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(54) Title: SUTURING DEVICES AND METHODS FOR SUTURING AN ANATOMIC VALVE

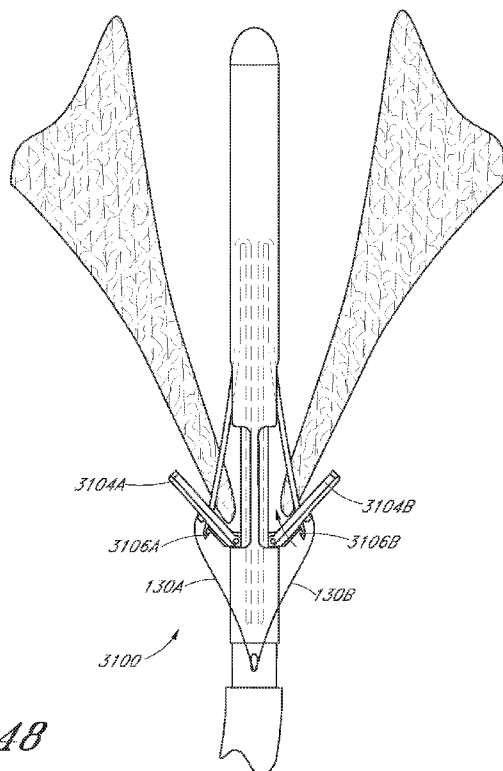


FIG. 48

(57) Abstract: Suturing apparatuses configured to suture biological tissue, such as an anatomical valve. The suturing apparatuses can comprise an elongate member having a proximal end, a distal end, one or more arms, and one or more needles. A protective member may be used to inhibit contact between a distal end of a needle and surrounding tissue. Methods for suturing bodily tissue such as an anatomical valve may be performed with the suturing apparatuses. The suturing apparatuses may be used to suture adjacent valve leaflets or the base of a valve in order to treat or repair the valve.





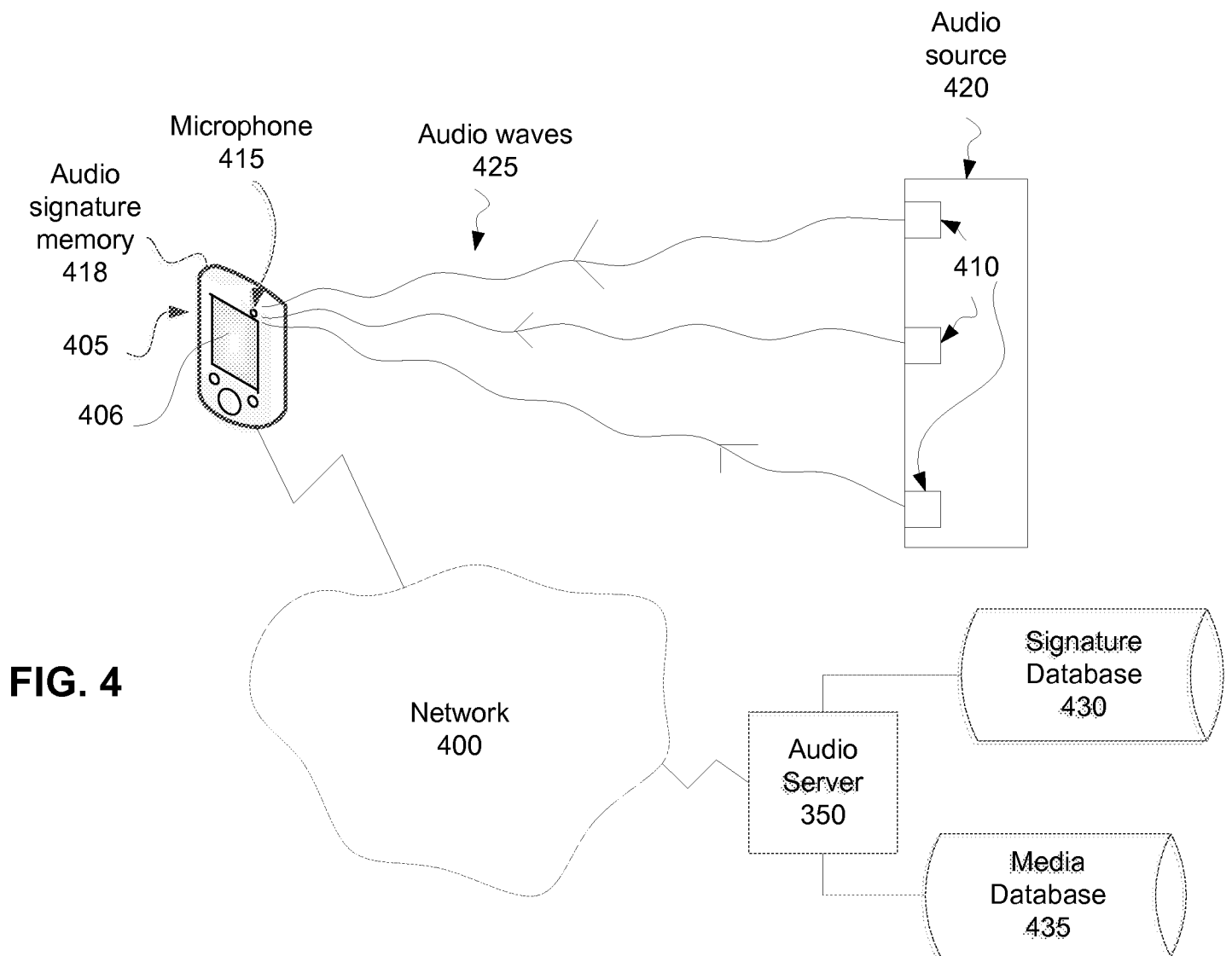
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[0006] A number of procedures have been developed to repair valves that do not close properly. Among these procedures is the Alfieri technique, sometimes called edge-to-edge repair, which involves suturing edges of the leaflets and pulling the leaflets closer together. In another technique, the chordae tendineae are replaced or shortened. A patch is sometimes applied to leaflets that have openings therein. In some instances, leaflets are reshaped by removing a section of the leaflet that is to be treated and the surrounding portion of the leaflet is sutured closed. Some valves are treated by attaching a ring around the outside of the malfunctioning valve. In a mitral valve annuloplasty, for example, a device such as in the shape of a ring or a partial ring may be implanted surrounding the mitral valve to pull the leaflets together. Sutures may be used to attach the annuloplasty ring to the base of the valve. Other valves may be replaced with biological or mechanical replacements. These procedures are frequently performed by highly invasive procedures, which sometimes require opening a patient's chest, stopping the patient's heart and routing blood through a heart-lung machine. Robotically-assisted procedures have been employed to reduce the size of the openings required for such procedures.

SUMMARY OF THE DISCLOSURE

[0007] Embodiments of suturing devices and methods for suturing biological tissue are disclosed herein. The suturing devices and their methods of use can be useful in a variety of procedures, such as treating (e.g., closing) wounds and naturally or surgically created apertures or passageways. For example, the suturing devices can be used to treat an anatomical valve, such as a heart valve, including heart valves that may be weakened or stretched, or have other structural defects, such as congenital defects, that cause them to close improperly. In some embodiments, one or more suturing devices can be used to treat or repair valves, such as the tricuspid, pulmonary, mitral, and aortic valves, for example. In some embodiments, one or more suturing devices can be used to perform procedures such as edge-to-edge repair (like an Alfieri technique), annuloplasty (with or without a ring or other implant), suturing of ventricular spaces, suturing of the chordae, suturing in other locations in the heart, replacement of the chordae tendineae, shortening of the chordae tendineae, patch application, leaflet reshaping, and attachment of prosthetics, such as rings and biological or mechanical replacement valves, for example.

[0008] In some embodiments, the suturing devices can be used to close or reduce a variety of other tissue openings, lumens, hollow organs or natural or surgically created passageways in the body. In some embodiments, the suturing devices can be used to suture prosthetics, synthetic materials, or implantable devices in the body. For example, the devices can be used to suture pledget within the body.

[0009] In some embodiments, a suturing device can comprise an elongate body having a distal end, a single arm, a needle, and a protective member. The single arm can be connected with the elongate body near the distal end for movement between a retracted position and an extended position. The arm can comprise a first suture mount located near a free end of the arm and configured to releasably retain a first suture portion. A needle can be configured to move between a retracted position and a deployed position to retrieve the first suture portion retained in the first suture mount when the first needle is moved from the retracted position to the advanced position and returned to the retracted position. The first protective member can be configured to inhibit contact between a distal end of the first needle and surrounding tissue during at least a portion of the movement of the first needle from its retracted position toward its deployed position.

[0010] In some embodiments, a suturing device can comprise an elongate body having a proximal end and a distal end, and a handle at the proximal end. A first arm and a second arm can connect to the elongate body near the distal end, and the first arm and the second arm can be configured to move between a first position, in which the first arm and second arm are retracted within the elongate body, and a second position, in which the first arm and the second arm have free ends extending away from the elongate body. The first arm and the second arm can form an angle between each other and can each have at least one suture mount at their free ends. The suture mounts can be configured to releasably retain a suture portion. A needle arm can connect to the elongate body proximal to the first and second arm, and can extend from a retracted position, in which the needle arm is retracted in the elongate body, to an extended position, in which the needle arm extends distally and outwardly from the elongate body. The needle arm can rotate around the elongate body at least between a first position where the needle arm is aligned with the free end of the first arm and a second position where the needle arm is aligned with the free end of the second arm. The device can also comprise a first needle and a second needle that can have a

retracted position in which a distal point of each needle is within the needle arm. The first needle can move from the retracted position to a deployed position in which the distal point of the first needle extends out of the needle arm into the suture mount of the first arm when the needle arm is in the first position. The second needle can move from the retracted position to a deployed position in which the distal point of the second needle extends out of the needle arm into the suture mount of the second arm when the needle arm is in the second position.

[0011] Methods of suturing anatomic valves are also described. In some embodiments, an elongate body can be positioned at least partially within the anatomic valve. An arm can be deployed from the elongate body with the first arm releasably holding a first suture portion. A free end of the arm can be positioned at or near a base of the valve. A first needle can be deployed from the elongate body such that the first needle penetrates the valve at a first location and engages the first suture portion. The valve tissue and surrounding anatomy can be protected from a distal end of the first needle as the first needle is deployed to the first location. The first suture portion can be drawing through the leaflet. A second suture portion can be passed through the valve at a second location. The first and second suture portions can be secured together.

[0012] In some embodiments, an anatomic valve can be sutured by positioning an elongate body at least partially within the anatomic valve, deploying an arm from the elongate body on a first side of a valve with the first arm releasably holding first and second suture portions. A free end of the arm can be positioned at or near a base of the valve. First and second needles can be deployed from the elongate body on a second side of the valve such that the first needle penetrates the valve at a first location and engages the first suture portion and the second needle penetrates the valve at a second location and engage the second suture portion. The first and second suture portions can be drawn through the valve from the first side to the second side. The first and second suture portions can be secured together.

[0013] In some embodiments, an anatomic valve can be sutured by positioning an elongate body at least partially within the anatomic valve and deploying at least two arms from the elongate body with each arm releasably holding a suture portion. A free end of each of the arms can be positioned at or near a base of the valve. Needles can be deployed

from the elongate body such that each needle penetrates the valve and engages a corresponding suture portion. The suture portions can be drawn through the leaflet. The suture portions can be secured together in groups of no less than two.

[0014] In some embodiments, an anatomic valve can be sutured by positioning a suturing device comprising an elongate body through the valve and extending a plurality of arms from the elongate body of the suturing device, with each of the arms carrying an end of a suture. At least a pair of arms can be positioned at or near a base of the valve. A protection member can be extended from the elongate body toward a first one of the arms positioned at or near a base of the valve. A needle can be advanced through the protection member, through tissue of the valve at a first location, and into contact with a first one of the suture ends carried by the first arm. The needle can be retracted through the tissue of the valve to draw the first suture end through the tissue. The protection member can be rotated along the elongate body such that the protection member extends toward a second one of the arms positioned at or near a base of the valve. A needle can be advanced through the protection member, through tissue of the valve at a second location, and into contact with a second one of the suture ends carried by the second arm. The needle can be retracted through the tissue of the valve to draw the second suture end through the tissue. A distance between the first and second locations can be closed with said suture placed through said locations.

[0015] In some embodiments, a mitral valve can be sutured by delivering a suturing device transapically through the heart and into the left ventricle. The suturing device can have a proximal end, a distal end, an elongate body extending between the proximal end and the distal end, and a handle at the proximal end. At least the distal end of the device can be delivered through the mitral valve. A first arm and a second arm can be extended from the elongate body from a first position, in which the first arm and the second arm are retracted into the elongate body, to a second position, in which the first arm and the second arm have free ends extending away from the elongate body. The first arm can carry a first suture end and the second arm can carry a second suture end. The first and second arm can be at or near a base of the valve on the atrial side of the valve.

[0016] A needle arm can be extended from a retracted position in which the needle arm is retracted into the elongate body to an initial extended position in which the

needle arm is located proximal to the arms. The needle arm in the initial extended position can extend outwardly away from the elongate body in a distal direction on the ventricular side of the valve between adjacent chordae. The needle arm can be rotated toward the first arm with the needle arm remaining on the ventricular side of the valve such that the needle arm extends toward the first arm positioned at or near a base of the valve.

[0017] A first needle can be advanced distally out of the needle arm, through tissue of the valve at a first location, and into contact with the first suture end. The first needle can be retracted through the tissue of the valve to draw the first suture end through the tissue, and a first length of suture can run from the first suture end through the tissue. The needle arm can be rotated toward the second arm with the needle arm remaining on the ventricular side of the valve such that the needle arm extends toward the second arm positioned at or near a base of the valve. A second needle can be advanced distally out of the needle arm, through tissue of the valve at a second location, and into contact with the second suture end. The second needle can be retracted through the tissue of the valve to draw the second suture end through the tissue, and a second length of suture can run from the second suture end through the tissue.

[0018] The needle arm can be rotated back to the initial extended position. The needle arm can be moved proximally back to the retracted position. The first and second arms can be moved from the second position back to the first position. The suturing device can be withdrawn from the mitral valve, and the first and second lengths of suture can remain within the tissue. A first distance between the first and second locations can be closed to a second distance between the first and second locations.

[0019] In some embodiments, tissue can be sutured by delivering a suturing device to a location adjacent the tissue. The suturing device can have a proximal end, a distal end, an elongate body extending between the proximal end and the distal end, and a handle at the proximal end. At least the distal end of the device can be delivered to the location adjacent the tissue. A first arm and a second arm can be extended from the elongate body from a first position, in which the first arm and the second arm are retracted into the elongate body, to a second position, in which the first arm and the second arm have free ends extending away from the elongate body and the first arm and second arm form an angle

between each other. The first arm can carry a first suture end and the second arm can carry a second suture end. The first and second arm can be adjacent a first side of the tissue.

[0020] A needle arm can be moved from a retracted position in which the needle arm is retracted into the elongate body to an extended position in which the needle arm extends toward the first arm. The needle arm can be located on the opposite side of the tissue from the first arm and the second arm. A first needle can be advanced out of the needle arm, through tissue at a first location, and into contact with the first suture end. The first needle can be retracted through the tissue to draw the first suture end through the tissue, and a first length of suture can run from the first suture end and through the tissue. The needle arm can be rotated toward the second arm such that the needle arm extends toward the second arm. A second needle can be advanced out of the needle arm, through tissue at a second location, and into contact with the second suture end. The second needle can be retracted through the tissue to draw the second suture end through the tissue, and a second length of suture can run from the second suture end and through the tissue.

[0021] The needle arm can be moved back to the retracted position. The first and second arms can be moved from the second position back to the first position. The suturing device can be withdrawn from the tissue location, and the first and second lengths of suture can remain within the tissue.

[0022] In some embodiments, an anatomic valve can be sutured by positioning an elongate body at least partially within the anatomic valve. A first arm can be deployed from the elongate body, and the first arm can releasably hold a first suture portion at a free end. The free end of the first arm can be positioned at or near an edge of a first leaflet on a first side of the valve. A first needle arm can be deployed from the elongate body on an opposite side of the valve such that the first leaflet is positioned between the needle arm and the first arm. A first needle can be deployed from the first needle arm such that the first needle penetrates the first leaflet at a first location and engages the first suture portion. The first suture portion can be drawn through the first leaflet. A second suture portion can be passed through the second leaflet at a second location, and the two leaflets can be drawn together using a suture placed through the first and second location.

[0023] The disclosure describes examples of some embodiments of the inventions. The designs, figures, and description are non-limiting examples of some

embodiments of the inventions. Other embodiments of the devices and methods may or may not include the features disclosed herein. Moreover, disclosed advantages and benefits may apply to only some embodiments of the inventions, and should not be used to limit the inventions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The above-mentioned and other features disclosed herein are described below with reference to the drawings of specific embodiments. The illustrated embodiments are intended for illustration, but not limitation. The drawings contain the following figures:

[0025] Figure 1 illustrates a method of providing access to an exemplifying use environment, such as an aortic valve of a heart.

[0026] Figure 2A illustrates a method of providing access to an exemplifying use environment, such as a mitral valve of a heart.

[0027] Figure 2B illustrates a method of providing access to an exemplifying use environment, such as a mitral valve of a heart.

[0028] Figure 3 is a perspective view of an embodiment of a suturing device with suture clasp arms in a retracted position and a casing shown in cross-section.

[0029] Figure 4 is an enlarged perspective view of the embodiment of Figure 3 with the casing shown in cross-section, showing suture catch mechanisms in a partially advanced position.

[0030] Figure 5 is a perspective view of the embodiment of Figure 3, with the suture clasp arms in an extended position and the suture catch mechanisms in a partially advanced position.

[0031] Figure 6 is a perspective view of the embodiment of Figure 3, as in Figure 5, showing a casing attached to the device.

[0032] Figure 7A is a plan view of the embodiment of Figure 3, with the suture clasp arms in an extended position.

[0033] Figure 7B is a plan view as in Figure 7A, but with the suture clasp arms retracted.

[0034] Figure 8 is a cross-sectional view of the embodiment of Figure 3, along a line VIII-VIII in Figure 6.

[0035] Figure 9 is a cross-sectional view of the embodiment of Figure 3, along a line IX-IX in Figure 7A.

[0036] Figure 10 is a schematic representation an embodiment of a suturing device positioned in a passage through a valve.

[0037] Figure 11 is a schematic representation as in Figure 10 with suture clasp arms positioned around first and second leaflets of the valve.

[0038] Figure 12 is a schematic representation as in Figure 11 with suture clasp arms retracted.

[0039] Figure 13 is a schematic representation as in Figure 12 showing suture catch mechanisms engaging the suture clasp arms.

[0040] Figure 14 is a schematic representation as in Figure 13 showing the suture catch mechanisms and suture portions retracted through the first and second leaflets.

[0041] Figure 15 is a schematic representation as in Figure 14 showing the suture portions extending through the first and second leaflets and being joined by a knot.

[0042] Figure 16 is a plan view of an embodiment of a suturing device system with two suturing devices and a suture joining device.

[0043] Figure 17 is a plan view of an embodiment of a suturing device with a suture clasp arm in an extended position.

[0044] Figure 18 is an enlarged perspective view of the distal end of the suturing device of Figure 17 with the suture clasp arm in an extended position.

[0045] Figure 19 is a schematic representation an embodiment of a first suturing device positioned in a passage through a valve.

[0046] Figure 20 is a schematic representation as in Figure 19 with a suture clasp arm positioned around a first leaflet of the valve.

[0047] Figure 21 is a schematic representation as in Figure 20 showing a suture catch mechanism engaging the suture clasp arm.

[0048] Figure 22 is a schematic representation as in Figure 21 showing the suture catch mechanism and a suture portion retracted through the first leaflet.

[0049] Figure 23 is a schematic representation as in Figure 22 showing a second suturing device positioned in the passage through the valve.

[0050] Figure 24 is a schematic representation as in Figure 23 with the suture clasp arm positioned around a second leaflet of the valve.

[0051] Figure 25 is a schematic representation as in Figure 24 showing a suture catch mechanism engaging the suture clasp arm.

[0052] Figure 26 is a schematic representation as in Figure 25 showing the suture catch mechanism and a suture portion retracted through the second leaflet.

[0053] Figure 27 is a schematic representation as in Figure 26 showing the suture portions extending through the first leaflet and the second leaflet and being joined by a first knot.

[0054] Figure 28 is a plan view of an embodiment of a suturing device with a suture clasp arm in an extended position.

[0055] Figure 29 is an enlarged perspective view of the distal end of the suturing device of Figure 28 with the suture clasp arm in an extended position.

[0056] Figure 30 is a schematic representation of an embodiment of a first suturing device positioned in a passage through a valve.

[0057] Figure 31 is a schematic representation as in Figure 30 with a suture clasp arm positioned around a first leaflet of the valve.

[0058] Figure 32 is a schematic representation as in Figure 31 showing a suture catch mechanism engaging the suture clasp arm.

[0059] Figure 33 is a schematic representation as in Figure 32 showing the suture catch mechanism and a suture portion retracted through the first leaflet.

[0060] Figure 34 is a schematic representation as in Figure 33 showing a second suturing device positioned in the passage through the valve so as to permit a suture clasp arm to extend from the second suturing device.

[0061] Figure 35 is a schematic representation as in Figure 34 with the suture clasp arm positioned around a second leaflet of the valve.

[0062] Figure 36 is a schematic representation as in Figure 35 showing a suture catch mechanism engaging the suture clasp arm.

[0063] Figure 37 is a schematic representation as in Figure 36 showing the suture catch mechanism and a suture portion retracted through the second leaflet.

[0064] Figure 38A is a plan view of an embodiment of a suturing device with two suture clasp arms in an extended position.

[0065] Figure 38B is an enlarged perspective view of the distal end of the suturing device of Figure 38A with the suture clasp arms in an extended position.

[0066] Figure 39A is an enlarged perspective view of a distal end of an embodiment of a suturing device with two suture clasp arms in a retracted position.

[0067] Figure 39B is an enlarged perspective view of the distal end of the suture device of Figure 39A with the suture clasp arms in an extended position.

[0068] Figure 40 is a schematic representation of an embodiment of a suturing device positioned in a passage through a valve.

[0069] Figure 41 is a schematic representation as in Figure 40 with a suture clasp arm positioned around a first leaflet of the valve.

[0070] Figure 42 is a schematic representation as in Figure 41 showing a suture catch mechanism engaging the suture clasp arm.

[0071] Figure 43 is a schematic representation as in Figure 42 showing the suture catch mechanism and a suture portion retracted through the first leaflet.

