to the fluid path set (not shown). After use, the closure member **168** can be reconnected to the cap **152** to prevent any remaining fluid from spilling from the cap **152**.

[00203] FIG. **53** is a cross-sectional side view of a syringe **104** in accordance with another aspect of the present disclosure. The syringe **104** has a rolling diaphragm **112** that is

encapsulated within the pressure jacket **110** with a fluid sleeve **184** disposed between the sidewall **134** of the rolling diaphragm **112** and the pressure jacket **110**. The fluid sleeve **184** is filled around the rolling diaphragm **112** after it is disposed within the pressure jacket **110**. The cap **152** encloses the fluid sleeve **184** within the pressure jacket **110**. The proximal end of the pressure jacket **110** may be sealed with a second cap **186** to prevent the fluid sleeve **184** from leaking through the proximal end of the pressure jacket **110**.

[00204] FIGS. **55A-55B** are a cross-sectional side views of a syringe **104** in accordance with another aspect of the present disclosure. With reference to FIGS. **55A-55B**, the fluid sleeve **184** may be in the form of a bag that surrounds the rolling diaphragm **112** within the pressure jacket **110** (FIG. **55A**) or as a bag proximal to rolling diaphragm **112** (FIG. **55B**). The plunger **144** has a check valve **188** to allow a retraction of the plunger **144** after fluid from the rolling diaphragm **112** is delivered. A sensor **190** may be provided within the pressure jacket **110** to detect a rupture of the fluid sleeve **184** or the rolling diaphragm **112**. With reference to FIG. **55A**, the rolling diaphragm **112** has a correspondingly-shaped fluid sleeve **184** provided along a longitudinal length of the rolling diaphragm **112**. In one aspect, the fluid sleeve **184** may be a mirror copy of the rolling diaphragm **112**. When inserted into the injector **102** (not shown), the rolling diaphragm **112** is fluidly connected to a fluid path set (not shown). During an injection procedure, the fluid sleeve **184** functions as a compression surface to drive the fluid from the interior volume **114** of the rolling diaphragm **112**. In particular, a portion of the injector **102**, such as the plunger **144**, acts on the fluid sleeve **184** to compress the fluid sleeve **184** against the rolling diaphragm **112**. In this manner, the compression force of the fluid sleeve **184** is evenly distributed across the entire surface of the rolling diaphragm **112** to minimize the residual volume of fluid remaining in the rolling diaphragm **112**. Gripping tabs **192** may be provided on one or both lateral portions of the fluid sleeve **184** and the rolling diaphragm **112** to facilitate handling of the assembly.

[00205] FIGS. **56A-56B** are cross-sectional side views of a syringe **104** in accordance with another aspect of the present disclosure. The rolling diaphragm **112** has a cap **152** that may be molded, adhered, screwed, or otherwise mechanically coupled to the distal end **130** of the rolling diaphragm **112**. Desirably, the connection between the cap **152** and the distal end **130** of the rolling diaphragm **112** is formed to withstand typical injection pressures. The cap **152** has a connector **154**, such as a luer-type connector, for connecting to a fluid path set **108**. In one

aspect, the fluid path set includes a corresponding connector for coupling to the connector **154** on the cap **152**. A piercing needle **156** is provided on the fluid path set **108** to allow piercing of a frangible seal **200** on the cap **152** which seals the discharge port **142** of the rolling diaphragm **112**. In the aspect shown in **FIG. 56B**, the piercing needle **156** may be built into the cap **152**. Once the frangible seal **200** is pierced, the interior volume **114** of the rolling diaphragm **112** is fluidly connected with the fluid path set **108**. With reference to **FIG. 54**, the rolling diaphragm **112** has a high-pressure seal **202** at its distal end **130** and the cap **152** has a low-pressure seal **204**.

[00206] **FIG. 58A** is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure. **FIG. 58B** is a partial cross-sectional perspective view of a seal shown in **FIG. 58A**. The discharge neck **140** of the rolling diaphragm **112** has a seal **200** that abuts against a seal **200a** of the cap **152** to create a double-seal arrangement. The cap **152** is desirably attached to the discharge neck **140** in one of the plurality of ways described herein. The cap **152** has a connection member **212**, formed as a plurality of external threads that threadably engage with the internal threads of the fluid path set **108**. The piercing needle **156** is formed on the terminal end of the fluid path set **108** for piercing through the double-seal arrangement in order to establish fluid communication between the interior volume **114** of the rolling diaphragm **112** and the fluid path set **108**.

[00207] With reference to **FIG. 59** is a cross-sectional side view of a syringe in accordance with another aspect of the present disclosure. The discharge neck **140** of the rolling diaphragm **112** is initially sealed. The cap **152** is attachable to the pressure jacket **110** such that a piercing needle **156** of the cap **152** may pierce the sidewall **134** of the rolling diaphragm **112** at the discharge neck **140**. In some aspects, the cap **152** may have a connection member **212**, formed as a plurality of external threads that threadably engage with the internal threads of the fluid path set **108** (not shown). The piercing needle **156** is formed on the terminal end of the cap **152** for piercing through the sidewall **134** of the rolling diaphragm **112** in order to establish fluid communication between the interior volume **114** of the rolling diaphragm **112**.

[00208] **FIG. 60A** is a side cross-sectional view of a seal for use with a syringe and rolling diaphragm in accordance with another aspect of the present disclosure, with a seal piercing element shown in a first sealed position. **FIG. 60B** is a side cross-sectional view of the seal shown in **FIG. 60B**, with the seal piercing element shown in a second pierced position. The seal

150 may have a base **151** and a sidewall **153** protruding substantially perpendicularly relative to the base **151**. The base **151** is piercable by a piercing element **155**, such as a spike provided on a fluid path set. Once the piercing element **155** pierces the base **151**, the base **151** fluidly seals around the circumference of the seal **150**. In addition, a body **157** of the piercing element **155** engages the sidewall **153** of the seal **150** to provide a secondary seal.

[00209] FIG. 61 is a cross-sectional side view of a rolling diaphragm **112** and a plunger **144** in accordance with another aspect of the present disclosure. The plunger **144** has an inner element **300** and an elastic element **310** wrapped around at least a portion of the inner element **300**. One end of the elastic element **310**, such as a proximal end **310a** or a distal element **310b**, may be secured to the inner element **300**, while the opposing end of the elastic element **310** is free to rotate about the inner element **300**. Upon rotation of one end of the elastic element **310** around the inner element **300** in a first direction, such as a clockwise or a counterclockwise direction, the elastic element **310** may be expanded radially outward to engage an inner surface of an outer element **320** that surrounds the inner element **300** and the elastic element **310**. The outer element **320** may be formed as a split cylinder with a slit extending along its longitudinal axis. An outer surface of the outer element **320** engages the sidewall **134** of the rolling diaphragm **112**. Thus, as the elastic element **310** expands against the inner surface of the outer element **320**, the outer element **320** expands radially outward such that its outer surface engages the sidewall **134** of the rolling diaphragm **112**. In this manner, the plunger **144** may move the sidewall **134** of the rolling diaphragm **112** to withdraw fluid or expel fluid from the interior volume **114** of the rolling diaphragm **112**. In some aspects, the elastic element **310**, in the expanded state, may engage the sidewall **134** of the rolling diaphragm **112**. Upon rotation of the elastic element **310** around the inner element **300** in a second direction opposite the first direction, the elastic element **310** may contract radially inward, thereby disengaging the outer element **320**. In some aspects, the elastic element **310**, in the contracted state, may disengage the sidewall **134** of the rolling diaphragm **112**.