[0072] Figure 44 is a schematic representation as in Figure 43 showing the suturing device positioned in the passage through the valve so as to permit a second suture clasp arm to extend from the suturing device.

[0073] Figure 45 is a schematic representation as in Figure 44 with the suture clasp arm positioned around a second leaflet of the valve.

[0074] Figure 46 is a schematic representation as in Figure 45 showing a suture catch mechanism engaging the suture clasp arm.

[0075] Figure 47 is a schematic representation as in Figure 46 showing the suture catch mechanism and a suture portion retracted through the second leaflet.

[0076] Figure 48 is a schematic representation of an embodiment of a suturing device positioned in a passage through a valve with a first suture clasp arm positioned around a first leaflet of the valve, and a second suture clasp arm positioned around a second leaflet of the valve.

[0077] Figure 49 is a schematic representation as in Figure 47 or 48 showing the suture portions extending through the first leaflet and the second leaflet.

[0078] Figure 50 is a schematic representation as in Figure 49 showing the suture portions extending through the first leaflet and the second leaflet and being joined by a first knot.

[0079] Figure 51 is a schematic representation as in Figure 50 showing the suture portions extending through the first leaflet and the second leaflet and being joined by a first knot that has been pulled between the leaflets.

[0080] Figure 52 is a schematic representation as in Figure 51 showing the suture portions extending through the first leaflet and the second leaflet and being joined by a first knot that has been pulled through one of the leaflets.

[0081] Figure 53 is a schematic representation as in Figure 49 showing the suture portions extending through the first leaflet and the second leaflet and being joined by a first knot.

[0082] Figure 54 illustrates placement of suture through a bicuspid valve near a central portion of each leaflet.

[0083] Figure 55 illustrates placement of three sutures through a bicuspid valve near a central portion of each leaflet.

[0084] Figure 56 illustrates placement of suture through a bicuspid valve at locations spaced from the center of each leaflet.

[0085] Figure 57 illustrates placement of suture through a bicuspid valve at multiple locations spaced from the center of each leaflet.

[0086] Figure 58 illustrates placement of suture through a tricuspid valve.

[0087] Figure 59 illustrates placement of suture through a valve.

[0088] Figure 60 illustrates placement of suture through a valve.

[0089] Figure 61 illustrates placement of suture through chordae tendineae and myocardium.

[0090] Figure 62 is a schematic perspective view of an embodiment of a suturing device comprising two needles and a single arm having two suture mounts.

[0091] Figure 63 is a schematic side view of the suturing device of Figure 62 with the arm extended and a protective member extended.

[0092] Figure 64 is a schematic side view of the suturing device of Figures 62 and 63 with a needle extended through the protective member.

[0093] Figure 65 is a schematic representation of the suturing device of Figures 62-64 positioned in a passage through a valve, such as the mitral valve via transapical entry.

[0094] Figure 66 is a schematic representation as in Figure 65 with the arm extended and the protective member extended.

[0095] Figure 67 is a schematic representation as in Figure 66 with the needle extended to pierce the valve and engage the arm.

[0096] Figure 68 is a schematic partial cross-sectional view of the arm, needles and valve of Figure 67, taken along line 68-68.

[0097] Figure 69 is a schematic partial cross-sectional view as in Figure 68 illustrating suture portions positioned through two locations in the valve.

[0098] Figure 70 is a schematic partial cross-sectional view as in Figure 69 with the suture portions secured together.

[0099] Figure 71 is a schematic partial cross-sectional view of an arm, a needle, and a valve similar to Figure 68, except the arm comprises a single suture mount and a single needle is illustrated.

[0100] Figure 72 is a schematic partial cross-sectional view as in Figure 71 with a first suture portion positioned through the valve and a second arm and a second needle illustrated in the process of placing a second suture portion through a second location in the valve.

[0101] Figure 73 is a schematic representation as in Figure 72 with two suture portions positioned through the valve and first ends of the suture portions being secured together.

[0102] Figure 74 is a schematic representation as in Figure 73 with the second suture ends having been pulled to draw the secured first ends toward a first side of the valve.

[0103] Figure 75 is a schematic representation as in Figure 74 with the second suture ends secured together.

[0104] Figure 76 is a schematic perspective view of an embodiment of a suturing device comprising two needles and a single arm having two suture mounts, the two needles being located distally of the arm and configured for proximal movement to engage the arm.

[0105] Figure 77 is a schematic representation of the suturing device of Figure 76 positioned within a passage of a valve, such as a mitral valve via access through the inferior vena cava and the atrial septum.

[0106] Figure 78 is a schematic representation as in Figure 77 with the arm extended and a protective member extended.

[0107] Figure 79 is a schematic representation as in Figure 78 with a needle advanced through the protective member to engage the arm.

[0108] Figure 80 is a schematic perspective view of a suturing device comprising two needles and a single arm having two suture mounts, the two needles being located proximally of the arm and configured for distal movement to engage the arm, and the arm having an extended position in which the arm is oriented at an angle of less than 90° relative to a longitudinal axis of the suturing device.

[0109] Figure 81 is a schematic representation of the suturing device of Figure 80 being positioned in a passage of a valve, such as a mitral valve such as by access through the inferior vena cava and the atrial septum, with the arm extended.

[0110] Figure 82 is a schematic representation as in Figure 81 with a protective member extended.

[0111] Figure 83 is a schematic representation as in Figure 82 with a needle being advanced through the protective member to engage the arm.

[0112] Figure 84 is a schematic representation of suture placement locations according to an embodiment.

[0113] Figure 85 is a schematic representation of suture placement locations according to an embodiment.

[0114] Figure 86 is a schematic illustration of a human heart showing the chordae tendineae.

[0115] Figure 87 is a schematic perspective view of an embodiment of a suturing device.

[0116] Figure 88 is a schematic illustration of the suturing device of Figure 87 with six arms extended, with each arm having two suture mounts, and a protective member extended.

[0117] Figure 89 is a schematic representation of the suturing device of Figures 87 and 88 positioned in a passage through a valve, such as the mitral valve via transapical entry.

[0118] Figure 90 is a schematic representation as in Figure 89 with the arms extended.

[0119] Figure 91 is a schematic representation as in Figure 90 with the protective member extended.

[0120] Figure 92 is a schematic representation as in Figure 91 with the protective member positioned for movement of a needle through the protective member to engage a first arm.

[0121] Figure 93 is a schematic representation as in Figure 92 with the protective member positioned for movement of a needle through the protective member to engage a second arm.

[0122] Figure 94 is a schematic representation as in Figure 93, with suture portions passed through 12 locations in the valve.

[0123] Figure 95 is a plan view of an embodiment of a suturing device.

[0124] Figure 96 is a schematic perspective view of an embodiment of a suturing device.

[0125] Figure 97 is a schematic perspective view of an embodiment of a suturing device with a needle arm and two suture arms in an extended position.

[0126] Figure 98 is a cross sectional view of an embodiment of a suture arm.

[0127] Figure 99 is a cross sectional view of a section of the device of Figure 95, showing the needle arm extended and aligned with an extended suture arm.

[0128] Figure 100 is a top view of the device of Figure 95, with the suture arms extended.

[0129] Figure 101 is a cross sectional view of a distal section of an embodiment of a needle arm.

[0130] Figure 102 is a top view of an embodiment of an extrusion.

[0131] Figure 103 is a schematic representation of the suturing device of Figure 95 positioned in a passage through a valve, such as the mitral valve via transapical entry.

[0132] Figure 104 is a schematic representation as in Figure 103 with the arms extended.

[0133] Figure 105 is a schematic representation as in Figure 104 with the arms positioned against the valve.

[0134] Figure 106 is a schematic representation as in Figure 105 with the protective member extended.

[0135] Figure 107 is a schematic representation as in Figure 106 with the protective member positioned for movement of a needle through the protective member to engage a first arm.

[0136] Figure 108 is a schematic representation as in Figure 107 with the needle engaging a first arm.

[0137] Figure 109 is a schematic representation as in Figure 108 with the needle arm in a position between the two suture arms.

[0138] Figure 110 is a schematic representation as in Figure 109 with the protective member positioned for movement of a needle through the protective member to engage a second arm.

[0139] Figure 111 is a schematic representation as in Figure 110 with the needle engaging a second arm.

[0140] Figure 112 is a schematic representation as in Figure 111 with the needle arm in a position between the two suture arms.

[0141] Figure 113 is a schematic representation as in Figure 112, with suture portions passed through two locations in the valve.

[0142] Figure 114 is a schematic representation as in Figure 112, showing the suture portions passing through two locations in the valve and being joined by a first knot.

[0143] Figure 115 is a schematic representation of a cross sectional side view of a valve, showing a tube positioned around a suture passing through the valve.

[0144] Figure 116 is a schematic representation as in Figure 115 showing two suture ends having been tightened and secured together.

[0145] Figure 117 is a side view of a knot placement device.

[0146] Figure 118 is a cross-sectional view of a knot and knot placement device.

[0147] Figure 119 is a cross-sectional view of an embodiment of a knot and knot placement device.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0148] Embodiments of suturing devices and methods for suturing biological tissue are disclosed herein. The suturing devices and their methods of use can be useful in a variety of procedures, such as treating (e.g., closing) wounds and naturally or surgically created apertures or passageways. For example, the suturing devices can be used to treat an anatomical valve, such as a heart valve, including heart valves that may be weakened or stretched, or have other structural defects, such as congenital defects, that cause them to close improperly. In some embodiments, one or more suturing devices can be used to treat or repair valves, such as the tricuspid, pulmonary, mitral, and aortic valves, for example. In some embodiments, one or more suturing devices can be used to perform procedures such as edge-to-edge repair (like an Alfieri technique), annuloplasty (with or without a ring or other implant), suturing of ventricular spaces, suturing of the chordae, suturing in other locations in the heart, replacement of the chordae tendineae, shortening of the chordae tendineae, patch application, leaflet reshaping, and attachment of prosthetics, such as rings and biological or mechanical replacement valves, for example.

[0149] In some embodiments, the suturing devices can be used to close or reduce a variety of other tissue openings, lumens, hollow organs or natural or surgically created passageways in the body. In some embodiments, the suturing devices can be used to suture prosthetics, synthetic materials, or implantable devices in the body. For example, the devices can be used to suture a pledget within the body.

Access Methods and Devices

[0150] Figure 1 illustrates an exemplifying use environment for suturing an aortic valve 4. Adaption of the devices and methods disclosed herein for suturing a heart valve may also be made with respect to procedures for suturing other bodily tissue and procedures for suturing prosthetics, synthetic materials, or implantable devices in the body. As depicted by Figure 1, a guide wire 10 can be advanced through the aorta 2 to a position at or near the aortic valve 4. The guide wire 10 can be advanced into the aorta 2 through a subclavian

artery (not shown). It is anticipated that the heart may be accessed through any of a variety of pathways. For example, the heart may be accessed through the inferior vena cava 3, the superior vena cava 5, or other vascular access. With the guide wire 10 in place, the physician can insert a sheath 12 to a position at or near the aortic valve 4. This sheath 12 is typically a single lumen catheter with a valve on its proximal end. The valve can be used, for example, to prevent extraneous bleed back or to introduce medication into the patient's body. A suturing device, such as those described further below, can then be advanced through the lumen of the sheath 12. In an alternative embodiment, the suturing device can be advanced over the guide wire 10 and positioned at or near the aortic valve 4 without the need to insert an introducer sheath 12.

[0151] Figure 2A illustrates another exemplifying use environment for suturing a mitral valve 8. As depicted by Figure 2A, a guide wire 10 is advanced into the left ventricle 6 of the heart through a puncture or incision 9 near an apex 7 of the left ventricle 6. The heart may be accessed through a limited thoracotomy, small trocar puncture, or small catheter puncture. Other access paths may be used. The guide wire 10 can then be further positioned at or near the mitral valve 8. With the guide wire 10 in place, the physician can insert a sheath 12 to the left ventricle 6. The sheath 12 can be placed at or near the mitral valve 8. The suturing device can then be advanced through the lumen of the sheath 12. In an alternative embodiment, the suturing device can be advanced over the guide wire 10 and positioned at or near the mitral valve 8 without the need to insert an introducer sheath 12.

[0152] Figure 2B illustrates another exemplifying access route for suturing a mitral valve 8. As depicted by Figure 2B, a guide wire 10 is advanced through the inferior vena cava 11 into the right atrium 13 of the heart and through a puncture or an incision near the atrial septum 15 and into the left atrium 17. The guide wire 10 can then be further positioned at or near the mitral valve 8. With the guide wire 10 in place, the physician can insert a sheath 12 to the left atrium 17. The sheath 12 can be placed at or near the mitral valve 8. The suturing device can then be advanced through the lumen of the sheath 12. In an alternative embodiment, the suturing device can be advanced over the guide wire 10 and positioned at or near the mitral valve 8 without the needs to insert an introducer sheath 12. In some embodiments, for any of the access routes discussed above, the device can be inserted without a guide wire.

Embodiments of Suturing Devices and Methods, Such as For Suturing Valve Leaflets

[0153] Figures 3-9 illustrate an embodiment of a suturing device 100 that can be used to suture an anatomical valve, such as a heart valve. While the device 100 will be described with reference to suturing an anatomical valve, such as a heart valve, the device 100 could be used to suture other biological tissue and implantable devices and materials. The suturing device 100 can comprise a distal assembly 102, one or more suture clasp arms 104 (also labeled as 104A, 104B), and one or more suture catch mechanisms 106 (referred to in some embodiments as “needles”). Each arm can have one or more suture portions 130 attached to it. The suturing device 100 can further comprise an elongate body (not shown) to facilitate manipulation of the suture clasp arm(s) 104 and the suture catch mechanism(s) 106 from a remote location. For example, the elongate body can comprise one or more lumens to accommodate a length of suture, or one or more actuator rods for manipulating the suture clasp arm(s) 104 and the suture catch mechanism(s) 106, or both. In some embodiments, the distal assembly 102 can comprise a portion of the elongate body.

[0154] The distal assembly 102 can comprise a proximal mount 108, distal mount 110, a hub 112, and a casing 114 (Figure 6). The proximal mount 108 can be fixedly connected to the distal mount 110 by the casing 114. The hub 112 can be positioned within the casing 114 for sliding movement between the proximal mount 108 and the distal mount 110.

[0155] The proximal mount 108 can be connected to the elongate body (not shown). Alternatively, a distal end of the elongate body can form or be integrally formed with the proximal mount 108. In some embodiments, the elongate body can comprise the casing 114. The proximal mount 108 can comprise one or more lumens 116, as shown in Figures 3 and 5.

[0156] The hub 112 can be fixedly connected to the suture catch mechanism(s) 106 and an actuator rod 118. The actuator rod 118 can move through a lumen 116 in the proximal mount 108. Accordingly, distal advancement of the actuator rod 118 causes distal advancement of the suture catch mechanism(s) 106. The hub 112 can comprise one or more lumens 120.

[0157] The suture clasp arm(s) 104 can be pivotally connected to the distal mount 110 such that the suture clasp arm(s) 104 can move between a retracted position, illustrated in Figures 3-4, and an extended position, illustrated in Figures 5-7A. Although the arms 104 of the device 100 that is illustrated in Figures 3-9 pivot about a distal end of the arms 104, the arms 104 can pivot about a proximal end of the arms 104 in other embodiments.

[0158] The suture clasp arm(s) 104 can be connected to an actuator rod 124, which can move through a lumen 116 in the proximal mount 108. The arm(s) 104, the distal mount 110, and the rod 124 can be connected such that distal movement of the rod 124 causes the arm(s) 104 extend and proximal movement of the rod 124 causes the arm(s) 104 to retract. In some embodiments, the arm(s) 104 can extend to a position that is substantially perpendicular to their fully-retracted position. In other embodiments, the arm(s) 104 can move less than 90° between the fully-retracted position and the fully-extended position.

[0159] The distal mount 110 can comprise one or more lumens 122 (Figure 5) to allow movement of the suture catch mechanism(s) 106 through the distal mount 110. Additionally or alternatively, the one or more lumens 122 can accommodate a length of suture, the actuator rod 124, or both.

[0160] The suture clasp arm(s) 104 can have suture clasps 126 to releasably hold a suture portion 130. The suture catch mechanism(s) 106 can be advanced to engage the suture portion(s) 130 held by the suture clasp arms(s). Once the suture catch mechanism(s) 106 have engaged the suture end portion(s) 130, the suture catch mechanism(s) 106 can be retracted to pull the suture ends from the suture clasps 126.

[0161] In some embodiments, the suture clasps 126 can be positioned on the suture clasp arm 104 such that the suture catch mechanism 106 retrieves the suture end portion 130 retained in the suture clasp 126 while the suture clasp arm 104 is at least partially retracted from its fully-extended position. In some embodiments, the suture clasps 126 can be positioned on the suture clasp arm 104 such that the suture catch mechanism 106 retrieves the suture end portion 130 retained in the suture clasp 126 while the suture clasp arm 104 is fully retracted. In some embodiments, the suture catch mechanism 106 can be advanced in a continuously longitudinal direction to engage the suture clasp 126 of the suture clasp arm 104 while the suture clasp arm is fully retracted. In some embodiments, the suture clasp 126 can be located on a proximally-facing side of a suture clasp arm 104 that pivots about a distal

end of the suture clasp arm. In some embodiments, the suture clasp 126 can be located on a distally-facing side of a suture clasp arm 104 pivots about a proximal end of the suture clasp arm.

[0162] In some embodiments, the suture clasp arm 104 can be configured to receive a tissue-piercing portion of the corresponding suture catch mechanism 106. For example, in some embodiments, when the suture catch mechanism 106 is fully advanced, the tissue-piercing portion can be fully received with the corresponding suture clasp arm 104. In some embodiments, the suture clasp arm 104 can receive the tissue-piercing portion of the suture catch mechanism 106 when the arm is at least partially closed. In some embodiments, suture clasp arm 104 can receive the tissue-piercing portion of the suture catch mechanism 106 when the arm is fully retracted.

[0163] In some embodiments, the device 100 can comprise a recess 140 between the suture clasp arm 104 and the distal mount 110, or other component of the distal assembly 102, when the suture clasp arm 104 is fully retracted, as illustrated in Figure 7B. In some embodiments, a tissue portion, such as a valve leaflet, can be received with the recess 140 with the suture clasp arm 104 fully retracted and without damaging the tissue portion. In some embodiments, the tissue portion can be held in the recess 140 by the suture clasp arm 104 while the suture clasp arm is fully retracted. In some embodiments, the tissue portion can be held in the recess 140 by the suture clasp arm 104 while the suture clasp arm is at least partially retracted.

[0164] In some embodiments, the recess 140 can have a size and shape to receive a leaflet of a valve between the elongate body and the arm when the arm is at least partially retracted without damaging the leaflet. In some embodiments, the recess 140 can have a size and shape to receive a leaflet of a valve between the elongate body and the arm when the arm is fully retracted without damaging the leaflet. In some embodiments, the recess 140 can have a size and shape to retain the leaflet between the elongate body and the arm when the arm is at least partially retracted without damaging the leaflet. In some embodiments, the recess 140 can have a size and shape to retain the leaflet between the elongate body and the arm when the arm is fully retracted without damaging the leaflet.

[0165] In some embodiments, the device 100 can be manipulated with the suture clasp arm(s) 104 in the extended position to place a tissue portion, such as a leaflet of a

valve, between the suture clasp arm 104 and the distal mount 110, as shown, for example, in Figure 11. In some embodiments, the suture clasp arm 104 can be at least partially closed about the tissue portion. In some embodiments, the suture clasp arm 104 can be fully closed about the tissue portion. In some embodiments, the suture clasp arm 104 can be at least partially retracted to securely hold the tissue portion between the suture clasp arm 104 and the distal mount 110. In some embodiments, the suture clasp arm 104 can be moved to the retracted position to securely hold the tissue portion between the suture clasp arm 104 and the distal mount 110, as shown, for example, in Figure 12. In some embodiments, the tissue portion is not damaged by closing the suture clasp arm 104 about the tissue portion or holding the tissue portion between the suture clasp arm 104 and the distal mount 110.

[0166] With the tissue portion held between the arm 104 and the distal mount 110, the corresponding suture catch mechanism 106 can be advanced to engage the suture portion 130 held by the suture clasp 126 of the arm 104, as shown, for example, in Figure 13. The suture portion 130 can then be drawn through the tissue portion by the suture catch mechanism 106, as shown, for example, in Figure 14. In other embodiments, the suture catch mechanism(s) 106 can be advanced toward the suture clasp arm(s) 104 and retrieve the suture ends from the suture clasps 126 when the arm(s) 104 are in the extended position. In some embodiments, the suture catch mechanism can be a needle.

[0167] In some embodiments, the distal assembly 102 can comprise a tube or conduit 128 to accommodate a suture and prevent damage to the suture by any component of the device 100. In some embodiments, the conduit 128 extends through a lumen 116 in the proximal mount 108, a lumen 120 in the distal mount 110, and a lumen 122 in the hub 112.

[0168] Further details regarding devices, structures, and methods that may be incorporated with the above embodiments are provided in U.S. Patent No. 7,090,686 and U.S. Patent Application Publication No. 2008/0269786, published on October 30, 2008, all of which are hereby incorporated by reference herein in their entireties and are to be included as part of this specification. For example, in some embodiments having a plurality of arms 106 and a plurality of suture catch mechanisms 106, each arm 104 and each suture catch mechanism 106 of the device 100 can be independently actuated to move individually between the retracted position and the extended position.

[0169] Figures 10-15 illustrate a method for suturing an anatomical valve according to one embodiment. For example, the method can be used to perform edge-to-edge repair of a mitral valve. The distal end of a suturing device 100 can be positioned between leaflets 132 of a valve, as shown in Figure 10. The device 100 can be advanced through the vasculature to the desired position using any of the access routes discussed above, and with or without a guide wire. For example, the device 100 can be advanced through the inferior vena cava into right atrium and through the septum and positioned in the passage through the mitral valve 8 (Figure 2).

[0170] The suturing device 100 can be advanced to allow suture clasp arms 104 to extend from the distal assembly 102. The suture clasp arms 104 can then be extended and the device 100 can be retracted until the suture clasp arms 104 extend around a first leaflet 132A and a second leaflet 132B of the valve, as shown in Figure 11.

[0171] Once the suture clasp arms 104 have been properly positioned around the first and second leaflets 132, the suture clasp arms 104 can be retracted to trap portions of the first and second leaflets 132, for example between the suture clasp arms 104 and the distal mount 110 in the recess 140, as illustrated in Figure 12.

[0172] With the first and second leaflets 132 trapped the suture catch mechanisms 106 can be advanced from the distal assembly 102 to penetrate the first and second leaflets 132 and engage the suture portions 130 held by the suture clasp arms 104, as illustrated in Figure 13.