[00210] FIG. 62 is a cross-sectional side view of a pressure jacket **110** in accordance with another aspect of the present disclosure. The pressure jacket **110** may have an adapter **110a** for releasably connecting the pressure jacket **110** with the injector **102**. An outer sidewall of the pressure jacket **110** has one or more tabs **330** that protrude radially outward relative to the outer sidewall. The one or more tabs **330** are received in corresponding slots **340** or engagement

mechanism formed on the adapter **110a**. In some aspects, the pressure jacket **110** may be secured to the adapter **110a** by inserting the pressure jacket **110** into a central opening on the adapter **110a** and rotating the pressure jacket **110** relative to the adapter **110a** in a first direction (such as $\frac{1}{4}$ of a turn in a clockwise or a counterclockwise direction) until the tabs **330** are received within the slots **340**. Once received, the tabs **330** retain the pressure jacket **110** locked with the adapter **110a** until the pressure jacket **110** is rotated in a second direction opposite the first direction (such as $\frac{1}{4}$ of a turn in a counterclockwise or a clockwise direction). The adapter **110a** may have a radial flange **350** protruding from an outer sidewall to prevent fluid from dripping into the injector **102**. One or more locking elements **360** may be provided on the adapter **110a** to removably lock the adapter **110a** with a corresponding locking mechanism on the injector **102**. In some aspects, the adapter **110a** may be removably locked with the injector **102**, such as by a bayonet connection.

[00211] FIG. 63A is a perspective view of a syringe having a pressure jacket **110** in accordance with another aspect of the present disclosure. FIG. 63B is a cross-sectional side view of the syringe shown in FIG. 63A. FIG. 63C is a perspective view of a rolling diaphragm **112** for use with the pressure jacket **110** shown in FIG. 63A. The syringe **104** includes the pressure jacket **110** that removably interfaces with the injector **102** (shown in FIG. 1), as described herein. The pressure jacket **110** has a distal end **116**, a proximal end **118**, and a sidewall **119** extending between the distal end **116** and the proximal end **118** along a longitudinal axis of the pressure jacket **110** to define an internal throughbore **121** (shown in FIG. 63B). In some aspects, the sidewall **119** of the pressure jacket **110** is shaped to receive at least a portion of the rolling diaphragm **112** (shown in FIG. 63B) within the throughbore **121**. The pressure jacket **110** is typically a reusable component, while the rolling diaphragm **112** is typically a single-use component. In another aspect, the rolling diaphragm **112** may be reusable such that the rolling diaphragm **112** is refillable with fluid. The sidewall **119** of the pressure jacket **110** has a first distal portion **360a** for receiving at least a portion of the rolling diaphragm **112**, and a second proximal portion **360b** for interfacing with the injector **102**. In some aspects, the second distal portion **360b** has a locking lug or lip **370** protruding radially outward from an outer surface of the second proximal portion **360b**. The locking lug or lip **370** may extend continuously or discontinuously around an outer circumference of the second proximal portion **360b**. In some aspects, the locking lug or lip **110** may have a connection interface to releasably secure the

pressure jacket **110** to a corresponding locking mechanism of the fluid injector **102** described in U.S. Patent Nos. 5,383,858 to Reilly et al.; 5,873,861 to Hitchins et al.; and 6,652,489 to Trocki et al., U.S. Patent Application No. 14/526,294, entitled “Self-Orienting Syringe and Syringe Interface”, and U.S. Patent Application No. 14/526,395, entitled “Self-Orienting Syringe and Syringe Interface”, the disclosures of which are incorporated herein by reference in their entirety.

[00212] With reference to **FIG. 63B**, the pressure jacket **110** has a cap **390** that is releasably secured to the distal end **116**. In some aspects, the cap **390** may be secured by a threaded engagement, a bayonet fitting, or another mechanical fastening arrangement with the distal end **116** of the pressure jacket **110**. For example, the cap **390** may have at least one projection **430** that is received inside at least one groove **440** on the pressure jacket **110** such that the cap **390** may be locked with the pressure jacket **110** by aligning the at least one projection **430** to fit within the groove **440**. In some aspects, the cap **390** may be formed from two or more separate elements that are joined together to form the cap **390**. For example, the cap **390** may have two elements joined together at a longitudinal cross-sectional plane of the cap **390**. A ring may be provided around at least a portion of the separate elements to retain the elements of the cap **390**. The cap **390** may have an inner element **400** with a nozzle **410** extending through the cap **390**. The nozzle **410** may be in fluid communication with the rolling diaphragm **112** to deliver fluid into or from the rolling diaphragm **112**. The nozzle **410** may have a connection interface for removably connecting to a connector **420** of a fluid path set **108** (shown in **FIG. 1**). The cap **390** may have a pocket **450** for collecting any fluid that may drip from the nozzle **410** and/or the connector **420**.