[0173] After the suture portions 130 have been engaged, the suture catch mechanisms 106 and engaged suture portions 130 are then retracted through the tissue of the first and second leaflets 132 into the distal assembly 102, as shown in Figure 14. The suture clasp arms 104 can be extended to release the first and second leaflets 132. After the first and second leaflets have been released, the device 100 can be advanced slightly so that the suture clasp arm 104 can be moved to the retracted position without pinching the leaflets 132. The first suturing device 100 can then be withdrawn from the valve.

[0174] As shown in Figure 15, after the suturing device 100 has been withdrawn, the suture portions 130 extend from the leaflets 132. The suture portions 130 can be pulled to draw the first leaflet 132A and the second leaflet 132B towards one another. The suture portions 130 can then be secured together to limit movement of the leaflets 132A, 132B

relative to one another, as illustrated in Figure 15 for example. In some embodiments, the sutures 130 can hold a portion of the leaflets 132A, 132B in contact with one another. In other embodiments, the sutures 130 merely hold the leaflets 132A, 132B in closer proximity to one another than they had previously been. The suture portions 130 can be secured together by tying a knot 134 according to any known method or by applying a knot 134, such as described in U.S. Patent Publication No. 2007/0010829 A1, published January 11, 2007, which is hereby incorporated by reference herein in its entirety and is considered a part of this specification. The suture portions 130 can be secured together exterior to the body or within the body. Any excess portion of sutures 130 can be trimmed. In some embodiments, one or more pledgets can be attached to the suture portions 130, either before or after the knot is tied or applied, and located distal and/or proximal to the knot 134.

[0175] Figure 16 illustrates an embodiment of a system of devices that can be used to suture an anatomical valve, such as a heart valve. In some embodiments, the device can be included in a system of devices used to suture an anatomical valve, such as the system illustrated in Figure 16. The system of Figure 16 includes two suturing devices 1100A,B, each of which can comprise a distal assembly 1102A,B, a single suture clasp arm 1104A,B, and a single suture catch mechanism 1106A,B (shown in Figures 21 and 25). Further description herein of either suturing device 1100A or 1100B may omit the letter A or B following the reference number, as it will be appreciated that the components described can refer to either device.

[0176] The devices can be substantially similar but with at least the exception that the single suture clasp arm 1104 of each suturing device is oriented generally opposite that of the other suturing device with respect to their handles 1144. As illustrated, the devices have elongate bodies of differing lengths, but in other embodiments the elongate bodies can be substantially the same length. The system can also include a suture joining device 135, which can be used to apply a knot to two or more suture ends or otherwise join two or more suture ends. Further details regarding the device for joining sutures are provided in U.S. Patent Application Publication No. 2011/0190793, published on August 4, 2011, which is hereby incorporated by reference herein in its entirety and should be considered as part of this specification. Additionally, description of a device for joining sutures can be found below, and with respect to Figures 117-119.

[0177] The suturing devices 1100A,B can comprise an elongate body 1142 to facilitate manipulation of the suture clasp arm 1104 and the suture catch mechanism (not visible) from a remote location. For example, the elongate body can comprise one or more lumens to accommodate a length of suture, or one or more actuator rods for manipulating the suture clasp arm 1104 and the suture catch mechanism, or both.

[0178] The suturing devices 1100A,B can comprise a handle 1144 with one or more actuators and/or pulls 1146 for moving the suture clasp arm 1104 and the suture catch mechanism 1106. In various embodiments, the handle can be of different shapes and configures, such as the handles of Figure 16, or the handle illustrated in Figure 17. Further details regarding handles and associated components, including actuator rods, are provided in U.S. Patent Application Publication No. 2008/0269786, published on October 30, 2008, which is hereby incorporated by reference herein in its entirety and is considered a part of this specification.

[0179] Figure 18 illustrates a distal assembly 1102A of one of the suturing devices 1100A with the suture clasp arm 1104A in an extended position. In some embodiments, the suture clasp arm 1104A can pivot about an axis located at a distal end of the suture clasp arm 1104A to move the suture clasp arm 1104A from a retracted position to an extended position, as illustrated in Figure 18. The same description can apply to the other suturing device 1100B.

[0180] Figures 19-27 illustrate a method according to one embodiment for suturing an anatomical valve, such as edge-to-edge repair of a mitral valve. Although the illustrated method involves two devices 1100A,B, each having a single suture clasp arm 1104 and a single suture catch mechanism 1106, the illustrated method can also be practiced using a single suturing device 1100 having more than one arm 1104 and more than one suture catch mechanism 1106, as described further below.

[0181] The distal end of a first suturing device 1100A can be positioned between leaflets 132 of a valve, as shown in Figure 19. The device 1100A can be advanced through the vasculature to the desired position using any of the access routes discussed above, and with or without a guide wire. For example, the device 1100A can be advanced through the inferior vena cava into right atrium and through the septum and positioned in the passage through the mitral valve 8 (Figure 2).

[0182] The suturing device 1100A can be advanced to allow a suture clasp arm 1104A to extend from the distal assembly 1102A. The suture clasp arm 1104A can then be extended and the device 1100A can be retracted until the suture clasp arm 1104A extends around a first leaflet 132A of the valve, as shown in Figure 20.

[0183] Once the suture clasp arm 1104A has been properly positioned around the first leaflet 132A, the suture catch mechanism 1106A can be advanced from the distal assembly 1102A to penetrate the first leaflet 132A and engage the suture portion 130A held by the suture clasp arm 1104A, as illustrated in Figure 21. In some embodiments, the suture clasp arm 1104A can be moved to the retracted position to securely hold a portion of the first leaflet 132A between the arm 1104A and the elongate body, for example, before the suture catch mechanism 1106A is advanced through the first leaflet 132A to engage the suture end, as described above.

[0184] After the suture portion 130A has been engaged, the suture catch mechanism 1106A and engaged suture portion 130A are then retracted through the tissue of the first leaflet 132A into the distal assembly 1102A, as shown in Figure 22. The device 1100A can be advanced slightly so that the suture clasp arm 1104A can be moved to the retracted position without pinching the first leaflet 132A. The first suturing device 1100A can then be withdrawn from the valve.

[0185] A second suturing device 1100B can then be advanced into the heart and positioned between the leaflets 132A, 132B of the valve, as shown in Figure 23. The suture clasp arm 1104B can then be extended and the device 1100B can be advanced such that the suture clasp arm 1104B extends around the tip of the second leaflet 132B, as shown in Figure 24.

[0186] Once the suture clasp arm 1104B has been properly positioned around the second leaflet 132B, the suture catch mechanism 1106B can be advanced from the distal assembly 1102B to penetrate the second leaflet 132B and engage the suture portion 130B held by the suture clasp arm 1104B, as illustrated in Figure 25. As noted above with respect to the first leaflet 132A, in some embodiments, the suture clasp arm 1104B can be moved to the retracted position to securely hold a portion of the second leaflet 132B between the arm 1104B and the distal assembly 1102B before the suture catch mechanism 1106B is advanced through the second leaflet 132B to engage the suture portion 130B.

[0187] After the suture portion 130B has been engaged, the suture catch mechanism 1106B and engaged suture portion 130B are then retracted through the tissue of the second leaflet 132B into the distal assembly 1102B, as illustrated in Figure 26. The suture clasp arm 1104B can then be closed after slightly advancing the device 1100B to avoid pinching the second leaflet 132B as the arm 1104B is closed. Once the suture clasp arm 1104B is closed, the suturing device 1100B can be withdrawn from the patient's heart.

[0188] As shown in Figure 27, after the suturing device 1100B has been withdrawn, the suture portions 130A,B will extend proximally from the leaflets 132A, 132B. The suture portions 130A,B can then be secured together, as illustrated in Figure 27, by tying a knot 134 according to any known method or by applying a knot 134. In some embodiments, one or more pledgets can be attached to the suture portions 130A,B, either before or after the knot is tied or applied, and located distal and/or proximal to the knot 134. The suture portions 130A,B can be secured together exterior to the body or within the body. Any excess portion of sutures 130 can be trimmed. The suture portions 130A,B can then be pulled to draw the first leaflet 132A and the second leaflet 132B towards one another. A second knot can then be tied or applied to the sutures 130 to limit movement of the leaflets 132A, 132B relative to one another, as described above. In some embodiments, the sutures 130 can hold a portion of the leaflets 132A, 132B in contact with one another. In other embodiments, the sutures 130 merely hold the leaflets 132A, 132B in closer proximity to one another than they had previously been.

[0189] When a device having a plurality of arms and a plurality of suture catch mechanisms is used, the device can be configured to place a single suture 130 through both the first leaflet 132A and the second leaflet 132B. The single suture 130 can be placed through the first and second leaflets 132 either simultaneously or sequentially. In some embodiments, the suture portions 130 can be pulled to draw the first leaflet 132A and the second leaflet 132B towards one another without applying a knot to the suture 130 beforehand. Accordingly, a single knot 134 can be applied to the suture 130 to hold the leaflets 132A, 132B in proximity to one another.

[0190] Figures 28 and 29 illustrate an embodiment of a suturing device 2100A that can be used to suture an anatomical valve, such as a heart valve. The suture device 2100A illustrated in Figures 28 and 29 is similar in some respects to the suturing devices

illustrated and described above. For example, the suturing device 2100A of Figures 28 and 29, like the suturing device 1100 of Figures 17 and 18, can comprise a distal assembly 2102A, a single suture clasp arm 2104A, and a single suture catch mechanism 2106A.

[0191] As illustrated in Figures 28 and 29, the suturing device 2100A can comprise an elongate body 2142A to facilitate manipulation of the suture clasp arm 2104A and the suture catch mechanism 2106A from a remote location. For example, the elongate body can comprise one or more lumens to accommodate a length of suture, or one or more actuator rods for manipulating the suture clasp arm 2104A and the suture catch mechanism 2106A, or both. The suturing device 2100A can comprise a handle with one or more actuators and/or pulls 2146A for moving the suture clasp arm 2104A and the suture catch mechanism 2106A. Further details regarding handles and associated components, including actuator rods, are provided in U.S. Patent Application Publication No. 2008/0269786, published on October 30, 2008, which is hereby incorporated by reference herein in its entirety and is considered a part of this specification.

[0192] In some embodiments, the suture clasp arm 2104A can pivot about an axis located at a proximal end of the suture clasp arm 2104A when the suture clasp arm 2104A is in a retracted position, as illustrated in Figures 28 and 29.

[0193] A method of suturing anatomical valves, such as edge-to-edge repair of a mitral valve, is illustrated in Figures 30-37. Although the illustrated method involves two devices 2100A,B, each having a single suture clasp arm 2104A,B and a single suture catch mechanism 2106A,B, the illustrated method can also be practiced using a device 2100 having more than one arm 2104 and more than one suture catch mechanism 2106, as discussed above, for example.

[0194] The distal end of a first suturing device 2100A can be positioned between leaflets 132 of a valve, as shown in Figure 30. The device 2100A can be advanced through the vasculature to the desired position using any of the access routes discussed above, and with or without a guide wire. For example, the device 2100A can be advanced through a subclavian artery into the aorta to position the device 2100A in the passage through the aortic valve 4 (Figure 1). Alternatively, the device 2100A can be inserted through a puncture or small incision 9 in the heart to position the device 2100A in the passage through the mitral

valve 8, as shown in Figure 2. Such a puncture can be located at or near the apex of the heart 7.

[0195] As illustrated in Figure 30, the suturing device 2100A can be positioned to allow a suture clasp arm 2104A to extend from the distal assembly 2102A. The suture clasp arm 2104A can then be extended and the device 2100A can be advanced until the suture clasp arm 2104A extends around a first leaflet 132A of the valve, as shown in Figure 31.

[0196] Once the suture clasp arm 2104A has been properly positioned around the first leaflet 132A, the suture catch mechanism 2106A can be advanced from the distal assembly 2102A to penetrate the first leaflet 132A and engage the suture portion 130A held by the suture clasp arm 2104A, as illustrated in Figure 32. In some embodiments, the suture clasp arm 2104A can be moved to the retracted position to securely hold a portion of the first leaflet 132A between the arm 2104A and the distal assembly 2102A before the suture catch mechanism 2106A is advanced through the first leaflet 132A to engage the suture end, as described above, for example.

[0197] As shown in Figure 33, once the suture portion 130A has been engaged, the suture catch mechanism 2106A and engaged suture portion 130A are then retracted through the tissue of the first leaflet 132A into the distal assembly 2102A. The device 2100A can be retracted slightly so that the suture clasp arm 2104A can be moved to the retracted position without pinching the first leaflet 132A. The first suturing device 2100A can then be withdrawn from the valve.

[0198] A second suturing device 2100B can then be advanced into the heart and positioned between the leaflets 132A, 132B of the valve, as shown in Figure 34. The suture clasp arm 2104B can then be extended and the device 2100B can be advanced such that the suture clasp arm 2104B extends around the tip of the second leaflet 132B, as shown in Figure 35.

[0199] In the illustrated embodiment, once the suture clasp arm 2104B has been properly positioned around the second leaflet 132B, the suture catch mechanism 2106B can be advanced from the distal assembly 2102B to penetrate the second leaflet 132B and engage the suture portion 130B held by the suture clasp arm 2104B, as illustrated in Figure 36. As noted above with respect to the first leaflet 132A, in some embodiments, the suture clasp arm 2104B can be moved to the retracted position to securely hold a portion of the second leaflet

132B between the arm 2104B and the distal assembly 2102B before the suture catch mechanism 2106B is advanced through the second leaflet 132B to engage the suture portion 130B.

[0200] After the suture portion 130B has been engaged, the suture catch mechanism 2106B and engaged suture portion 130B are then retracted distally through the tissue of the second leaflet 132B into the distal assembly 2102B, as illustrated in Figure 37. The suture clasp arm 2104B can then be closed after slightly retracting the device 2100B to avoid pinching the second leaflet 132B. Once the suture clasp arm 2104B is closed, the suturing device 2100B can be withdrawn from the patient's heart.

[0201] In some embodiments, a suturing device 3100 can have a plurality of arms 3104. In some embodiments, the arms can be spaced at varying intervals around the circumference of the elongate body. In some embodiments, a plurality of arms can extend from one side of the elongate body and a corresponding plurality of arms can extend from an opposite side of the elongate body. Figures 38A and 38B illustrate a view of a suturing device 3100 having two arms 3104A,B. As illustrated, the arms are spaced approximately 180 degrees from each other about the elongate body 3142. In some embodiments, the suturing device can have two suture catch mechanisms 3106A,B, one associated with each arm. The device can be designed so that the plurality of arms is deployed simultaneously, and that the plurality of suture catch mechanisms is deployed simultaneously. Alternatively, the device can be designed so that each arm and each suture catch mechanism can be deployed separately. In some embodiments, the suturing device can be used as a system with a suture joining device 135, as discussed above with respect to Figure 16. Many aspects of the suturing device can function substantially the same as aspects of the device described with respect to Figures 28-37. Unless discussed otherwise, components can be considered to have substantially the same function and operate in substantially the same manner as similarly labeled components described with respect to Figures 28-37. As a non-limiting example, the device can comprise a distal assembly 3102 and a handle with one or more actuators and/or pulls 3146 for moving the suture clasp arms 3104 and deploying the suture catch mechanisms 3106.

[0202] In some embodiments, a suturing device can have a distal assembly 3102' as seen in Figures 39A and 39B. Figure 39A illustrates a device with two suture arms

3104A',B' that are in a retracted position. In Figure 39B, both suture arms 3104A',B' are in an extended position, and suture catch mechanisms 3106A',B' have extended through the corresponding arms at suture clasps 3126A',B'. In some embodiments, the arms can extend and retract simultaneously or in sequence, and in some embodiments the suture catch mechanisms can extend and retract simultaneously or in sequence. Also as illustrated, in some embodiments a suturing device can comprise a tapered portion 3113' at a distal end and/or a guide wire lumen 3111' that can be used if the device advances over a guide wire.

[0203] A method of suturing anatomical valves, such as edge-to-edge repair of a mitral valve, with a dual arm suturing device is illustrated in Figures 40 – 47. The method is described with reference to the suturing device 3100 of Figures 38A and 38B, but any dual arm suturing device can be used, such as one with a distal assembly as described with reference to Figures 39A and 39B. The suturing device 3100 can be advanced to a desired position between leaflets 132 of a valve, as shown in Figure 40, by any of the methods discussed above with reference to the method of Figures 30-37, and with or without a guide wire. In the embodiment illustrated, the suturing device 3100 may be delivered transapically into the left ventricle, and delivered so that the distal end of the device extends through the mitral valve into the left atrium. However, the device can also be designed for an approach to pass through the septum between the right and left atrium, through the mitral valve and into the left ventricle. The locations and configurations of the suture clasp arms 3104 and the suture catch mechanisms 3106 may be appropriately designed based on the desired method of approach and based on the desired location to be sutured. For example, while the arms 3104 in the embodiment of Figure 40 are shown proximal to the suture catch mechanisms 3106, in a different device the arms 3104 may be located distal to the suture catch mechanisms.

[0204] For suturing a mitral valve as shown in Figure 40, the device can be positioned such that at least one of the suture clasp arms, a first arm 3104A, can be extended from the device, and the device can be advanced until the first arm 3104A extends around or adjacent to a first leaflet of the valve 132A, as shown in Figure 41. Accordingly, when suturing the mitral valve, the arm 3104A can be positioned on a proximal side, or the ventricular side, of the leaflet 132A. The arm 3104A carries an end of a suture portion 130A.

Figure 40 shows arm 3104A being deployed independently of arm 3104B, but in other embodiments, both arms can be deployed together.

[0205] As described with respect to Figure 32, once the first suture clasp arm 3104A is properly positioned, the suture catch mechanism 3106A can be advanced from the distal assembly 3102 from a location distal to the leaflet 132A (or on the atrial side of the leaflet, for a mitral valve procedure) to penetrate the first leaflet 132A and engage the suture portion 130A held by the first suture clasp arm 3104A, as illustrated in Figure 42. In some embodiments, the first suture clasp arm 3104A can be moved to the retracted position to securely hold a portion of the first leaflet 132A between the first arm 3104A and the distal assembly 3102 before the suture catch mechanism 3106A is advanced through the first leaflet 132A to engage the suture end.

[0206] As shown in Figure 43, once the suture portion 130A has been engaged, the suture catch mechanism 3106A and engaged suture portion 130A are then retracted through the tissue of the first leaflet 132A into the distal assembly 3102. The device 3100 can be retracted slightly so that the first suture clasp arm 3104A can be moved to the retracted position without pinching the first leaflet 132A, as illustrated in Figure 44. The suturing device 3100 can then be retracted at least far enough to allow the second suture clasp arm 3104B to extend from the device.

[0207] As illustrated in Figure 45, the second suture clasp arm 3104B can extend from the device and the device can be advanced, and moved laterally if necessary, such that the second suture clasp arm 3104B extends around the tip of the second leaflet 132B. In some embodiments, the second suture clasp arm 3104B can extend before or while the first arm 3104A is retracted.

[0208] As with the first arm 3104A, once the second suture clasp arm 3104B has been properly positioned around the second leaflet 132B, a suture catch mechanism 3106B can be advanced from the distal assembly 3102 to penetrate the second leaflet 132B and engage the suture portion 130B held by the suture clasp arm 3104B, as illustrated in Figure 46. As noted above with respect to the first leaflet 132A, in some embodiments, the suture clasp arm 3104B can be moved to the retracted position to securely hold a portion of the second leaflet 132B between the arm 3104B and the distal assembly 3102 before the suture catch mechanism 3106B is advanced through the second leaflet 132B to engage the suture

portion 130B. In some embodiments, the suture catch mechanism can be the same catch mechanism as the one used with the first arm 104A. In the illustrated embodiment, the suture portions 130A,B are portions of separate sutures, but in some embodiments the suture portions 130A,B can be portions of the same suture.

[0209] After the suture portion 130B has been engaged, the suture catch mechanism 3106B and engaged suture portion 130B are then retracted distally through the tissue of the second leaflet 132B into the distal assembly 3102, as illustrated in Figure 47. The suture clasp arm 3104B can then be closed after slightly retracting the device 3100 to avoid pinching the second leaflet 132B. Once the suture clasp arm 3104B is closed, the suturing device 3100 can be withdrawn from the patient's heart.

[0210] In some embodiments, the first suture clasp arm 3104A and the second suture clasp arm 3104B can both be extended from the device at substantially the same time and extend around opposite tips of the leaflets 132A, 132B, as illustrated in Figure 48. In other embodiments, the clasp arms can be extended at the same time, but with one having extended before the other. Also as illustrated, suture catch mechanisms can be advanced through the suture clasp arms 3104A, 3104B at substantially the same time. In other embodiments, both clasp arms can extend around the leaflets but the suture catch mechanisms can advance one before the other.

Methods For Drawing Sutured Leaflets Closer Together

[0211] As shown in Figure 49, after one or more of the suturing devices has been withdrawn, the suture portions 130A, 130B will extend proximally from the leaflets 132A, 132B. The methods for drawing sutured leaflets closer together described herein with respect to Figures 49-59 can apply equally to orientations, such as that of Figure 15, reflected in embodiments where suturing devices take different access routes to a valve. Additionally, for all methods described herein, one or more pledgets can be attached to the suture portion(s), either before or after a knot is tied or applied, and located distal and/or proximal to the knot. Figure 49 illustrates four strands of suture portion extending from the leaflets, which can comprise either a single suture if the arms described above were carrying the same suture, or two separate sutures, one sutured to each leaflet, if the arms described above were carrying their own suture. If the four strands illustrated in Figure 49 are part of the same

suture, the ends of the suture may be pulled from outside of the body to apply tension to the suture and draw the leaflets together. The suture portions can be secured together by tying a knot, applying a knot or otherwise joining the suture portions together according to known methods.

[0212] In some embodiments, for example where two separate sutures are sutured to the leaflets 132A and 132B, two ends of the separate sutures can then be secured together, as illustrated in Figure 50, by tying a knot 134 according to any known method or by applying a knot 134. The suture portions 130A,B can be secured together exterior to the body or within the body. Any excess portion of sutures can be trimmed. In some embodiments, the free ends of the suture portions 130A,B can then be pulled to draw the first leaflet 132A and the second leaflet 132B towards one another, with the knot or joined portion between the leaflets as illustrated in Figure 51. A second knot can then be tied or applied to the sutures 130A,B to limit movement of the leaflets 132A,B relative to each other.

[0213] In some embodiments, after the knot has 134 has been applied and positioned as shown in Figure 51, just one of the free ends can be pulled initially, drawing the knot through one of the leaflets and out of the body, as illustrated in Figure 52. This leaves a single suture passing through the leaflets. The two portions of the single suture can then be pulled to draw the first leaflet and second leaflet towards each other and a second knot can be tied or applied to the two portions.

[0214] In some embodiments, where two separate sutures and four suture portions extend from the leaflets, rather than initially securing two ends of the suture portions together, all four portions can be secured together according to any of the methods discussed herein, as illustrated in Figure 53.

[0215] In some embodiments, where a single suture is positioned through the leaflets or a pair of sutures is positioned through the leaflets such as shown in Figures 51 and 52, one end of the suture can be secured to a second suture, the second suture can be drawn through the leaflets by pulling on the first suture, and a knot can be tied or applied to the second suture. In this embodiment, a first suture placed by the suturing device can be utilized to guide a second suture or another piece of material across the leaflets. The second suture or other piece of material is, in some embodiments, thicker or stronger than the first

suture. In some embodiments, the second piece of material has a greater surface area to engage tissue, which can advantageously minimize dissection of tissue.

[0216] To accomplish placement of the second suture or additional piece of material in the place of the first suture, the second suture or other piece of material can be attached to one end or a first portion of the already placed suture. The first suture can be attached to the second suture or other piece of material by forming a knot by any known manner, or by otherwise joining them, for example, by welding the material together.

[0217] Thereafter, the other end or a second portion of the first suture can be pulled away from the leaflets. This causes the thicker suture to be drawn through the tissue and across the leaflets into the same position where the first suture(s) was placed. After the thicker suture has been pulled across the leaflets, the ends of the second suture or piece of material will in one embodiment be outside of the body.

[0218] The second suture or other piece of material can be detached from the original suture, and if the original suture has not already been removed from the patient, it can then be removed. With the ends of the second suture or other piece of material extending from the opening and out of the patient, that suture or material can be secured together by tying a knot according to any known method or by applying a knot, such as described in U.S. Patent Publication No. 2007/0010829 A1, published January 11, 2007, which is hereby incorporated by reference herein in its entirety and is considered a part of this specification.

[0219] In some embodiments, once the suture or other material is used to draw the leaflets closer together and the knot is made or applied, the suture or other material can hold a portion of the leaflets 132A, 132B in contact with one another. In other embodiments, the suture or other material merely hold the leaflets 132A, 132B in closer proximity to one another than they had previously been.

[0220] When a suturing device having two arms 3104 and two suture catch mechanisms 3106 is used, as discussed with reference to Figures 38A – 48, the device 3100 can be configured to place a single suture 130 through both the first leaflet 132A and the second leaflet 132B, either simultaneously or sequentially. In some such embodiments, the suture portions 130 can be pulled to draw the first leaflet 132A and the second leaflet 132B towards one another without applying a knot to the suture 130 beforehand. Accordingly, a

single knot 134 can be applied to the suture 130 to hold the leaflets 132A, 132B in proximity to one another.

[0221] The suture or sutures 130 can be placed through the leaflets 132 at locations selected by the physician to treat a problem of a particular valve. For example, in some embodiments, a suture or sutures 130 can be passed through the leaflets 132 at locations in or near a central region of the leaflets 132, as illustrated in Figure 54. Figure 55 illustrates an embodiment in which three sutures 130 have been passed through the leaflets 132 in a central region of the leaflets. In some embodiments, a suture or sutures 130 can be passed through a portion of the leaflets 132 that is in proximity to a periphery of the valve, as illustrated in Figure 56. In some embodiments, sutures 130 can be applied to multiple locations between two leaflets 132, as illustrated in Figure 57. In some embodiments, sutures 130 can be applied to multiple locations between more than two leaflets 132, as illustrated in Figure 58 with respect to a tricuspid valve.

[0222] Figures 59 and 60 illustrate other manners of placing suture through leaflets of a valve. In some embodiments, suture can be placed as shown in Figure 59 or 60 using the devices illustrated in Figures 17-18 and 28-29. The devices can be introduced through the same or different access routes. For example, one device can be introduced to the heart through the vasculature while another device is introduced transapically. In some embodiments, a first suture can be placed through a first leaflet by a first device 1100 as illustrated in Figures 19-22 and a second suture can be placed through a second leaflet by a second device 2100 as illustrated in Figures 30-33. The second suture can be placed before the first suture in some embodiments. In embodiments involving the placement of multiple sutures, the multiple sutures can be joined with a single knot or with multiple knots. Further information regarding devices and methods for placing suture as shown in Figures 59 and 60 is provided in U.S. Patent Application Publication No. 2008/0269786, published on October 30, 2008, and, in particular, the embodiments described in association with Figures 10I-L, 27-28B, 36-39A-K.

Devices and Methods For Techniques Other Than Valve Repair

[0223] The devices and methods described and referenced herein can be used to perform other techniques for valve repair. For example, the devices and methods described

above can be used to apply a suture to one or more of the chordae tendineae 136 and myocardium 138, as illustrated in Figure 61, to restore tension to chordae tendineae that have been come elongated. In some embodiments, the applied suture can be used as a guide suture to deliver a second suture or other material (e.g. artificial chordae) through the chordae, as described above. The devices and methods described above can be used to suture a patch to natural or surgically-created openings in leaflets. The devices and methods described above can be used to attach a ring around the outside of the malfunctioning valve. The devices and methods described above can be used to suture prosthetics to the heart.

Further Embodiments of Additional Suturing Devices, Such As For Suturing A Base Of A Valve

[0224] Figure 62 is a schematic perspective view of an exemplifying embodiment of a distal end 4102 of a suturing device 4100 that can be used to suture an anatomical valve, such as a heart valve. The suturing device 4100 can comprise two suture catch mechanisms 4106 and a single arm 4104 located in proximity to a distal end 4102 of an elongate body 4142. The arm is configured for movement between a retracted position and an extended position. In some embodiments, the arm can be moved between the retracted and extended position by rotation around an end of the arm that is pivotally coupled to the elongate body 4142. In other embodiments, the arms can be advanced along their length out of an opening in the elongate body 4142, as shown and described in U.S. Patent No. 6,911,034, issued on June 28, 2005, which is hereby incorporated by reference herein in its entirety and is considered a part of this specification.

[0225] In the embodiment of Figure 62, the single arm 4104 comprises two suture clasps or mounts 4126 in proximity to a free end of the arm 4104. In some embodiments, the arm 4104 can comprise more than two suture clasps 4126. The suture clasps 4126 can be located at or near the free end of the arm 4104. The arm 4104 of this embodiment is sufficiently long to be able to position the suture clasps 4126 at or near a base of a heart valve, such as the mitral valve for example. The arm 4104 illustrated in Figure 62 extends generally orthogonally to a longitudinal axis of the elongate body 4142.

[0226] The suture clasps 4126 of the arm 4104 are spaced from one another by a distance. The distance between the suture clasps can vary among different embodiments.

The magnitude of separation corresponds generally to the magnitude of separation between locations of suture placement in the tissue. The magnitude of separation between the suture clasps can be varied depending on the desired use.

[0227] In the exemplifying embodiment of Figure 62, the two suture catch mechanisms 4106 are illustrated as needles. The needles can be operated simultaneously in some embodiments and sequentially in other embodiments. As described in connection with the preceding embodiments, the suture catch mechanisms can be deployed and retracted to retrieve suture portions 130 that are releasably held by the arm 4104 (see Figures 65-68). Although the embodiment illustrated in Figure 62 comprises two needles, the suturing device can comprise more than two needles in some embodiments. The arm(s) 4104 will typically be configured to have the same number of suture mounts as the number of suture catch mechanisms, with each suture mount releasably carrying a suture portion.

[0228] The exemplifying embodiment of Figure 62 also includes protective members 4107 (also described herein as “needle arms”). The protective members 4107 are configured to inhibit contact between a distal end of the suture catch mechanisms and surrounding tissue during at least a portion of the deployment of the needles. In general, the protective members protect the tissue surrounding the suturing device 4100 from damage by the suture catch mechanisms 4106 as the suture catch mechanisms are moved from their retracted positions to the locations of the valve where the suture portions are to be passed through the valve.

[0229] As illustrated in Figure 62, in embodiments comprising a plurality of suture catch mechanisms, the suturing device can have a separate protective member corresponding to each suture catch mechanism. In other embodiments, the suturing device can have a single protective member configured to protect surrounding tissue from two or more suture catch mechanisms at the same time.

[0230] In some embodiments, such as that of Figure 62, the protective members can have a generally sleeve-like configuration to generally surround the suture catch mechanisms 4106. The protective members can entirely surround a circumference of the suture catch mechanisms in some embodiments. In other embodiments, the protective members can merely partially surround a circumference of the suture catch mechanisms. For example, whether surrounding one or more suture catch mechanisms, the protective member

can in some embodiments have a generally U-shaped cross-section with the opening in the protective member being oriented to face the elongate body when the protective member is extended. In some embodiments, a protective member can completely surround more than one needle in a single lumen.

[0231] The protective members preferably extend over the distal ends of the suture catch mechanisms, extend beyond the distal ends of the suture catch mechanisms, or both.

[0232] The protective members 4107 of the exemplifying embodiment of Figure 62 can be moved between a retracted position and an extended position. As illustrated in Figure 63, the protective member 4107 can be extended from the elongate body 4142 in advance of the corresponding suture catch mechanism 4106 such that the distal end of the suture catch mechanism is not exposed to the surrounding tissue as the suture catch mechanism is moved toward the location of the valve to be sutured.

[0233] In some embodiments, the suture catch mechanism 4106 can be advanced toward the location for suture placement and the arm 4104 once the protective member 4107 has been advanced to the location for suture placement, as illustrated in Figure 64 for example. After the suture catch mechanism has retrieved the suture portion from the arm as discussed in connection with the foregoing embodiments, the suture catch mechanism 4106 and the protective member 4107 can be retracted into the elongate body 4142 with the suture portion 130. The protective members can be placed generally at the location to be sutured before the needles are moved from their retracted positions in some embodiments. In other embodiments, the needles can be moved toward their deployed positions while the protective members are extended. For example, the distal end of the protective member can be located beyond a distal end of the corresponding needle as both are advanced. In this example, once the distal end of the protective member has been placed generally at the location to be sutured, the distal end of the needle can then be advanced beyond the distal end of the protective member to penetrate the tissue of the valve.

[0234] When a plurality of suture catch mechanisms 4106 are advanced toward the arm 4104 simultaneously, the protective members 4107 may also be advanced simultaneously. Alternatively, the protective members 4107 may be sequentially advanced even though the suture catch mechanisms are advanced simultaneously. The protective

members 4107 can, in some embodiments, be advanced simultaneously, although the suture catch mechanisms are advanced sequentially. The use of multiple suture catch mechanisms per arm, as well as the use of the protective member, can be incorporated into any of the devices described herein, including the edge-to-edge repair devices previously described.

[0235] Figures 65-70 schematically illustrate use of the suturing device 4100 of Figures 62-64 according to an embodiment. The valve shown in Figures 65-70 can be a mitral valve 8 and the suturing device can be inserted into the valve via a transapical opening, or using any of the access routes discussed above, with or without a guide wire. Although reference is made to the mitral valve in connection with Figures 65-70, the description can apply to valves other than the mitral valve.

[0236] As illustrated in Figure 65, the distal assembly 4102 of the suturing device 4100 is advanced into the passage through the mitral valve 8. The distal assembly 4102 is advanced sufficiently far through the passage to permit the arm 4104 to be opened without damaging surrounding tissue. Once the arm 4104 is extended, the suturing device is retracted through the passage such that the free end of the arm 4104 is adjacent a base of the valve as illustrated in Figure 66. A protective member 4107 is then advanced to position the distal end of the protective member 4107 at or near a base of the valve. A leaflet 132 of the valve can be posited between the arm 4104 and the protective member in some embodiments, such as that illustrated in Figure 66. Once the protective member has been advanced, the suture catch mechanism 4106 is advanced through the tissue of the valve to engage the arm 4104 as illustrated in Figure 67.

[0237] Figure 68 is a schematic a partial cross-sectional view of the arm 4104, the suture catch mechanisms 4106, and the valve of Figure 67 taken along line 68-68. Although Figure 68 illustrates both needles positioned through the tissue at the same time, such an arrangement may not occur in some embodiments, for example when a first needle is deployed and retracted before a second need is deployed.

[0238] The suture catch mechanisms 4106 are retracted through the tissue with the suture portions 130 into the elongate body 4142. The protective members 4107 can be retracted into the elongate body 4142 before, after, or with the suture catch mechanisms 4106. Figure 69 illustrates the suture portions 130 positioned through the valve with the suturing device 100 being withdrawn from the valve.

[0239] With the suture portions 130 positioned through the valve, the suture portions are tightened to draw together the locations of suture penetration. As illustrated in Figure 70, the sutures are then secured together by tying or other methods as described above or in the patents incorporated by reference, which form a part of this specification.

[0240] In another embodiment, a suturing device 5100 of a configuration similar to that of Figures 62-64 may be used, except that the arm 5104 comprises a single suture clasp 5126 rather than a plurality of suture clasps 5126. As illustrated in Figure 71, when a device having an arm 5104A with a single suture clasp is used, the suturing device is positioned at least partially in the mitral valve 8 as illustrated and described in connection with Figures 65-67. Figure 71 is a schematic partial cross-sectional view of an arm, a needle, and a valve taken along line 68-68 in Figure 67 according to an embodiment employing a suturing device having an arm comprising a single suture mount. As illustrated in Figure 71, the arm 5104A has been positioned on a first side of the valve and a suture catch mechanism 5106A has passed through the tissue of the valve from a second side of the valve. The suture catch mechanism 5106A is then retracted to position the suture portion 130 through the valve as illustrated in Figure 72.

[0241] A second arm 5104B is then positioned to place a second suture portion at a location spaced from the first location as illustrated in Figure 72. The second arm can be attached to the same elongate body 5142 as the first arm 5104A in some embodiments. In other embodiments, the second arm can be attached to a second device of similar or identical configuration to the prior device. If a second device is employed, it may be introduced into the mitral valve according to the steps described above in connection with Figures 65-67 and 71 and a second suture portion is placed through the valve as the suture catch mechanism 106 is retracted through the valve.

[0242] Figure 73 illustrates two separate suture portions positioned through the tissue of the valve 8. Also as illustrated in Figure 73, first ends of the suture portions 130 are then secured together by knotting or other means, such as described above or in the patents incorporated by reference, which form a part of this specification. The second ends of the suture portions 130 are then pulled to draw the suture portions through the tissue and position the secured first ends of the suture portions adjacent one side of the tissue, as illustrated in

Figure 74. The suture portions 130 are tightened to draw together the locations of suture penetration through the tissue and secured together, as illustrated in Figure 75

[0243] Figure 76 is a schematic perspective view of an exemplifying embodiment of a suturing device comprising a two suture catch mechanisms 6106 and a single arm 6104 located in proximity to a distal end of an elongate body 6142. The suturing device illustrated in Figure 76 is similar to the suturing device of Figure 62, except (1) the suture catch mechanisms 6106 of suturing device of Figure 76 are located distally of the arm 6104 and configured to be moved proximally from the retracted position to the deployed position, (2) the arm 6104 of the embodiment of Figure 76 extends distally and outwardly from the elongate body 6142 such that an angle between the arm 6104 and a longitudinal axis of the elongate body 6142 is less than 90°, and (3) other changes to the device of Figure 76 compared to the device of Figure 62 resulting from the first two differences as will be understood from the foregoing embodiments.

[0244] Figures 77-79 schematically illustrate use of the suturing device 6100 of Figure 76 according to an embodiment. The valve shown in Figures 77-79 can be a mitral valve 8 and the suturing device can be inserted into the valve via access through the inferior vena cava and the atrial septum, with or without a guide wire. Although reference is made to the mitral valve in connection with Figures 77-79, the accompanying description can apply to valves other than the mitral valve.

[0245] As illustrated in Figure 77, the distal assembly 6102 of the suturing device 6100 is advanced into the passage through the mitral valve 8. The arm 6104 is extended from the elongate body 6142 and the suturing device is advanced through the passage such that the free end of the arm 6104 is adjacent a base of the valve as illustrated in Figure 77. A protective member 6107 is then advanced to position the distal end of the protective member 6107 at or near a base of the valve. A leaflet 132 of the valve can be posited between the arm 6104 and the protective member in some embodiments, such as that illustrated in Figure 78. Once the protective member has been advanced, the suture catch mechanism 6106 is advanced through the tissue of the valve to engage the arm 6104 as illustrated in Figure 79.

[0246] Two suture portions are then passed through the valve tissue essentially in the same manner illustrated and described in connection with Figures 68-70. In embodiments wherein an arm of the suturing device comprises only a single suture mount,

the suture portions can be placed through the valve tissue in essentially the same manner illustrated and described in connection with Figures 71-75.

[0247] Figure 80 is a schematic perspective view of an exemplifying embodiment of a suturing device comprising two suture catch mechanisms 7106 and a single arm 7104 located in proximity to a distal end of an elongate body 7142. The suturing device illustrated in Figure 80 is similar to the suturing device of Figure 76, except the suture catch mechanisms 7106 of suturing device of Figure 80 are located proximally of the arm 7104 and configured to be moved distally from the retracted position to the deployed position and the suturing device of Figure 80 includes other changes compared to the device of Figure 76 resulting from the arrangement of the arm and suture catch mechanisms as will be understood from the foregoing embodiments.

[0248] Figures 81-83 schematically illustrate use of the suturing device 7100 of Figure 80 according to an embodiment. The valve shown in Figures 81-83 can be a mitral valve 8 and the suturing device can be inserted into the valve via access through the inferior vena cava and the atrial septum, with or without a guide wire. Although reference is made to the mitral valve in connection with Figures 81-83, the accompanying description can apply to valves other than the mitral valve.

[0249] As illustrated in Figure 81, the distal assembly 7102 of the suturing device 7100 is advanced into the passage through the mitral valve 8. The distal assembly 7102 is advanced sufficiently far through the passage to permit the arm 7104 to be opened without damaging surrounding tissue. Once the arm 7104 is extended, the suturing device is retracted through the passage such that the free end of the arm 7104 is adjacent a base of the valve as illustrated in Figure 82. A protective member 7107 is then advanced to position the distal end of the protective member 7107 at or near a base of the valve. A leaflet 132 of the valve can be posited between the arm 7104 and the protective member in some embodiments, such as that illustrated in Figure 82. Once the protective member has been advanced, the suture catch mechanism 7106 is advanced through the tissue of the valve to engage the arm 7104 as illustrated in Figure 83.

[0250] Two suture portions are then passed through the valve tissue essentially in the same manner illustrated and described in connection with Figures 68-70, except that the positions of the arm and the suture catch mechanisms have been exchanged relative to the

valve. In embodiments wherein an arm of the suturing device comprises only a single suture mount, the suture portions can be placed through the valve tissue in essentially the same manner illustrated and described in connection with Figures 71-75, except that the positions of the arm and the suture catch mechanisms have been exchanged relative to the valve.

[0251] Using the methods illustrated and described in connection with Figures 65-75, 77-79, and 81-83 sutures can be passed through a variety of locations near a base of a valve. For example, Figure 84 and 85 schematically illustrate locations 148 where suture can be placed in a valve. As illustrated in Figure 84, the suture can be placed through valve tissue at locations 148 generally between adjacent leaflets 132. Alternatively or additionally, sutures may be placed through locations 148 at or near a base of a leaflet 132 approximately at the middle of the leaflet 132 as illustrated in Figure 85. The devices and methods illustrated and described in connection with Figures 65-75, 77-79, and 81-83 can be used to perform other procedures, such as attachment of a ring around the outside of the malfunctioning valve and attachment of prosthetic devices to tissue. The protective member or needle arm described above can also be utilized in the embodiments of the suturing device described above for suturing valves, such as edge-to-edge suturing of mitral valves. In such embodiments, the needle arms may be deployed to a position that pinches the leaflet between the suture clasp arm and the needle arm. The suture catch mechanism or needle may then be advanced from out of the needle arm, through tissue of the leaflet, and into engagement with the suture end held by the suture clasp arm.

[0252] Although methods have been described for suturing valve tissue using a suturing device having an arm with a single suture mount and using a suturing device with multiple suture mounts in a single arm, other embodiments can employ a suturing device comprising an arm having more than two suture clasps and a corresponding number of needles configured to retrieve suture portions from each of the suture clasps.

[0253] Figure 86 schematically illustrates the chordae tendineae in the left ventricle of a human heart. Positioning the arms of a suturing device on a side of a valve (e.g., the atrial side) opposite the chordae tendineae can facilitate protection of the chordae tendineae from damage and facilitate the procedure by avoiding tangling of the arms with the chordae tendineae. Protection members (also described herein as “needle arms”), such as those described herein above and below, can help avoid damage to the chordae tendineae by

suture catch mechanisms, such as needles for example, located on the same side of the valve as the chordae tendineae (e.g., the ventricular side).

Suturing Devices and Methods Having A Plurality Of Arms, Such as For Suturing A Base Of A Valve

[0254] Figures 87 and 88 illustrate an exemplifying embodiment of a suturing device 8100 having an elongate body and comprising more than one suture arm 8104 at the distal end of the elongate body, with each arm having two suture clasps 8126. Such embodiments can facilitate performance of annuloplasty. The illustrated embodiment comprises six arms 8104, with each arm having two suture mounts 8126, the arms extending perpendicular to a longitudinal axis of the elongate body. Each of the illustrated suture mounts releasably carries a suture portion for retrieval by a suture catch mechanism. Other embodiments can comprise fewer arms or more arms than 6. In some embodiments, the device can comprise a single arm. In some embodiments, the arm(s) can rotate about the elongate body.

[0255] The arms illustrated in Figure 88 are sized to allow the suture mount to be placed at or near a base of the valve when the body of the device is placed in an opening of the valve. In some embodiments, the arms are sized and configured such that each of the suture mounts on all of the arms are at or in proximity of the base of the valve when the device is in a valve and the arms have been deployed. For example, the arms can each have a length of about 1.5 cm and the suture mounts can be located at or near an outermost point of the arms. In other embodiments, the arms may be longer or shorter than 1.5 cm. Various embodiments can have arms of different lengths to accommodate the size of the particular valve to be sutured and the anatomy of the intended patient.