[00213] With reference to **FIG. 63C**, at least a portion of the rolling diaphragm **112** may be removably secured to the cap **390**. In some aspects, an inner sidewall of the cap **390** may have one or more threads **440** (shown in **FIG. 64B**) that engage the corresponding threads **140b** (shown in **FIG. 5A**) on the rolling diaphragm **112**. In other aspects, the rolling diaphragm **112** may be secured to the cap **390** by a snap-fit, interference fit, adhesive connection, co-molding or any other mechanical fastening arrangement. The rolling diaphragm **112** may have a built-in cap **390**. The rolling diaphragm **112** may be pre-filled with fluid, or may be empty such that it can be filled with fluid. In various aspects, the rolling diaphragm **112** may be removably or non-removably connected to the cap **390**. Desirably, the rolling diaphragm **112** is secured to the cap **390** prior to being inserted into the throughbore **121** of the pressure jacket **110**. After securing

the cap **390** to the pressure jacket **110**, the plunger **144** (shown in **FIG. 2**) may engage the rolling diaphragm **112** to deliver fluid into or from the rolling diaphragm **112**, as described herein.

[00214] **FIG. 64A** is a top perspective view of an alternative embodiment for the cap **390** for use with the pressure jacket **110** shown in **FIG. 63A**. The cap **390** may have a one-piece configuration with a threaded interface for connecting the rolling diaphragm **112** to the cap **390**.

[00215] While aspects of a fluid delivery system and a syringe having a rolling diaphragm for use therefor were provided in the foregoing description, those skilled in the art may make modifications and alterations to these aspects without departing from the scope and spirit of the disclosure. Accordingly, the foregoing description is intended to be illustrative rather than restrictive. The disclosure described hereinabove is defined by the appended claims and all changes to the disclosure that fall within the meaning and the range of equivalency of the claims are to be embraced within their scope.

WE CLAIM:

1. A rolling diaphragm for receiving a medical fluid therein, the rolling diaphragm comprising:

a proximal end comprising an end wall for engagement with a plunger, a distal end received within a throughbore of a pressure jacket, the distal end having a nozzle, and a sidewall extending between the proximal end and the distal end along a longitudinal axis, at least a portion of at least one of the sidewall and the end wall having non-uniform thickness,

wherein at least a portion of the sidewall is flexible such that the sidewall rolls upon itself when acted upon by the plunger such that an outer surface of the sidewall at a folding region is folded in a radially inward direction as the plunger is advanced from the proximal end to the distal end and wherein the outer surface of the sidewall unrolls as the folding region is unfolded in a radially outward direction as the plunger is retracted from the proximal end to the distal end,

wherein the end wall has a radiused folding edge that transitions into a distally extending ramp having continuously increasing thickness, and

wherein the end wall has a plunger engagement portion protruding proximally from a central region of the ramp.

2. The rolling diaphragm of claim 1, wherein the end wall has one or more ribs protruding radially outward from the plunger engagement portion toward the radiused folding edge.

3. The rolling diaphragm of claim 1, wherein a first portion of the sidewall distal of an approximate midpoint of the rolling diaphragm has a first thickness, wherein a second portion of the sidewall proximal of the approximate midpoint of the rolling diaphragm has a second thickness, and wherein the first thickness is larger than the second thickness.

4. The rolling diaphragm of claim 1, wherein the proximal end has a rigid plunger monolithically formed with the proximal end.

5. The rolling diaphragm of claim 1, wherein the plunger engagement portion is received within an opening on the plunger.