[0256] The embodiment of Figures 87 and 88 comprises 12 suture catch mechanisms (not illustrated), one for each suture mount of the device. The suture catch mechanisms can be of the type described above and in the patents incorporated by reference (which form a part of this specification), such as needles for example. These needles may be located in carriers in a portion of the elongate body proximal to the arms, arranged circumferentially around the elongate body to correspond in location to the suture mounts on the ends of the arms. The suture catch mechanisms may be actuated by a user to move in a

proximal-to-distal direction, extending outwardly away from the elongate body to penetrate through tissue and into engagement with the suture mounts. Proximal retraction of the suture catch mechanism carries suture away from the arms through the tissue and back into the arms. The suture catch mechanisms can be operated independently of each other, or can be operated in groups in some embodiments. For example, two or more needles can be operated simultaneously in some embodiments. Other embodiments are contemplated where there are fewer needles than suture mounts provided on the device, but additional needles can be loaded and reloaded as desired to penetrate through tissue and retrieve suture. In certain embodiments, needles can be housed in a carrier that is rotatable around the circumference of the elongate body to position the needles in the desired location relative to the suture mounts.

[0257] The suturing device illustrated in Figures 87 and 88 comprises a protection member 8107 that is configured to protect surrounding tissue, e.g. chordae tendineae, from movement of the suture catch mechanisms. The protection member illustrated in Figures 87 and 88 is an elongate body comprising two lumens 8150 extending through a length of the protection member, although the protection member can comprise other numbers of lumens in some embodiments, as discussed above.

[0258] The protection member 8107 of this embodiment is configured to move between a retracted position parallel to a longitudinal axis of the elongate body and an outwardly extending, deployed position. The protection member is also configured to rotate about the longitudinal axis of the suturing device while the protection member is in the retracted position, the deployed position, and locations between the retracted position and the deployed position in order to point the protection member toward a desired arm. In some embodiments, the protection member is configured to rotate about the suturing device only when the protection member is in a selected one or more positions, e.g. fully-retracted position, fully-deployed position, or selected position between full retraction and full deployment.

[0259] In some embodiments, the protection member and a cooperating portion of the suturing device can be configured with detents to assist a user in determining when the protection member is aligned with a suture catch mechanism and arm as the protection member rotates. In alternative embodiments, rather than having a single rotating protection

member, multiple protection members may be provided, for example, one per arm, having a number of lumens corresponding to the number of suture mounts in each arm.

[0260] The suturing device illustrated in Figures 87 and 88 can be used to suture a valve without stopping the beating of the heart. In some embodiments, suturing of the heart while beating can allow the effect of suture placement on valve operation to be observed during the procedure, thereby allowing the procedure to be tailored to the needs of the particular valve by placing only those sutures required to repair the valve. For example, if the desired repair of the valve has not been achieved by the placement of initial sutures, continued use of the same device or additional devices may be employed through the same access path (e.g., through a transapical opening) until the procedure is observed to be successful on the beating heart. Once the practitioner observes this success, any access path which has been created to perform the procedure (e.g., the transapical opening) can be closed.

[0261] Figures 89-94 schematically illustrate a method of suturing using the device of Figures 87 and 88, and more specifically illustrates a method of performing a valve annuloplasty on a beating heart. As illustrated in Figure 89, a distal end 8102 of the suturing device 8100 is positioned in the passage through the valve, such as the mitral valve 8, using any of the access routes discussed above, and with or without a guide wire. The device is advanced through the valve a sufficient distance to allow the arms 8104 to be deployed without damage to the valve or walls of the heart.

[0262] Figures 89-94 are illustrated to schematically represent transapical access of the device to the mitral valve 8. However, as discussed herein, other access routes can be used and other valve can be sutured. In Figure 89, the valve is shown in cross section along a plane passing through a longitudinal axis of the suturing device 8100. In Figures 90-92, the valve is shown in cross section on two planes, which both intersect the longitudinal axis of the suturing device 8100. A first plane extends along the arm 8104 which is illustrated at approximately a 9 o'clock position from the elongate body of the suturing device. The second plane extends along the arm 8104 which is illustrated at approximately a 5 o'clock position relative to the elongate body of the suturing device. Thus, five of the arms 8104 are illustrated in Figures 90-92 as generally overlying leaflets 132 of the valve, with a portion of one of the leaflets which underlies the sixth arm being hidden from view. In Figure 91, the

planes of cross section of the valve pass generally through the longitudinal axis of the suturing device and extend generally along the arms 8104 which are illustrated at the 5 o'clock and 7 o'clock positions such that all six of the illustrated arms are shown generally overlying the leaflets 132 of the valve 8. The chordae tendineae are omitted from view in Figures 89-94.

[0263] Once the arms have been extended, the device 8100 can be retracted through the valve 8 to place the ends of the arms at or near the base of the valve 8, as illustrated in Figure 90. In certain embodiments, the length of the arms will not correspond exactly with the size of the valve. In such embodiments, two of the arms may be placed in a desired location with respect to the base of the valve where sutures are desired to be placed. The protective member 8107 is then moved from the retracted position toward the deployed position as illustrated in Figure 91.

[0264] As shown in Figure 91, the protective member 8107 when deployed can be moved to positions located angularly between the suture arms 8104. In other embodiments, the protective member 8107 when deployed can be positioned at a rotational orientation relative to the body of the suturing device 8100 that is aligned with at least one of the suture mounts of a suture arm. The ability to move the protective member between the arms can be advantageous in some embodiments. For example, movement of the protective member between the arms can allow the protective member to be rotated about the device between a position aligned with a first arm 8104A, as illustrated in Figure 92, and a position aligned with a second arm 8104B, as illustrated in Figure 93, without damage to the chordae tendineae. This feature can also help avoid tangling of the protective member 8107 with the chordae tendineae as a reduced number of instances of deployment and retraction occur.

[0265] In one embodiment, the protective member 8107 is first deployed and positioned in alignment with a suture mount 8126 of the first arm 8104A, as shown in Figure 92. The end of the protective member 8107 may be located near the end of the arm 8104A, but on the opposite side of tissue of valve 132. In some embodiments, the end of the protective member 8107 is positioned a few millimeters away from the arm 8104A. In other embodiments, this distance may be adjustable. A first suture catch mechanism, such as a needle, can be deployed through one of the lumens of the protective member 8107, through

tissue of valve 132, and into the suture mount 8126A of the first arm 8104A. Retraction of the suture catch mechanism carries a first suture end portion through the tissue of valve 132 and into the elongate body.

[0266] With the suture catch mechanism retracted and the protective member 8107 deployed, the protective member can be rotated into alignment with a suture mount of the second arm 8104B, as shown in Figure 93, for example. A second suture catch mechanism, such as a needle, can be deployed through the other of the lumens of the protective member 8107, through tissue of valve 132, and into the suture mount 8126B of the second arm. This suture mount of the second arm preferably holds the second end of the suture mounted in the first arm. Retraction of the suture catch mechanism carries the second suture end portion through the tissue of valve 132 and into the elongate body. The suturing device at this point has desirably placed a suture along the circumference of the valve at an angular distance corresponding to the angular distance between the ends of the two adjacent suture arms.

[0267] At this point in the procedure only one of the suture mounts from the first arm and the second arm has been used, preferably the suture mounts closest to the corresponding adjacent arm. The protection member 8107 may then be retracted and rotated to a location between another pair of arms, such as the second arm and the third arm. The device 8100 may also be desirably repositioned such that the second and third arms may be positioned as needed at the base of the valve 132. The steps discussed in connection with Figures 90-93 are then repeated to place a second suture through two additional locations in the valve. In embodiments wherein these steps are repeated for each of the pairs of adjacent suture arms, six sutures 130 may be positioned through the valve as illustrated schematically in Figure 94. Opposing ends of each suture can then be tightened and secured together by any known method, such as those described herein.

[0268] In some embodiments, methods similar to those described in connection with Figures 89-94 can be used to attached a prosthetic device to cardiac tissue.

Suturing Devices And Methods Having Two Arms, Such As For Suturing A Base Of A Valve

[0269] Figures 95-97 illustrate an embodiment of a suturing device 9100 that can be used to suture an anatomical valve, such as a heart valve. For example, the suturing device 9100 (as well as similar devices described above) can be used to perform an annuloplasty by plication, where suture(s) are applied to a section of a valve and the suture(s) is tightened to reduce the size of the valve to remodel the valve. The suturing device 9100 illustrated in Figures 95-97 is similar in some respects to suturing devices illustrated and described above. For example, the suturing device can comprise an elongate body 9142 and a distal assembly 9102 that can have one or more suture arms 9104, as in the suturing device of Figures 87 and 88 described above. As illustrated, the suturing device has only a single suture mount 9126 on each suture arm 9104, although in some embodiments it can have multiple suture mounts 9126 on each arm 9104. As described above, the suture mounts 9126 can be configured to releasably hold a suture portion.

[0270] In some embodiments, the suturing device can have multiple suture arms 9104 and multiple protective members or needle arms 9107. In the illustrated embodiments, the device has two suture arms 9104A,B and a single needle arm 9107. The configuration and deployment of the arms, as well as other features and ways of operating the suturing device, may be as shown and described in the U.S. Patent No. 6,911,034, the entirety of which is hereby incorporated by reference. The suture arms can be positioned near a distal end of the device, and the needle arm can be positioned proximally to the suture arms, as illustrated in Figures 95-97. The suture arms and the needle arm can each have a retracted position in which they are retracted within the elongate body, as illustrated in Figure 96. Each suture arm can also have an extended position in which the suture arm rotates about one end and extends away from the elongate body. In some embodiments, the arms 9104A,B can extend perpendicular to a longitudinal axis of the elongate body when in the extended position. The needle arm can also be deployed to an extended position, in which the needle arm extends away from the elongate body and toward a distal end of the elongate body. Figure 97 illustrates an embodiment where both suture arms and the needle arm are in the extended position.

[0271] As described above, various embodiments can have arms 9104A,B of different lengths to accommodate the size of the particular valve to be sutured and the anatomy of the intended patient. In some embodiments, the arms are sized and configured such that each of the suture mounts on the arms are at or in proximity of the base of a valve when the device is in the valve and the arms have been deployed. In some embodiments, when the arms have been deployed and the suture mounts are at or in proximity of the base of a valve, the needle arm can be on an opposite side of the valve. In some embodiments, the needle arm in its extended position can extend into alignment with a suture mount of a suture arm, but with the valve between them. Additionally, in some embodiments a suture arm can comprise a sharp edge 10105, or any hook, point, needle tip, knurling, or other roughening at a distal end on a surface that faces toward a proximal end of the elongate body when the suture arm is extended, as illustrated in Figure 98. The sharp edge or other roughening can help retain the suture arm in a position against tissue of an anatomic valve.

[0272] Also as described above, the needle arm 9107 can be configured to protect surrounding tissue from movement of a suture catch mechanism, which in some embodiments can be a needle 9106. The needle arm can comprise one or more lumens 9150 through which one or more needles 9106 can pass. In the illustrated embodiment of Figure 97, the needle arm has two lumens, each of which can be associated with a needle 9106 and a suture mount 9126.

[0273] In some embodiments, the needle arm can rotate around the elongate body. As illustrated in Figure 97, the needle arm can extend between the two suture arms 9104A,B. In Figure 99, the needle arm has rotated into alignment with one of the suture arms 9104A and a suture mount 9126A. Figure 99 illustrates a cross sectional view of a section of the elongate body with the suture arm 9104A and the protection member 9107 in their extended positions, and the needle arm aligned with the suture arm 9104A. As illustrated, a needle 9106 is positioned within the needle arm 9107. In some embodiments, the needle 9106 can be positioned within the needle arm before the needle arm is deployed to its extended position.

[0274] In some embodiments, the elongate body can comprise a rotating sleeve 9160, which can surround an inner cylinder, and which can house the needle 9106 and the needle arm 9107 when the needle arm is in the retracted position. As illustrated, when the

needle arm is in its extended position the needle runs through the rotating sleeve, exits the rotating sleeve into a gap, and then enters the needle arm. In some embodiments, the needle can run directly into the needle arm without passing first to a gap between the rotating sleeve and the needle arm. In some embodiments, discussed in more detail below, at least part of the needle can be within an extrusion. In some embodiments, the extrusion can be located only within the needle arm. In some embodiments, the extrusion can extend from the needle arm when the needle arm is in its extended position into the rotating sleeve.

[0275] When the needle arm begins to move into the extended position from a retracted position within the rotating sleeve it first moves distally until it engages extension surface 9164. The extension surface angles the needle arm away from the elongate body, such that as the needle arm continues to move forward it moves both away from the elongate body and toward a distal end of the elongate body. In some embodiments, the extension surface 9164 can be at approximately a 45 degree angle. In some embodiments, the needle arm can extend at approximately a 45 degree angle. In other embodiments, the extension surface can be at an angle less than or greater than 45 degrees, and the needle arm can be at an angle less than or greater than 45 degrees. As the needle arm is retracted, it can engage against retraction surface 9166 which can guide the needle arm back into its retracted position within the rotating sleeve 9160. In some embodiments, the retraction surface can comprise a gap that can allow a needle and/or extrusion to pass through it.

[0276] In some embodiments, the rotating sleeve 9160 can be configured to rotate about a longitudinal axis of the elongate body. In some embodiments, in addition to being able to rotate, the rotating sleeve can move proximally or distally along the inner cylinder. As the rotating sleeve rotates, the needle arm can rotate with it. As described with respect to Figures 87 and 88, the sleeve and needle arm, in various embodiments, can be configured to rotate while the needle arm is in the retracted positioned, the extended position, and/or in locations between the retracted position and the extended position in order to point the needle arm toward a desired arm. In some embodiments, when the needle arm is pointed toward a desired arm a gap of greater than or equal to 3 millimeters (or about 3 millimeters) and/or less than or equal to 5 millimeters (or about 5 millimeters) can exist between the needle arm and the suture arm. In some embodiments, the needle arm can point between two arms and a gap of greater than or equal to 3 millimeters (or about 3 millimeters) and/or less

than or equal to 5 millimeters (or about 5 millimeters) can exist between the needle arm and a plane on which the two arms lie.

[0277] In some embodiments, the elongate body can have one or more detents 9162, which can be positioned such that as the rotating sleeve rotates it can engage a detent when the needle arm is in alignment with a suture arm 9104. In some embodiments, the detent or detents can be configured such that as the rotating sleeve engages with the detent the sleeve moves distally. In some embodiments, this can be achieved by creating a bayonet connection between the sleeve and the detent(s). The distal motion of the rotating sleeve can drive the needle arm distally, and can be configured such that the needle arm engages tissue of the valve, pinching the valve between the tissue and the suture arm. If the needle arm rotates back, the rotating sleeve can disengage the detent, moving proximally and releasing the valve. In some embodiments, the needle arm can move distally as it comes into alignment with a suture arm, but does not pinch the valve. In some embodiments, the needle arm can move distally as it comes into alignment with a suture arm, but can rotate back without moving proximally.

[0278] Pinching the valve can help facilitate suturing a valve without stopping the beating of the heart, because it can help ensure desired placement of sutures. As discussed above, suturing of the heart while beating can allow the effect of suture placement on valve operation to be observed during the procedure, thereby allowing the procedure to be tailored to the needs of the particular valve by placing only those sutures required to repair the valve. For example, if the desired repair of the valve has not been achieved by the placement of initial sutures, continued use of the same device or additional devices may be employed through the same access path (e.g., through a transapical opening) until the procedure is observed to be successful on the beating heart. Once the practitioner observes this success, any access path which has been created to perform the procedure (e.g., the transapical opening) can be closed.

[0279] Figure 100 illustrates a view of the suturing device from a distal end. As illustrated, the first and second suture arms 9104A,B have been extended and extend away from the elongate body at approximately 90 degrees from each other. In some embodiments, the suture arms can be positioned at less than 90 degrees from each other, and in other embodiments the suture arms can be positioned at more than 90 degrees from each other.

The distance 9127 between the suture mounts 9126A,B can define the initial width of a suture or other element that can be tightened when performing an annuloplasty. In some embodiments, the distance 9127 can be greater than or equal to 10 millimeters (or about 10 millimeters) and/or less than or equal to 15 millimeters (or about 15 millimeters). Also illustrated in Figure 100 is a guide wire 10 and a guide wire lumen 9111 through which the guide wire can pass. As discussed above, in some embodiments the device can advance over a guide wire to reach a location within the heart.

[0280] Figure 101 illustrates a cross sectional view of a distal end of a needle arm 9107. In some embodiments, the needle arm can have one or more channels through which needles can pass. In some embodiments, as illustrated, a needle arm can have one or more extrusions 9170 positioned within one or more channels of the needle arm. The extrusion can be configured to receive a needle 9106, as illustrated. In some embodiments, the needle arm can have one or more of a draft 9174, a tunnel 9172, and/or a suture retaining area 9176, with the extrusion extending only as far as the draft 9174. The draft 9174 can guide a needle into the tunnel 9172, which can help ensure that the needle is aligned to pass through a suture clasp or mount 9126 and receive a section of a suture. The suture retaining area 9176 can be of a size sufficient to house both a needle and a portion of suture caught by the needle. In some embodiments, the needle 9106 can be pre-loaded to the illustrated position, extending through the extrusion and through the tunnel 9172, before a needle arm is deployed to an extended position. In some embodiments, the needle can be pre-loaded into other positions within the needle arm and/or extrusion, such as within the extrusion but short of the tunnel. The needle 9106 as illustrated in Figure 101 (or in any of the embodiments described elsewhere herein) may have a hook at its distal end to engage a portion of suture held by arm 9104A or 9104B. Sutures as described herein (or elsewhere in the specification) may have ends that are flattened with a hole formed therein for engaging the needle, as described in the U.S. Patent No. 7,090,686, the entirety of which is hereby incorporated by reference.

[0281] In some embodiments, the needle arm can have a single extrusion 9170 with one or more lumens 9150. Figure 102 illustrates a top view of an extrusion 9170 with two lumens 9150 configured to hold two needles 9106. In some embodiments, the needle arm can have multiple extrusions, each extrusion associated with one or more needles. In some embodiments, the needle arm can have a draft, tunnel, and/or a suture retaining area as

described above for each lumen and/or needle. In Figure 102, the extrusion has parallel sides and rounded corners. In other embodiments, the extrusion or extrusions can be square, rounded, ovular, or of any shape that can fit within a needle arm. The various embodiments and configurations of an extrusion or extrusions can be used with any protective member ("needle arm") discussed in the present application.

[0282] Figures 103-112 illustrate schematically one method of using a suturing device to perform an annuloplasty. The illustrated procedure represents transapical access of the device to the mitral valve 8, although as discussed herein other access routes can be used, including routes by which the device enters the valve from the atrial side, and other valves can be sutured. The device can also access the valve with or without a guide wire. The valve is shown without surrounding tissue, and in Figure 103 a distal end of the device has been inserted through the valve, with the suture arms 9104A,B and needle arm 9107 in the retracted position. The needle arm is positioned approximately equidistant between the two arms, although in some embodiments the needle arm can be positioned closer to one arm or the other. Also illustrated schematically are chordae tendineae 133 extending from the ventricle side of the valve.

[0283] The suture arms can be placed in their extended positions, as illustrated in Figure 104. In some embodiments they can reach their extended position simultaneously, and in some embodiments one arm can begin to extend or reach the extended position before the other arm begins to extend. With the suture arms extended, the device can be retracted until the arms engage tissue of the valve, as illustrated in Figure 105. As illustrated, the suture mounts 9126A,B are along a base of the valve on the same leaflet. In some embodiments, the arms do not extend all the way to the base of the valve, and in some embodiments each arm can be over a different leaflet.

[0284] Either before, after, or while the suture arms are extending or the device is retracted such that the suture arms can engage tissue of the valve, the needle arm can be deployed to an initial extended position, such as past the chordae, for example. Figure 106 illustrates the needle arm in the extended position and the suture arms in place on the valve. The needle arm 9107 can then rotate toward a first arm 9104A until it is aligned with the arm, as illustrated in Figure 107. As discussed above, in some embodiments, when the needle arm is aligned with the arm it can extend distally and pinch the valve between the

suture arm and the needle arm. In other embodiments, there can be a gap between the needle arm and the valve.

[0285] As the needle arm rotates, it can displace chordae tendineae 133 positioned between the needle arm and the first arm. One advantage of having the needle arm positioned initially equidistant between the two arms 9104A,B is that it minimizes the distance that the needle arm may need to travel to reach each arm, which can minimize stress on any displaced chordae. The needle arm when extended is preferably positioned between adjacent chordae tendineae, such that movement of the needle arm between the first and second arms does not cause the needle arm to tangle with the chordae tendineae.

[0286] Once the needle arm is aligned with the suture arm, a needle 9106A can be extended out of the needle arm and through the suture mount 9126A, as illustrated in Figure 108. As discussed above, retraction of the needle can carry a first suture end portion from the suture mount, through tissue of the valve, and into the elongate body. The needle arm can then rotate back to its initial extended position, bringing a length of suture 130A with it, as illustrated in Figure 109.

[0287] From the initial extended position, the needle arm 9107 can rotate toward second arm 9104B until it is aligned with the arm, as illustrated in Figure 110. In some embodiments, the needle arm can pinch the valve tissue against the arm, as discussed above. Also as discussed above, and as illustrated, the needle arm can displace chordae tendineae 133 positioned between the needle arm and the second arm 9104B.

[0288] A separate needle 9106B can extend through the needle arm and through the suture mount, as illustrated in Figure 111, and then retract into the elongate body with a second suture end portion. The needle arm can then return to its initial extended position, as illustrated in Figure 112, with a length of suture extending from each arm through the valve and into the needle arm. In some embodiments, the elongate body can have an initial detent that informs a user when the needle arm has returned to its initial extended position.

[0289] The suture arms and the needle arm can retract into the elongate body. In some embodiments, the needle arm and/or the suture arms can retract into the elongate body before the needle arm returns to the initial extended position, or without the needle arm returning to the initial extended position. Once the needle arm and suture arms are retracted,

the device can be removed from the valve and the heart, leaving the suture lengths running through the valve.

[0290] In some embodiments, the two suture end portions can be parts of separate sutures, as illustrated in Figure 113. The two suture ends that pass through the gap in the valve can be secured together by tying a knot 134 according to any known method or by applying a knot 134, such as described in U.S. Patent Publication No. 2007/0010829 A1, published January 11, 2007, which is hereby incorporated by reference herein in its entirety and is considered a part of this specification. Figure 114 illustrates the sutures after they have been joined together. In some embodiments, the two suture end portions can be ends of the same suture, and it is not necessary to secure the two suture ends together as seen in Figure 113.

[0291] One or more of the loose suture ends can then be pulled, as described with reference to Figures 50 and 51, bringing the suture against the valve. The remaining ends can be tightened and tied according to any of the methods described above, such as Figures 69 and 70 and accompanying description, to thereby draw together the locations of suture penetration. In some embodiments, as described above, the initial distance between the set of suture penetrations can be greater than or equal to 10 millimeters (or about 10 millimeters) and/or less than or equal to 15 millimeters (or about 15 millimeters). In some embodiments, the distance between the set of suture penetrations can be tightened to a second distance greater than or equal to 6 millimeters (or about 6 millimeters) and/or less than or equal to 8 millimeters (or about 8 millimeters). The connection between the set of suture penetrations can be referred to as a plication, and in some embodiments multiple plications can be inserted into the valve with the suturing device. The plications can be positioned and sized to reshape the valve according to a desired treatment goal.

[0292] In some embodiments, a tube 9137 can be inserted over the suture, as illustrated in Figure 115, which is a cross sectional view of a valve with a plication. The tube can be made of metal or a plastic, such as polypropylene, and can be straight or curved. In embodiments where the two suture end portions are part of separate sutures, the tube can be inserted over one of the suture ends that pass through the gap in the valve before the suture ends are secured together. In some embodiments, the tube 9137 can be secured to the two free ends of separate sutures that pass through the gap in the valve, rather than sliding loosely

over the joined sutures. The loose ends can then be pulled until the tube sits against or is near the valve. In embodiments where the two suture end portions are part of the same suture, the tube can be inserted over and/or attached to the suture before the suture is attached to the device, or in some embodiments the tube can be attached to the suture after the suture is attached to the device. The tube can be set to a desired length and can help control the distance that the locations of suture penetration are drawn together, as illustrated in Figure 116. In some embodiments, a pledget can be used instead of a tube. With the tube or pledget in place, a knot can be applied on the opposite side of the valve, as illustrated in Figure 116.

[0293] In some embodiments, in order to maintain consistent tightening among multiple plications, or to monitor the tightening of a single plication, a strain gauge can be connected to the suture. In some embodiments, a strain gauge can be built into the handle of the device. The plication can be tightened until the strain gauge indicates a desired value. In some embodiments, a first plication can be tightened to a desired distance, and the value measured by a strain gauge recorded. Subsequent plications can then be tightened to approximately the same reading of the strain gauge.

[0294] Because the chordae were pushed aside as the needle arm rotated between the two suture arms, the suture on the ventricle side can run in a generally direct route between the suture penetrations. This can help prevent unnecessary strain on chordae that could result if the suture took a circuitous path around chordae as it ran from one suture penetration to the next. Tightening the suture could pull the suture tight against the base of one or more chordae, potentially damaging the chordae.

Example Device For Applying Knots

[0295] Varying embodiments described herein rely on joining one or more sutures together. The following description relates to devices and methods of joining sutures. Figure 117 illustrates one embodiment of a knot placement device 900 that can be used to apply a knot to the suture portion 130. The knot placement device 900 can include a handle 902 and a shaft 904 extending distally from the handle. The handle 902 can include an elongate tubular body extending from a proximal end to a distal end, and can include an actuator 906 and a distal end portion 910. The handle 902 can further comprise a cam 908

and a spring 912, shown in its rest position, disposed between the cam 908 and end portion 910. The actuator 906 can be a thumb or finger button in contact with the cam 908. End portion 910 can be fixedly attached to an outer tube 914 by glue, press fit, injection molding, or other suitable means known to one of ordinary skill in the art. An intermediate tube 916 can be concentrically and slidably disposed within the outer tube 914. A push rod 918 can be concentrically and slidably disposed within the intermediate tube 916 and fixedly attached to the cam 908. It should be appreciated that it is contemplated that the knot placement device 900 does not necessarily comprise an intermediate tube 916; however its inclusion provides certain benefits.

[0296] Depression of the actuator 906 causes the cam 908 to move distally, compressing the spring 912, thereby moving the push rod 918. After traveling for a certain desired distance, the cam 908 engages a proximal end of the intermediate tube 916, causing the intermediate tube 916 to also move distally. Upon release of the actuator 906, the spring 912 expands to move the cam 908 and the push rod 918 proximally. In the illustrated embodiment, the intermediate tube 916 can be freely slidable over the push rod 918.

[0297] In one embodiment, not shown, the cam 908 can include a detent in the surface which contacts the actuator 906. The detent can signal to the user a specific degree of advancement of the push rod 918, the intermediate tube 916, or both. For example, the detent can signal that the push rod has been advanced sufficiently far to insert the plug into the knot body, as described below. The detent can also indicate travel up until, but not including, the point at which the cam 908 engages the intermediate tube 916. The detent can be shaped so as to prevent the actuator 906 from returning to its original position. The cam can comprise multiple detents to indicate multiple increments of travel. To return the actuator to its initial position, the actuator and cam can include a mechanism such that after the actuator can be fully depressed, the actuator can automatically return to its initial position. Alternatively, the actuator can have a locked configuration, either at one of the detents or in a fully depressed configuration, and the handle can include a mechanism by which a second actuator can be used to release the cam and actuator to return to their initial positions.

[0298] In one embodiment, not shown, the intermediate tube 916 can comprise a keyway and the outer tube 914, the end portion 910, or both can comprise a key.

Alternatively, the intermediate tube 916 can comprise a key and the outer tube 914, the end portion 910, or both can comprise a keyway. Providing such a key and keyway can be used to keep the intermediate tube 916 aligned with the outer tube. Other embodiments are contemplated to maintain rotational alignment of the intermediate tube, such as rotationally fixing the intermediate tube relative to the push rod. Providing such a key and keyway can also be used to constrain the range of sliding movement of the intermediate tube 916.

[0299] As shown in Figure 118, a knot, comprising a knot body 924 and a plug 926, can be disposed within the outer tube 914 at its distal end. In another embodiment, the knot body can include an atraumatic tip 932. The tip 932 can be rounded and have an outer diameter about the same as that of the outer tube 914. The tip can also include a flat transition 934 as well. The tip 932 can be integrally formed with the knot body 924 or can be separately attached. As illustrated, the tip 932 can have an aperture 936 extending axially through the tip, opening to the cavity inside the knot body. When the knot is delivered into a patient as described above, the atraumatic tip prevents damage to the patient.

[0300] Alternatively, the fit between the knot body 924 and the outer tube 914 cannot retain the knot body 924 in the outer tube 914. The knot body 924 can be at the distal end of the outer tube 914, and can protrude slightly distal to the distal end of outer tube 914. The plug 926 can be positioned proximal to the knot body 924, and can be slidably disposed within the intermediate tube 916, having a distal end located proximally from the knot body and distally from the push rod 918. The plug 926 has an outer dimension configured to be inserted into an inner cavity of the knot body 924. The intermediate tube 916 can be sized and positioned such that its distal end can abut knot body 924.

[0301] As shown in Figure 118, the outer tube 914 can include a side hole 920 near its distal end. The intermediate tube 916 can include a slot (not shown) extending proximally from its distal end, forming a C-shaped cross section. At a proximal end of the slot, a sharpened cutting surface can be provided to cut suture 130, as described below. The slot can also be spaced from the distal end of the intermediate tube, such that the distal end of the tube still forms a complete circle in cross-section. The outer tube 914, intermediate tube 916 and push rod 918 can be made of any suitable material, including but not limited to metals, plastics, and a combination of metals and plastics.

[0302] As shown in Figure 118, in a preloaded configuration, the knot placement device 900 can include a threader 928 comprising a tab 931 and a looped wire 930 passing through the side hole 920 in the outer tube 914. The wire 930 extends through the slot 122 located in the intermediate tube 916, and through knot body 924, exiting through opening 936 at the distal end of the knot body 924. The threader 928 can be used to load the suture into the knot placement device as described below. The threader 928 also prevents the knot body 924 from escaping from the placement device 900 when the knot body can be provided with an outer dimension of the same or smaller size than the inner wall of the outer tube 914.

[0303] With reference to Figure 118, the knot body 924 can be generally tubular and comprise a proximal end, a distal end, and a longitudinal axis. The knot body 924 further defines an inner cavity and can include an opening 936 at its distal end. The knot body can be of a generally constant inner diameter and outer diameter. Alternatively, the inner diameter, the outer diameter, or both can generally taper along the longitudinal axis of the knot body. Alternatively, the inner diameter, the outer diameter, or both can generally taper along a portion of the longitudinal axis and can be of a generally constant inner diameter, outer diameter or both over a portion of the longitudinal axis.

[0304] The opening 936 at the distal end of the knot body can, in some embodiments, be of a reduced diameter relative to an inner cavity of the knot body 924. The knot body also can include an opening at the proximal end. The opening at the proximal end can, in some embodiments, be of a reduced diameter relative to an inner cavity of the knot body 924. The knot body can further comprise protrusions 938 extending from the inner surface of the knot body 924 toward the longitudinal axis. Protrusions 938 can be formed as rings as illustrated, or as spirals, spikes, bumps, or other suitable structures or combinations of structures.

[0305] Referring to Figure 118, in one embodiment, the knot body 924 can be located distally from the plug 926 within the outer tube 914. The plug can be sized to be inserted into the inner cavity of the knot body 924, and can have a tapered configuration. Alternatively, the plug 926 can have a constant cross-section over a majority of its length, with a tapered, chamfered or rounded distal end for facilitating insertion into the knot body 924. The outer dimension of the plug 926 can be slightly larger than the inner dimension of the cavity of the knot body 924, such that when the plug is inserted into the cavity, a

relatively secure fit can be provided between the two. The protrusions 938 within the knot body further facilitate the relative securement. The plug 926 can also comprise indentations, not shown, for receiving the protrusions 938 to secure the plug 926 more surely in the knot body 924. Other embodiments are contemplated wherein protrusions can be formed on the plug 926 with or without indentations formed in the inner cavity of the knot body 924. It is also contemplated that in some embodiments both the plug 926 and the knot body 924 can comprise protrusions and indentations, respectively. In certain embodiments, insertion of the plug 926 into the knot body 924 can cause the knot body 924 to slightly expand. Both the knot and the knot body can be formed of any suitable resilient materials, and in one embodiment, can be made from the same material as the suture, more preferably polypropylene.

[0306] FIGS. 118-119 illustrate one embodiment for placing a knot utilizing the knot placement device 900 described above. A pair of sutures ends 130 can be passed through the loop 930 of threader 928. The threader can be preloaded into the knot placement device 900 as described above. The tab 931 of threader 928 can be pulled proximally to dispose suture 130 in the device. Suture 130 can be held in tension, by hand or otherwise, while the device 900 can be advanced until the knot body 924 or shaft 904 contacts at least one tissue portion. The actuator 906 can be depressed to advance the push rod 918, thereby forcing the plug 926 distally into the knot body 924 and trapping suture 130 there between the plug 926 and the knot body 924. The actuator can be further depressed until the cam 908 contacts the proximal end of intermediate tube 916, causing the intermediate tube 916 to contact knot body 924 and eject the knot from the shaft 904. Advancement of intermediate tube 916 can also cause cutting surface to sever suture 130 where it extends out of opening. The knot placement device can then be removed, leaving the knot in place against the tissue portions.

[0307] In one embodiment, the knot can be ejected from the shaft 904 while leaving the sutures 130 un-severed. For example, the knot can be ejected before the cutting surface reaches the suture 130. In another embodiment, no intermediate tube can be provided, and the suture can be cut manually.

[0308] In an embodiment including the intermediate tube, the device 900 can be configured such that the distal ends of the outer tube 914, intermediate tube 916, and the

push rod 918 lie generally flush relative to one another and can be held relatively in position. This position can be held, for example, by depressing the actuator until it rests in a detent in cam 908. The detent can signal to the user that the plug 926 has been inserted into knot body 924, but also that the sutures 130 have not been cut. At such time, the placement device can be used to further advance the knot against tissue portions using the distal end surface of the shaft. The actuator can be further depressed to advance the push rod 918 and intermediate tube 916 to sever sutures 130.

[0309] The actuator 906 and cam 908 can also be provided with locking mechanisms that prevent the actuator 906 from returning to its original position. Further details are provided in U.S. Patent Application Publication No. 2006/0069397, published on March 30, 2006, the entirety of which is hereby incorporated by reference herein. Such an embodiment can be advantageous to hold the push rod flush with the distal end of the outer tube to provide a surface that can be utilized to further advance and position the knot against tissue portions.

[0310] It will be appreciated that other embodiments can be contemplated without use of the intermediate tube, but can still be capable of severing the suture. For example, the push rod can be provided with portions of differing diameter. A distal, smaller diameter can be sized to engage the plug 926 to push the plug into the knot body 924. A proximal, larger diameter can be provided on the push rod, which can include a sharpened surface at the transition between the larger and smaller diameter sections. Once the smaller portion of the push rod pushes the plug 926 into the knot body 924, the larger portion of the push rod can engage the knot body 924 to push the knot out of the placement device, while the sharpened surface on the push rod can sever the suture.

[0311] In the embodiment described above, when the knot body 924 and the plug 926 as described above are secured together, suture portions extending through the inner cavity of the knot body will be fixedly secured therein, forming a knot. It will be appreciated that many other embodiments can be possible for forming a knot, including various other shapes and configurations for the knot body and plug, as well as embodiments wherein only one component can be used to provide securement relative to a suture. It will also be appreciated that in those embodiments in which the knot can include a knot body and

plug, the plug can be located within the shaft proximally from the knot body or the knot body can be located within the shaft proximally from the plug.

[0312] After the procedure within the heart is complete, any path that has been opened to provide access for entry of the suturing device to the body (e.g., the transapical opening) can be closed. Additional details regarding closure of transapical openings are provided in U.S. Patent Publication No. 2011/0190793 A1, entitled METHODS AND APPARATUSES FOR SUTURING OF CARDIAC OPENINGS, which is hereby incorporated by reference herein in its entirety and forms a part of this specification.

[0313] Although the foregoing description of the preferred embodiments has shown, described and pointed out the fundamental novel features of the invention, it will be understood that various omissions, substitutions, and changes in the form of the detail of the apparatus as illustrated as well as the uses thereof, may be made by those skilled in the art, without departing from the spirit of the invention. For example, while the suturing device is described with respect to suturing a valve of a patient's heart, it is further envisioned that the suturing device could be used to close or reduce a variety of other tissue openings, lumens, hollow organs or natural or surgically created passageways in the body. The suturing device can have any suitable number of arms, such as two or four or more, and any given arm can have one or more suture clasps or openings.

WHAT IS CLAIMED IS:

1. A suturing device, comprising:
 - an elongate member comprising a distal end;
 - an arm connected with the elongate member near the distal end for movement between a retracted position and an extended position, the arm comprising at least one suture mount located near a free end of the arm and configured to releasably retain a suture portion;
 - a needle configured to move between a retracted position and a deployed position to retrieve the suture portion retained in the at least one suture mount when the needle is moved from the retracted position to the deployed position and returned to the retracted position; and
 - a protective member configured to inhibit contact between a distal end of the needle and surrounding tissue during at least a portion of the movement of the needle from its retracted position toward its deployed position.
2. The suturing device of Claim 1, wherein the protective member is configured to move between a retracted position and an extended position.
3. The suturing device of Claim 2, wherein the protective member is configured to move from its retracted position to its extended position before the needle is deployed.
4. The suturing device of Claim 2, wherein the protective member is configured to move from its retracted position to its extended position while the needle is being moved from its retracted position to its deployed position.
5. The suturing device of Claim 2, wherein the protective member comprises a sleeve and the needle is configured to extend through the sleeve when the needle is in its deployed position.
6. The suturing device of Claim 2, wherein the protective member is configured to partially surround a circumference of the needle when the needle is in its deployed position.
7. The suturing device of Claim 1, comprising a first needle and a second needle and wherein the arm comprises a first suture mount and a second suture mount located near a free end of the arm and configured to releasably retain a second suture portion, the second needle being configured to move between a retracted position and a deployed position to

retrieve the second suture portion retained in the second suture mount when the second needle is moved from the retracted position to the deployed position and returned to the retracted position.

8. The suturing device of Claim 7, wherein the protective member is configured to inhibit contact between a distal end of the second needle and surrounding tissue during at least a portion of the movement of the second needle from its retracted position toward its deployed position.

9. The suturing device of Claim 8, wherein the protective member is configured to partially surround the first and second needles when the first and second needles are in their deployed positions.

10. The suturing device of Claim 9, wherein the protective member has a generally U-shaped cross-section.

11. The suturing device of Claim 7, comprising a first protective member and a second protective member, the first protective member being configured to inhibit contact between a distal end of the first needle and surrounding tissue during at least a portion of the movement of the first needle from its retracted position toward its deployed position and the second protective member being configured to inhibit contact between a distal end of the second needle and surrounding tissue during at least a portion of the movement of the second needle from its retracted position toward its deployed position.

12. The suturing device of Claim 1, comprising a plurality of arms, and wherein the protective member is moveable into alignment with each of the arms.

13. The suturing device of Claim 12, comprising at least two needles and at least two arms, wherein the arms in their extended positions have free ends that are spaced apart from each, and the protective member is configured to house the at least two needles and move between locations adjacent each of the free ends of the arms.

14. The suturing device of Claim 12, wherein the suturing device comprises six arms and twelve needles.

15. The suturing device of Claim 12, wherein the protective member comprises a pair of lumens.

16. A suturing device, comprising:
an elongate body comprising a proximal end and a distal end;

a handle at the proximal end;

a first arm and a second arm near the distal end, wherein the first arm and the second arm are configured to move between a first position wherein the first arm and second arm are retracted within the elongate body, and a second position wherein the first arm and the second arm have free ends extending away from the elongate body and the first arm and the second arm form an angle between each other, each of the first arm and the second arm comprising at least one suture mount at their free ends and configured to releasably retain a suture portion;

a needle arm positioned proximal to the first and second arm, the needle arm configured to extend from a retracted position wherein the needle arm is retracted in the elongate body to an extended position wherein the needle arm extends distally and outwardly from the elongate body, the needle arm configured to rotate around the elongate body at least between a first position wherein the needle arm is aligned with the free end of the first arm and a second position wherein the needle arm is aligned with the free end of the second arm;

a first needle configured to move between a retracted position in which a distal point of the first needle is within the needle arm to a deployed position in which the distal point of the needle extends out of the needle arm into the suture mount of the first arm when the needle arm is in the first position; and

a second needle configured to move between a retracted position in which a distal point of the second needle is within the needle arm to a deployed position in which the distal point of the needle extends out of the needle arm to a suture mount of the second arm when the needle arm is in the second position.

17. The device of Claim 16, wherein the needle arm in the extended position extends from the elongate body at approximately a 45 degree angle.

18. The device of Claim 16, wherein the first arm and second arms each comprise a sharp edge at the free end facing toward the proximal end of the elongate body configured to engage tissue.

19. The device of Claim 16, wherein the needle arm is configured to move from its retracted position to its extended position before the first or second needle is deployed.

20. The device of Claim 16, wherein the needle arm is configured to move from its retracted position to its extended position while the first or second needle is being moved from its retracted position to its deployed position.

21. The device of Claim 16, further comprising an extrusion positioned within the needle arm, wherein the first and second needles are configured to extend through the extrusion when in their deployed positions.

22. The device of Claim 21, wherein the extrusion comprises a first and a second lumen, the first and second needles configured to extend through the first and second lumen, respectively, when in their deployed positions.

23. The device of Claim 21, wherein the needle arm comprises a first and second narrowing section at a distal end thereof, the first and second narrowing section configured to align the first and second needle with the first and second suture mount, respectively.

24. The device of Claim 16, wherein the elongate body further comprises a rotating sleeve that rotates with the needle arm and a first and second detent configured to engage the rotating sleeve when the needle arm is in its first and second position, respectively.

25. The device of Claim 16, wherein the needle arm moves distally when the rotating sleeve engages the first and second detents.

26. A method of suturing an anatomic valve, comprising:
positioning a suturing device comprising an elongate body through the valve;
extending a plurality of arms from the elongate body of the suturing device, each of the arms carrying an end of a suture;
positioning at least a pair of arms at or near a base of the valve;
extending a protection member from the elongate body toward a first one of the arms positioned at or near a base of the valve;
advancing a needle through the protection member, through tissue of the valve at a first location, and into contact with a first one of the suture ends carried by the first arm;
retracting the needle through the tissue of the valve to draw the first suture end through the tissue;

rotating the protection member along the elongate body such that the protection member extends toward a second one of the arms positioned at or near a base of the valve;

advancing a needle through the protection member, through tissue of the valve at a second location, and into contact with a second one of the suture ends carried by the second arm;

retracting the needle through the tissue of the valve to draw the second suture end through the tissue; and

closing a distance between the first and second locations with said suture placed through said locations.

27. The method of Claim 26, wherein the valve is a mitral valve.

28. The method of Claim 26, further comprising delivering the suturing device through a transapical opening.

29. The method of Claim 26, further comprising advancing the needles through tissue of a beating heart.

30. The method of Claim 26, wherein each of the arms comprises a pair of suture mounts for releasably holding end portions of one or more sutures.

31. The method of Claim 26, wherein the suturing device comprises six arms.

32. The method of Claim 26, wherein extending a protection member comprises extending the protection member between adjacent chordae, and wherein the protection member remains between the adjacent chordae until the second suture end is drawn through the tissue.

33. A method of suturing a mitral valve, comprising:

delivering a suturing device transapically through the heart and into the left ventricle, the suturing device comprising a proximal end and a distal end, an elongate body extending between the proximal end and the distal end, and a handle at the proximal end;

delivering at least the distal end of the suturing device through the mitral valve;

extending a first arm and a second arm from the elongate body from a first position wherein the first arm and the second arm are retracted into the elongate body

to a second position wherein the first arm and the second arm have free ends extending away from the elongate body, the first arm carrying a first suture end and the second arm carrying a second suture end;

positioning the first and the second arm at or near a base of the valve on the atrial side of the valve;

extending a needle arm from a retracted position wherein the needle arm is retracted into the elongate body to an initial extended position wherein the needle arm is located proximal to the arms, wherein the needle arm in the initial extended position extends outwardly away from the elongate body in a distal direction on the ventricular side of the valve between adjacent chordae;

rotating the needle arm toward the first arm with the needle arm remaining on the ventricular side of the valve such that the needle arm extends toward the first arm positioned at or near a base of the valve;

advancing a first needle distally out of the needle arm, through tissue of the valve at a first location, and into contact with the first suture end;

retracting the first needle through the tissue of the valve to draw the first suture end through the tissue, a first length of suture running from the first suture end and through the tissue;

rotating the needle arm toward the second arm with the needle arm remaining on the ventricular side of the valve such that the needle arm extends toward the second arm positioned at or near a base of the valve;

advancing a second needle distally out of the needle arm, through tissue of the valve at a second location, and into contact with the second suture end;

retracting the second needle through the tissue of the valve to draw the second suture end through the tissue, a second length of suture running from the second suture end and through the tissue;

rotating the needle arm back to the initial extended position;

moving the needle arm proximally back to the retracted position;

moving the first and second arms from the second position back to the first position;

withdrawing the suturing device from the mitral valve, the first and second lengths of suture remaining within the tissue; and

closing a first distance between the first and second locations to a second distance between the first and second locations.