6. The rolling diaphragm of claim 5, wherein the plunger engagement portion is non-removably secured with at least a portion of the plunger.

7. The rolling diaphragm of claim 5, wherein at least a portion of the plunger engagement portion is expanded radially outward after it is inserted into the opening on the plunger to retain the plunger engagement portion within the opening of the plunger.

8. The rolling diaphragm of claim 1, wherein an interior of the rolling diaphragm is pre-filled with a medical fluid.

9. The rolling diaphragm of claim 1, wherein the nozzle has a connector for connecting to a fluid path set.

10. The rolling diaphragm of claim 9, wherein the connector is a luer connector.

11. The rolling diaphragm of claim 1, wherein the nozzle has a piercable seal for sealing an interior of the rolling diaphragm.

12. The fluid delivery system of claim 1, wherein the nozzle has a first seal between the nozzle and the sidewall of the rolling diaphragm and a second seal at an interface for connecting the nozzle to a fluid path set.

13. A syringe for a fluid delivery system, the syringe comprising:
a pressure jacket having a distal end, a proximal end, and a throughbore extending between the distal end and the proximal end; and
a rolling diaphragm disposed within the throughbore of the pressure jacket, the rolling diaphragm having a proximal end having an end wall in engagement with a plunger, a

distal end received at the distal end of the pressure jacket, the distal end of the rolling diaphragm having a nozzle, and a sidewall extending between the proximal end and the distal end of the rolling diaphragm along a longitudinal axis, at least one of the end wall and at least a portion of the sidewall having a non-uniform thickness,

wherein at least a portion of the sidewall of the rolling diaphragm is flexible and rolls upon itself such that an outer surface of the sidewall at a folding region is folded in a radially inward direction as the plunger is advanced from the proximal end to the distal end of the rolling diaphragm and such that the outer surface of the sidewall unrolls as the folding region is unfolded in a radially outward direction as the plunger is retracted from the proximal end to the distal end of the rolling diaphragm,

wherein the end wall has a radiused folding edge that transitions into a distally extending ramp having continuously increasing thickness, and

wherein the end wall has a plunger engagement portion protruding proximally from a central region of the ramp.

14. The syringe of claim 13, wherein the pressure jacket has a removable closure for enclosing at least a portion of the rolling diaphragm.

15. The syringe of claim 14, wherein the removable closure has a threaded end for engaging corresponding threads on the distal end of the pressure jacket or wherein the removable closure has one or more radially extending tabs for insertion into corresponding slots for engaging a bayonet locking mechanism on the distal end of the pressure jacket.

16. The syringe of claim 14, wherein the proximal end of the pressure jacket has a connection interface for releasably connecting to a fluid injector.

17. A fluid delivery system, comprising:
a fluid injector comprising at least one reciprocally operable piston;
a plunger operably connectable to the piston;

a pressure jacket having a distal end, a proximal end, and a throughbore extending between the distal end and the proximal end, the pressure jacket operably connectable to the fluid injector; and

a rolling diaphragm disposed within a throughbore of the pressure jacket, the rolling diaphragm having a proximal end comprising an end wall in engagement with the plunger, a distal end received at the distal end of the pressure jacket, the distal end of the rolling diaphragm having a nozzle, and a sidewall extending between the proximal end and the distal end of the rolling diaphragm along a longitudinal axis, at least a portion of at least one of the sidewall and the end wall having non-uniform thickness,

wherein at least a portion of the sidewall of the rolling diaphragm is flexible and rolls upon itself such that an outer surface of the sidewall at a folding region is folded in a radially inward direction as the plunger is advanced by the piston from the proximal end to the distal end of the rolling diaphragm and such that the outer surface of the sidewall unrolls as the folding region is unfolded in a radially outward direction as the plunger is retracted by the piston from the proximal end to the distal end of the rolling diaphragm,

wherein the end wall has a radiused folding edge that transitions into a distally extending ramp having continuously increasing thickness, and

wherein the end wall has a plunger engagement portion protruding proximally from a central region of the ramp.