34. The method of Claim 33, wherein the needle arm in the initial extended position is approximately equidistant from the first and second arms.

35. The method of Claim 33, wherein the first arm and the second arm form an angle of approximately 90 degrees between each other.

36. The method of Claim 33, wherein the first distance is between about 10 and about 15 millimeters and the second distance is between about 6 and about 8 millimeters.

37. The method of Claim 33, further comprising the step of repeating the procedure at a third location and a fourth location.

38. The method of Claim 33, wherein the first suture end and second suture end are ends of different sutures.

39. The method of Claim 33, wherein the distance between the first and second locations is closed by applying a knot to a suture placed between the first and second locations.

40. The method of Claim 33, wherein closing the distance comprises inserting one of the first suture end or the second suture end through a section of tubing of a desired length, joining the first and second suture ends to form a single suture, and tightening the single suture until the second distance is approximately equal to the desired tubing length.

41. The method of Claim 33, wherein closing a first distance comprises joining the first and second suture ends to form a single suture and tightening the single suture until a strain gauge connected to the suture indicates a desired value.

42. The method of Claim 33, wherein rotating the needle arm toward the first arm comprises rotating the needle arm and extending it further toward the first arm, thereby pinching the valve between the needle arm and the first arm.

43. The method of Claim 33, further comprising the step of rotating and retracting the needle arm toward the initial extended position prior to rotating the needle arm toward the second arm, and wherein rotating the needle arm toward the second arm comprises

rotating the needle arm and extending it further toward the second arm, thereby pinching the valve between the needle arm and the second arm.

44. The method of Claim 33, wherein the elongate body comprises a rotating sleeve that rotates with the needle arm, and wherein rotating the needle arm toward the first arm comprises rotating the needle arm until the rotating sleeve engages a first detent.

45. The method of Claim 33, further comprising rotating the needle arm back to the initial extended position before moving the needle arm proximally back to the retracted position.

46. The method of Claim 45, wherein the elongate body comprises a rotating sleeve that rotates with the needle arm, and rotating the needle arm back to the initial extended position further comprises rotating the needle arm until the rotating sleeve engages an initial detent.

47. The method of Claim 33, wherein the needle arm remains between the adjacent chordae until the second suture end is drawn through the tissue.

48. A method of applying suturing to tissue, comprising:

- providing a suturing device, the suturing device comprising a proximal end and a distal end, an elongate body extending between the proximal end and the distal end, and a handle at the proximal end;

- delivering at least the distal end of the suturing device to a location adjacent the tissue;

- extending a first arm and a second arm from the elongate body from a first position wherein the first arm and the second arm are retracted into the elongate body to a second position wherein the first arm and the second arm have free ends extending away from the elongate body and the first arm and the second arm form an angle between each other, the first arm carrying a first suture end and the second arm carrying a second suture end;

- positioning the first and the second arm adjacent a first side of the tissue;

- moving a needle arm from a retracted position wherein the needle arm is retracted into the elongate body to an extended position wherein the needle arm extends toward the first arm, the needle arm being located on the opposite side of the tissue from the first arm and the second arm;

advancing a first needle out of the needle arm, through the tissue at a first location, and into contact with the first suture end;

retracting the first needle through the tissue to draw the first suture end through the tissue, a first length of suture running from the first suture end and through the tissue;

rotating the needle arm toward the second arm such that the needle arm extends toward the second arm;

advancing a second needle out of the needle arm, through the tissue at a second location, and into contact with the second suture end;

retracting the second needle through the tissue to draw the second suture end through the tissue, a second length of suture running from the second suture end and through the tissue;

moving the needle arm back to the retracted position;

moving the first and second arms from the second position back to the first position; and

withdrawing the suturing device from the tissue location, the first and second lengths of suture remaining within the tissue.

49. The method of Claim 48, wherein the location is a mitral valve.

50. The method of Claim 49, further comprising delivering the suturing device transapically into the left ventricle of the heart, and wherein positioning the first and the second arm at or near a base of the valve comprises positioning the first and the second arm at or near a base of the valve on the atrial side of the valve.

51. The method of Claim 48, further comprising closing a distance between the first and second locations using a suture placed between the first and second locations.

52. The method of Claim 48, wherein the angle between the first arm and the second arm when extended is approximately 90 degrees.

53. The method of Claim 48, wherein the first suture end and second suture end are ends of the same suture.

54. The method of Claim 48, wherein the first suture end and second suture end are ends of different sutures.

55. The method of Claim 48, wherein the needle arm is moved from a retracted position first to an initial extended position between the first arm and the second arm.

56. The method of Claim 55, wherein the initial extended position is between adjacent chordae, and wherein the protection member remains between the adjacent chordae until the second suture end is drawn through the tissue.

57. A method of suturing an anatomic valve, comprising:
positioning an elongate body at least partially within the anatomic valve;
deploying an arm from the elongate body with the arm releasably holding a suture portion;
positioning a free end of the arm at or near a base of the valve;
deploying a needle from the elongate body such that the needle penetrates the valve at a first location and engages the suture portion;
protecting tissue of the valve and surrounding anatomy from a distal end of the needle as the needle is deployed to the first location;
drawing the suture portion through the valve;
passing a second suture portion through the valve at a second location; and
securing together the first and second suture portions.

58. The method of Claim 57, wherein said protecting tissue comprises moving a protection member between a retracted position and a deployed position.

59. The method of Claim 58, wherein the protective member surrounds a circumference of the needle and extends beyond the distal end of the needle until the protective member reaches the deployed position.

60. The method of Claim 58, wherein the protective member is moved to the deployed position before the needle is deployed.

61. The method of Claim 58, wherein the protective member is moved to the deployed position as the needle is deployed.

62. The method of Claim 57, wherein the needle penetrating the valve at a first location is a first needle, and wherein passing the second suture portion through the valve comprises deploying a second needle from the elongate body such that the second needle penetrates tissue and retrieves the second suture portion from a second arm deployed from the body.

63. The method of Claim 62, wherein the second needle is deployed simultaneously with the first needle.

64. The method of Claim 62, wherein the second needle is deployed after the first needle.

65. The method of Claim 62, further comprising protecting tissue of the valve and surrounding anatomy from a distal end of the second needle as the second needle is deployed.

66. The method of Claim 57, wherein passing the second suture portion through the valve comprises:

- positioning a second elongate body at least partially within the anatomic valve;

- deploying a second arm from the elongate body with the second arm releasably holding the second suture portion;

- positioning a free end of the second arm at or near a base of the valve;

- deploying a second needle from the second elongate body such that the second needle penetrates the valve at a second location and engages the second suture portion;

- protecting tissue of the valve and surrounding anatomy from a distal end of the second needle as the second needle is deployed to the second location; and

- drawing the second suture portion through the leaflet.

67. A method of suturing an anatomic valve, comprising:

- positioning an elongate body at least partially within the anatomic valve;

- deploying an arm from the elongate body on a first side of a valve with the first arm releasably holding first and second suture portions;

- positioning a free end of the arm at or near a base of the valve;

- deploying first and second needles from the elongate body on a second side of the valve such that the first needle penetrates the valve at a first location and engages the first suture portion and the second needle penetrates the valve at a second location and engages the second suture portion;

- drawing the first and second suture portions through the valve from the first side to the second side; and

securing together the first and second suture portions.

68. The method of Claim 67, wherein the second needle is deployed simultaneously with the first needle.

69. The method of Claim 67, wherein the second needle is deployed after the first needle.

70. A method of suturing an anatomic valve, comprising:
positioning an elongate body at least partially within the anatomic valve;
deploying at least two arms from the elongate body with each arm releasably holding a suture portion;
positioning a free end of each of the arms at or near a base of the valve;
deploying needles from the elongate body such that each needle penetrates the valve and engages a corresponding suture portion;
drawing the suture portions through the leaflet; and
securing the suture portions together in groups of no less than two.

71. The method of Claim 70, wherein the needles are sequentially deployed.

72. The method of Claim 71, wherein each needle is deployed independently of the other needles.

73. The method of Claim 71, wherein the needles are deployed in pairs.

74. The method of Claim 70, wherein each arm releasably holds at least a pair of suture portions.

75. The method of Claim 70, wherein six arms are positioned near a base of the valve.

76. The method of Claim 70, wherein the second needle is deployed with the first needle.

77. A method of suturing an anatomic valve, comprising:
positioning an elongate body at least partially within the anatomic valve;
deploying a first arm from the elongate body with the first arm releasably holding a first suture portion at a free end;
positioning the free end of the first arm at or near an edge of a first leaflet on a first side of the valve;

deploying a first needle arm from the elongate body on an opposite side of the valve, wherein when the needle arm is deployed, the first leaflet is positioned between the needle arm and the first arm;

deploying a first needle from the deployed first needle arm such that the first needle penetrates the first leaflet at a first location and engages the first suture portion;

drawing the first suture portion through the first leaflet;

passing a second suture portion through a second leaflet at a second location;
and

drawing together the two leaflets using a suture placed through the first and second locations.

78. The method of Claim 77, wherein the first needle arm is moved to the deployed position before the first needle is deployed.

79. The method of Claim 77, wherein the first needle arm is moved to the deployed position as the first needle is deployed.

80. The method of Claim 77, comprising pinching the first leaflet between the first needle arm and the first arm.

81. The method of Claim 77, wherein passing the second suture portion through the second leaflet comprises deploying a second needle from the elongate body such that the second needle penetrates tissue and retrieves the second suture portion from a free end of a second arm deployed from the body, the free end of the second arm positioned at or near an edge of the second leaflet.

82. The method of Claim 81, wherein the second needle is deployed simultaneously with the first needle.

83. The method of Claim 81, wherein the second needle is deployed after the first needle.

84. The method of Claim 83, wherein the second arm is deployed from the body after the first needle is deployed.

85. The method of Claim 81, wherein the second needle is deployed from a second needle arm that is deployed from the elongate body.

86. The method of Claim 77, wherein passing the second suture portion through the second leaflet comprises deploying a second needle from a second elongate body such that the second needle penetrates tissue and retrieves the second suture portion from a free end of a second arm deployed from the second elongate body, the free end of the second arm positioned at or near an edge of the second leaflet.

87. The method of Claim 77, wherein the elongate body is delivered transapically to a mitral valve.

88. The method of Claim 77, wherein the elongate body is delivered transeptally through the left atrium to a mitral valve.

89. The method of Claim 77, wherein the first arm holds a plurality of suture portions at a free end thereof.

90. The method of Claim 77, wherein the first suture portion and second suture portion are separate sutures.

91. The method of Claim 90, further comprising connecting the first suture portion to the second suture portion to provide a continuous length of suture extending through the first and second locations.

92. The method of Claim 77, wherein the two leaflets are drawn together by applying a knot to the suture portions.

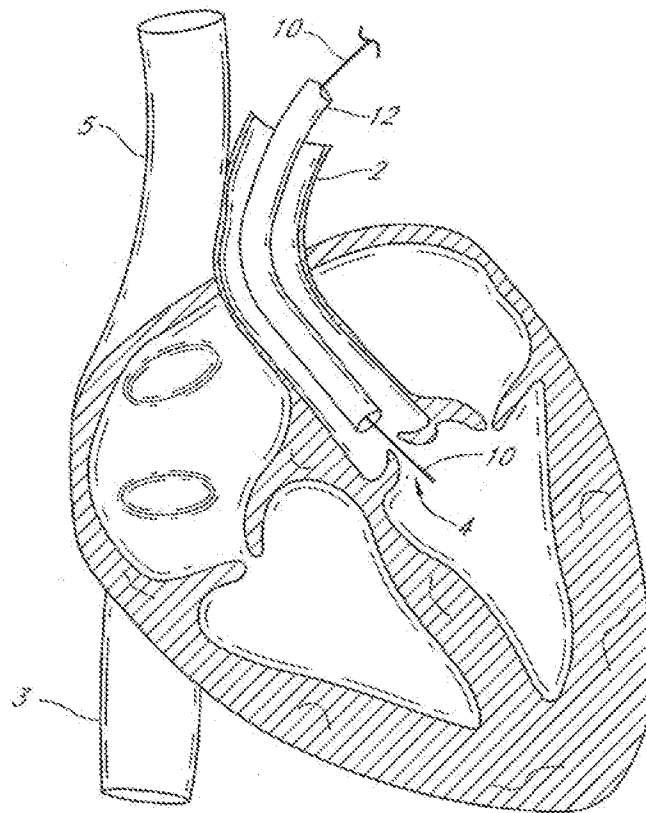


FIG. 1

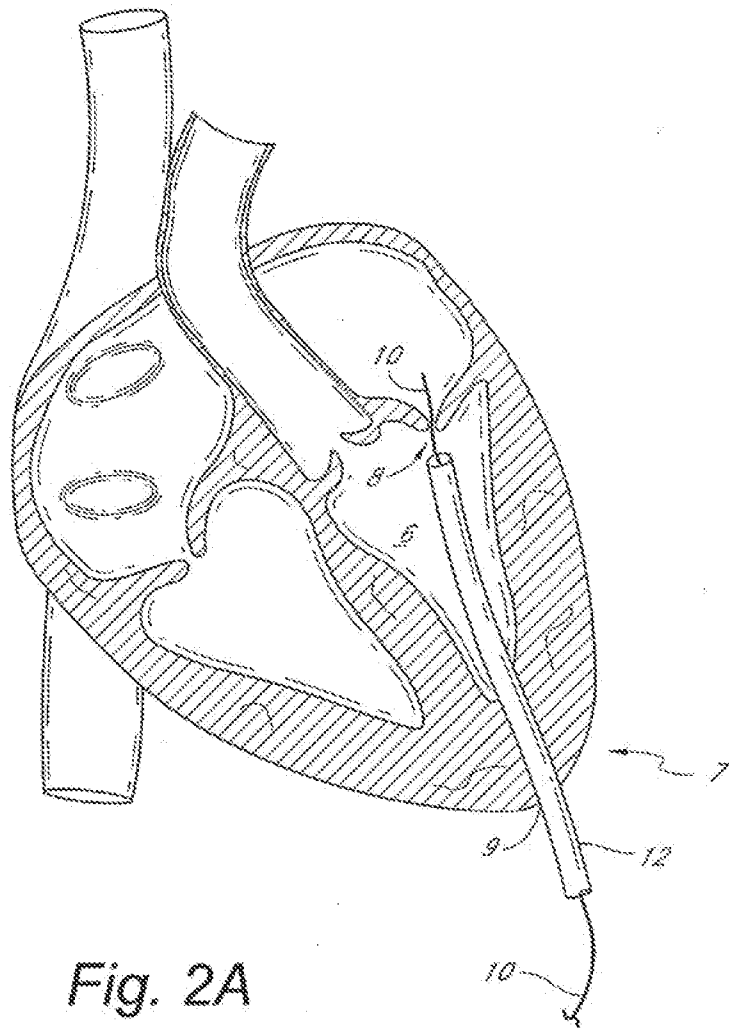


Fig. 2A

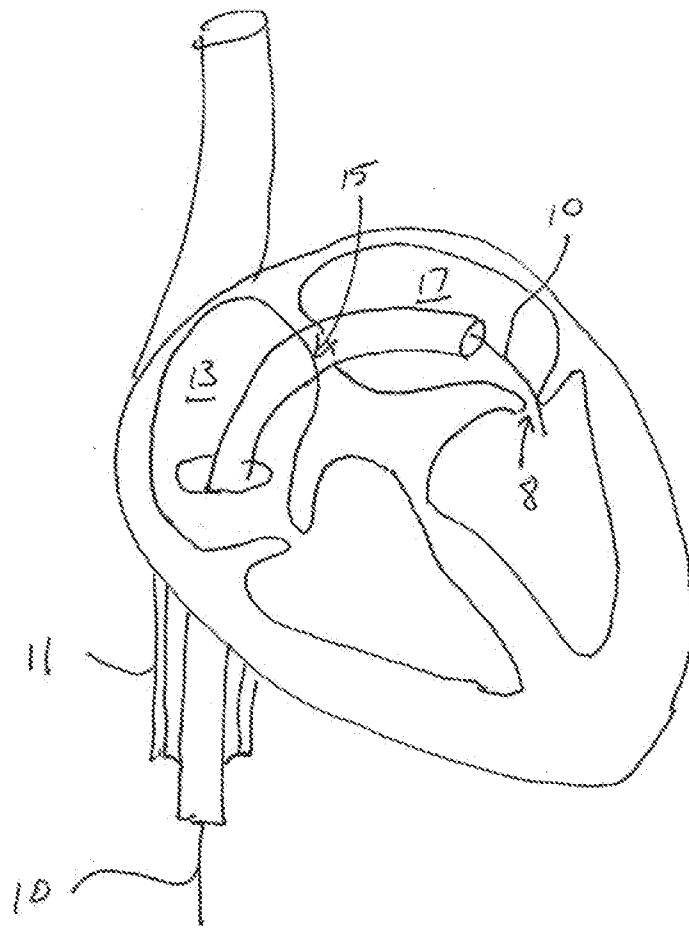
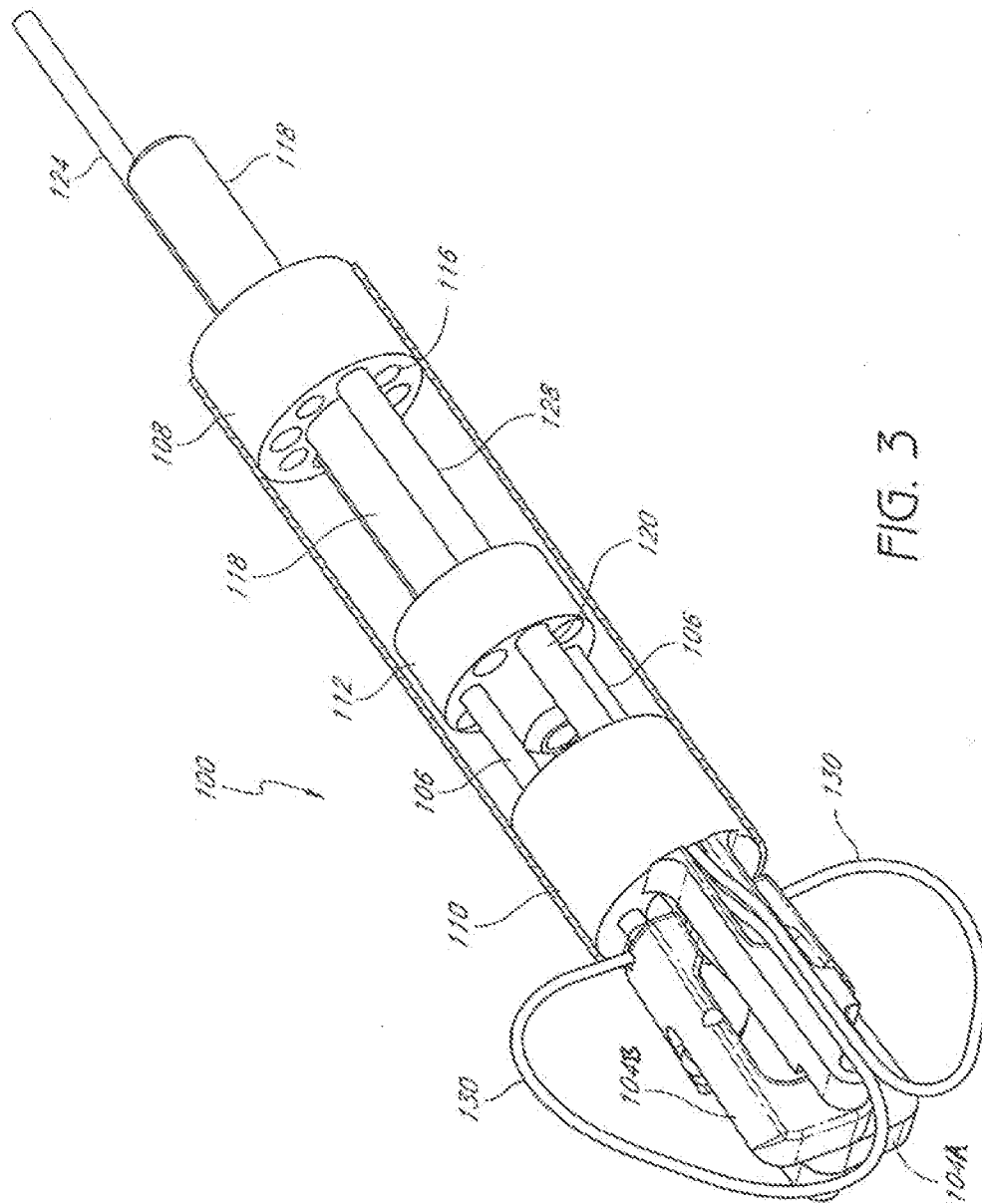


Fig 2B



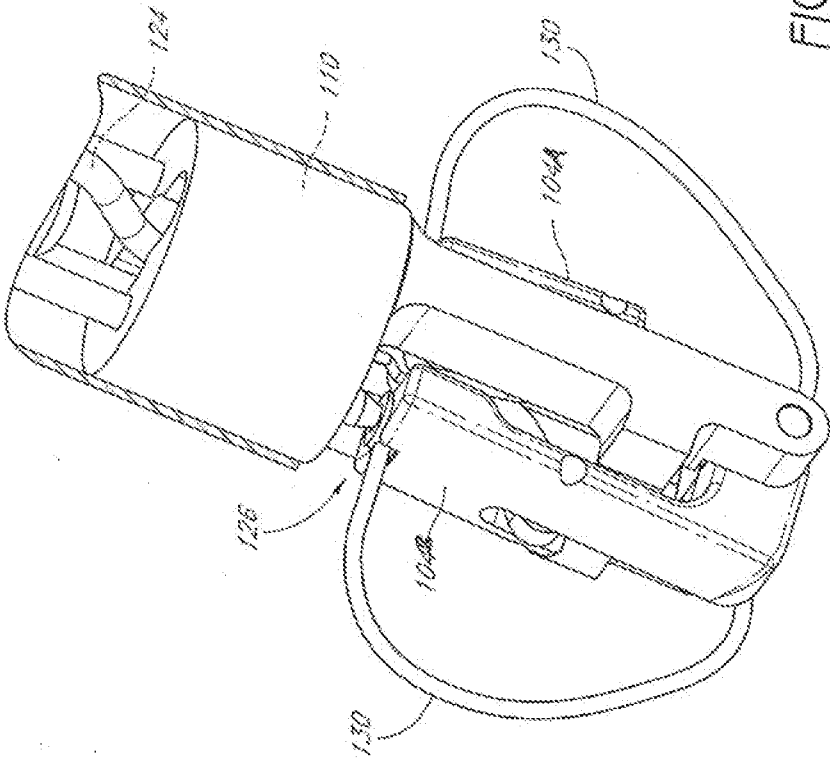


FIG. 4

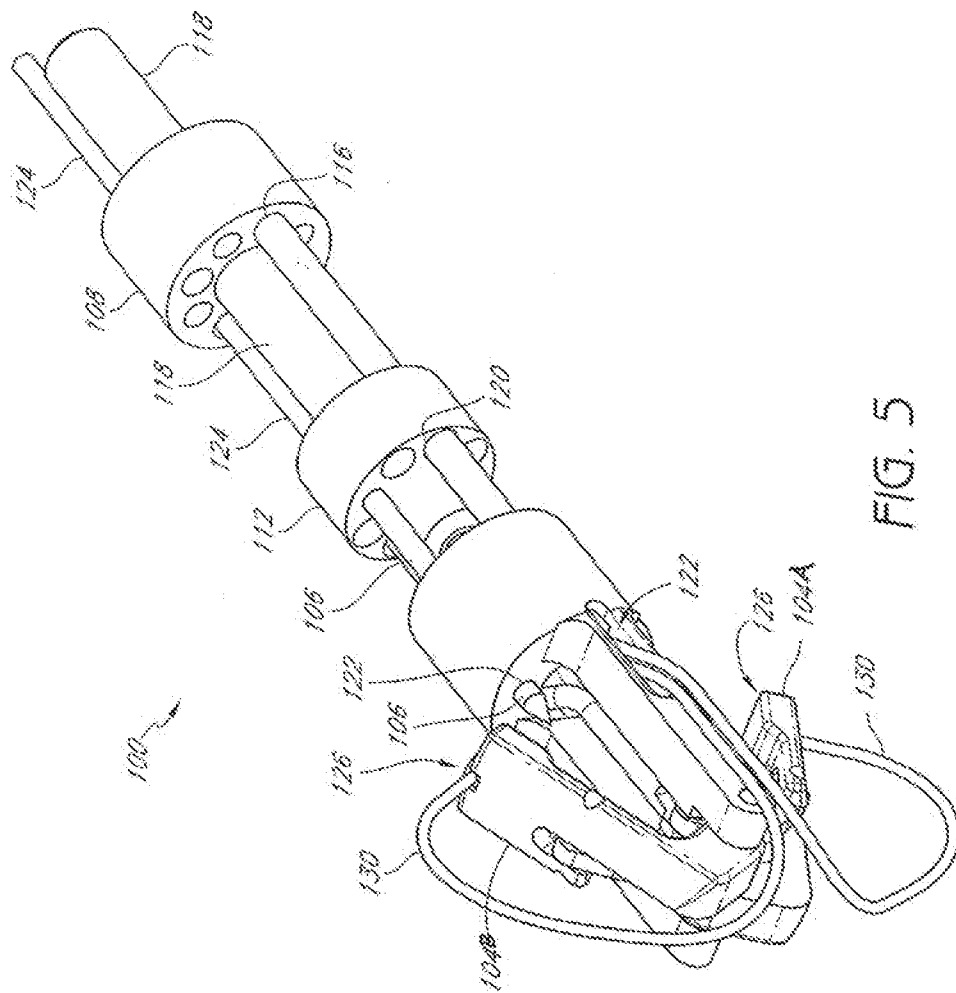
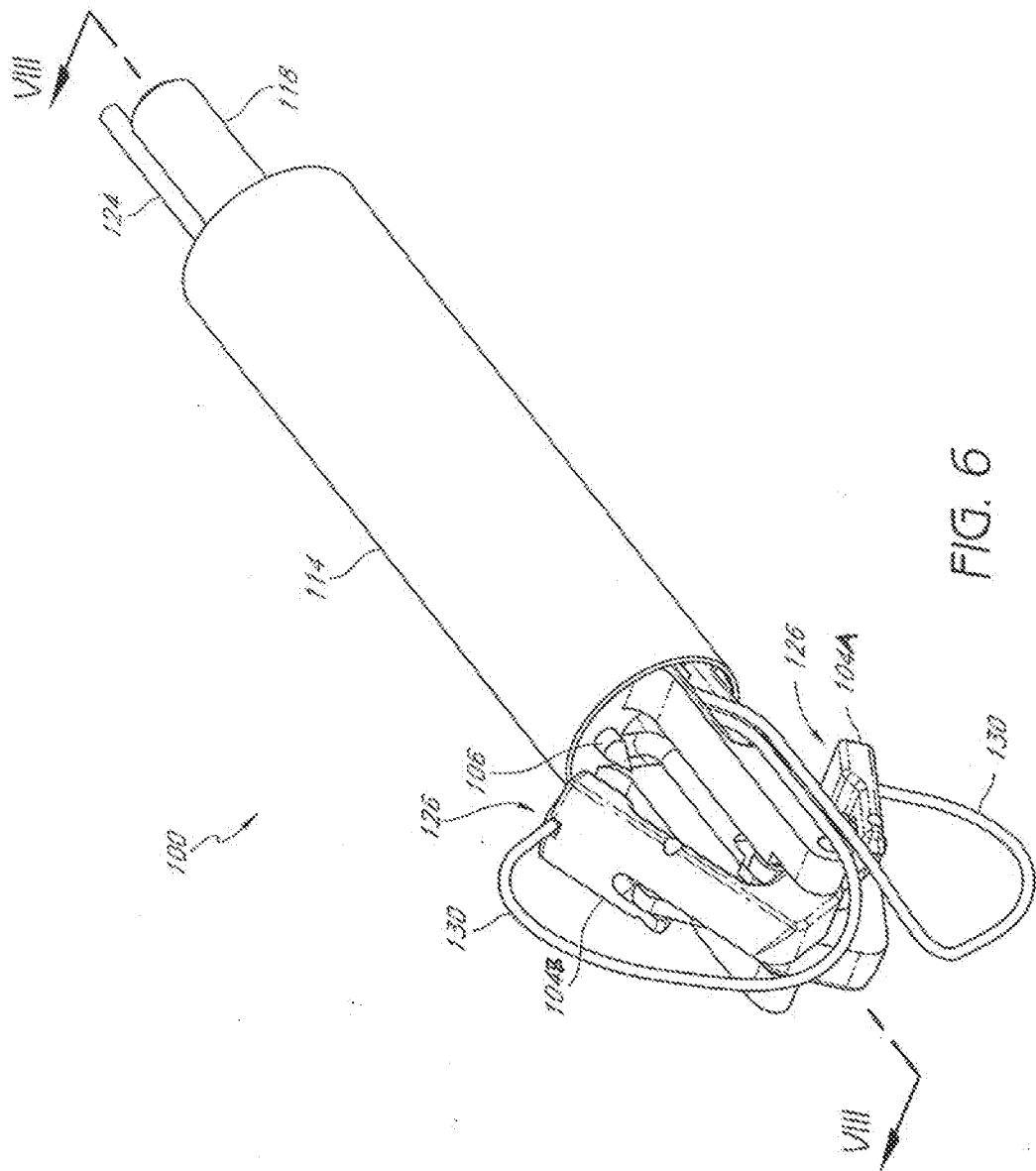


FIG. 5



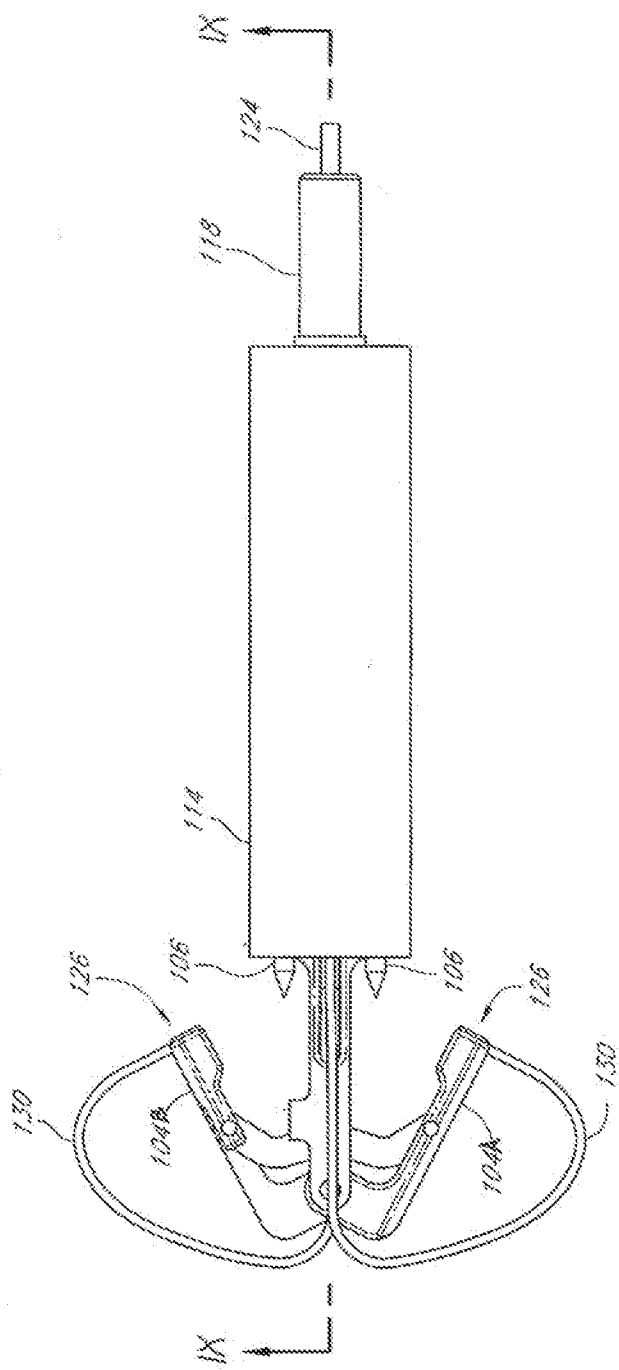


FIG. 7A

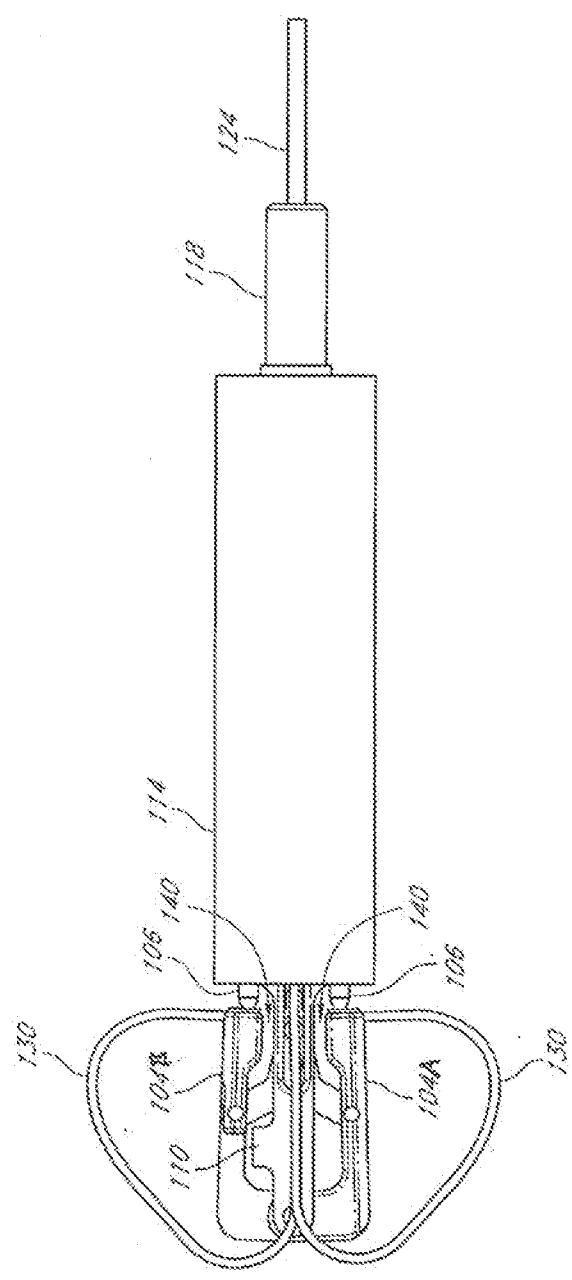


FIG. 7B

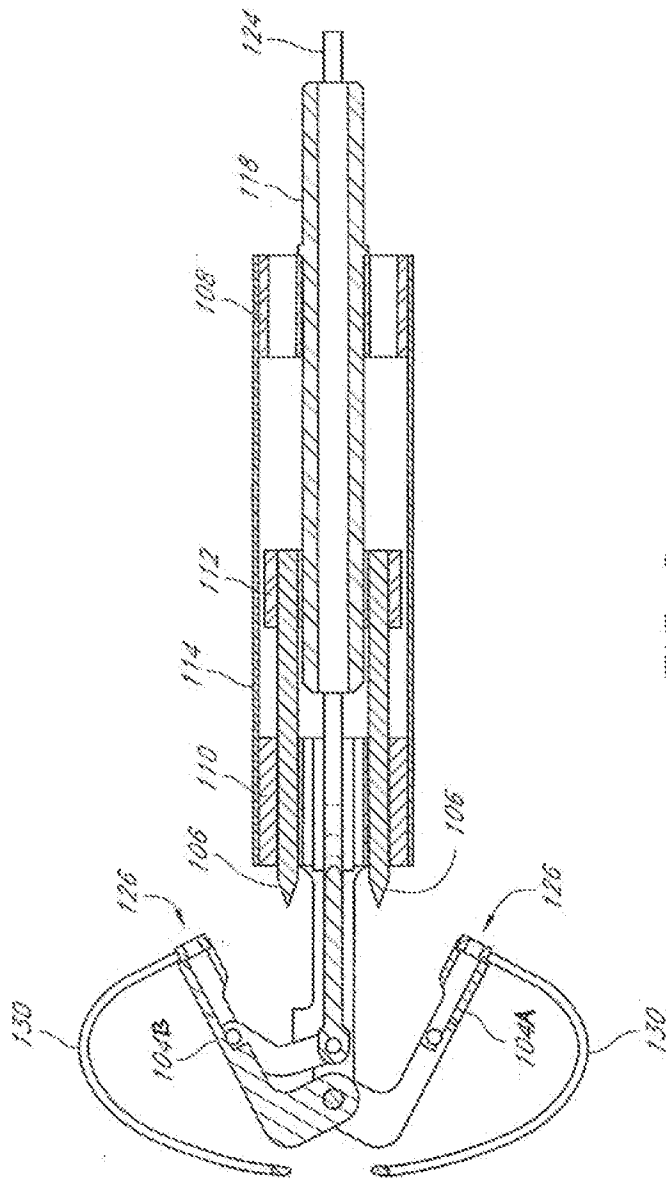


FIG. 8

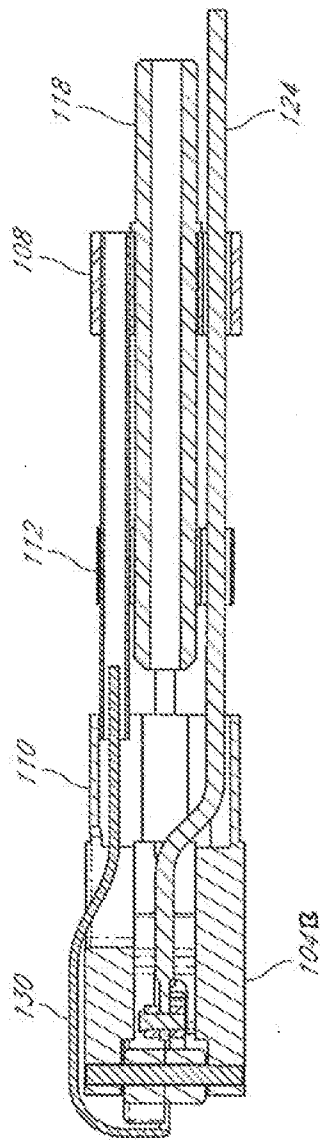


FIG. 9

12/93

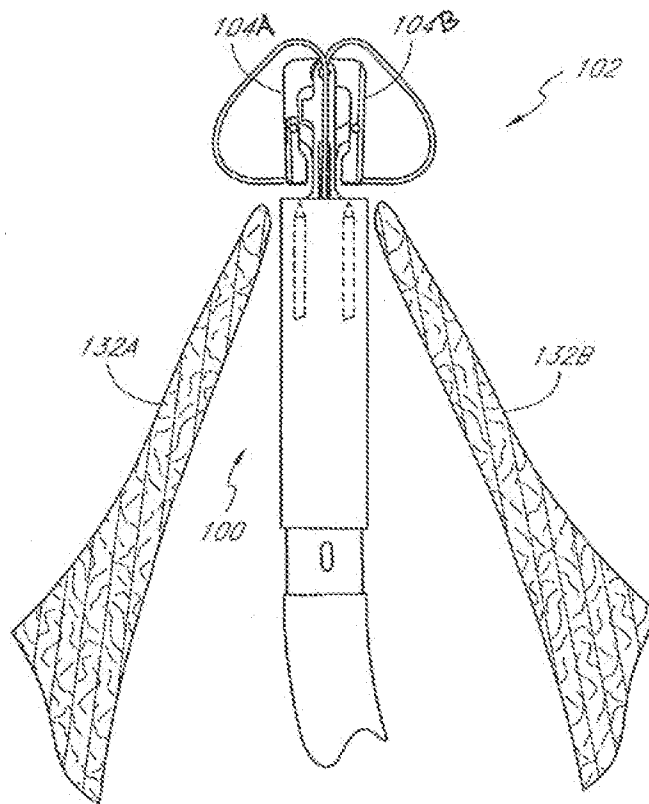


FIG. 10

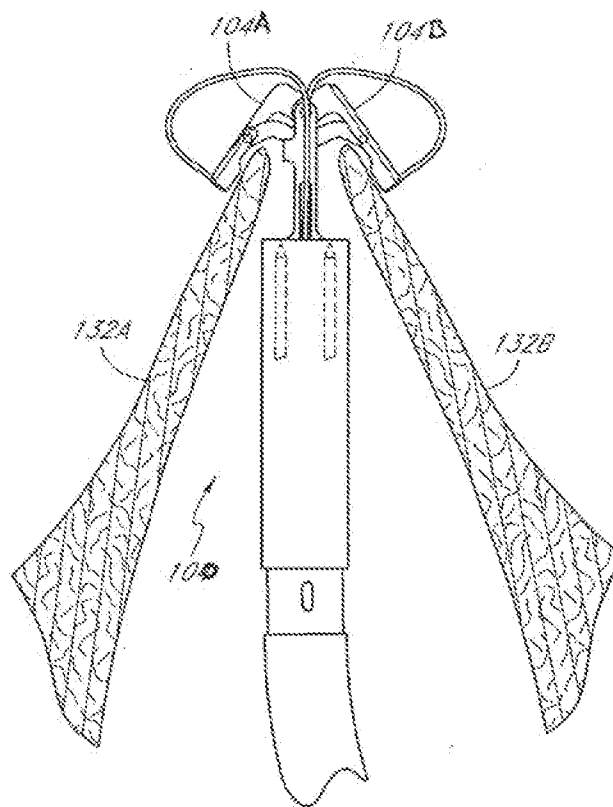


FIG. 11

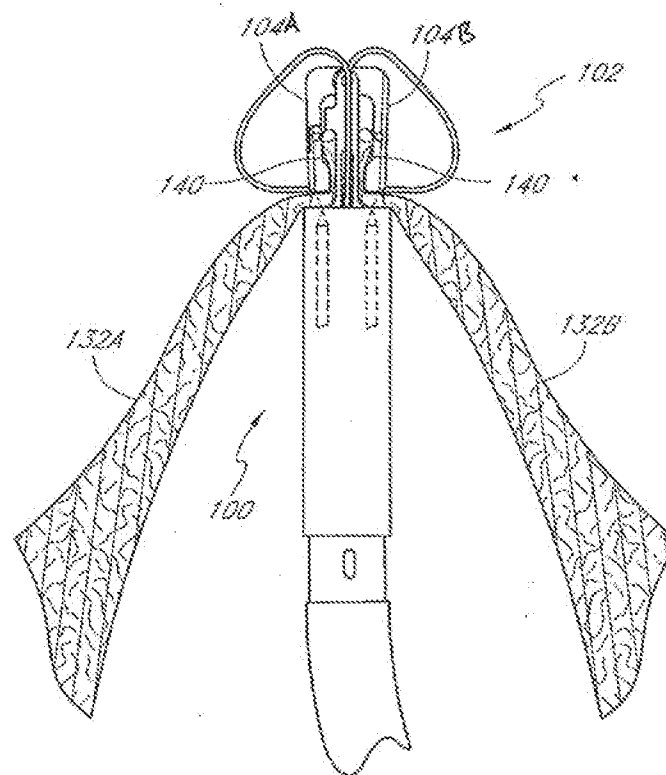


FIG. 12

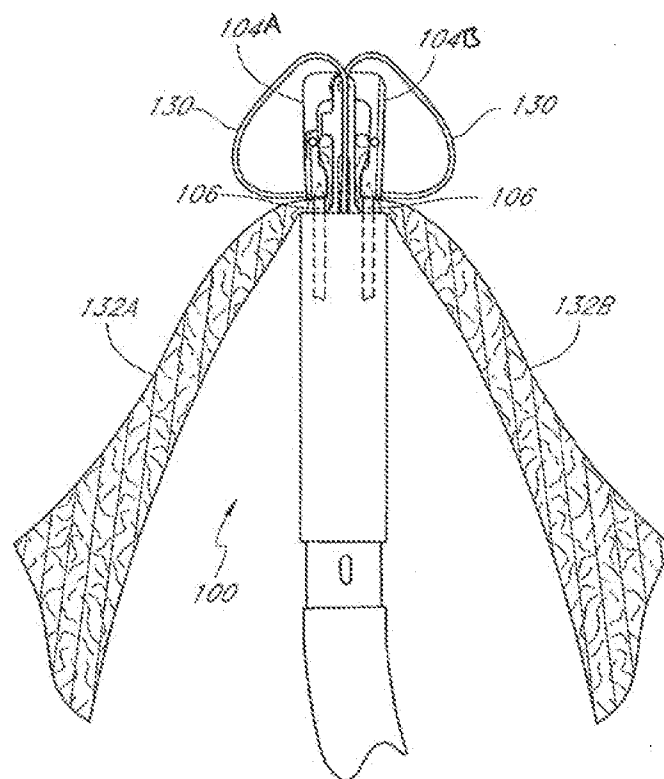


FIG. 13

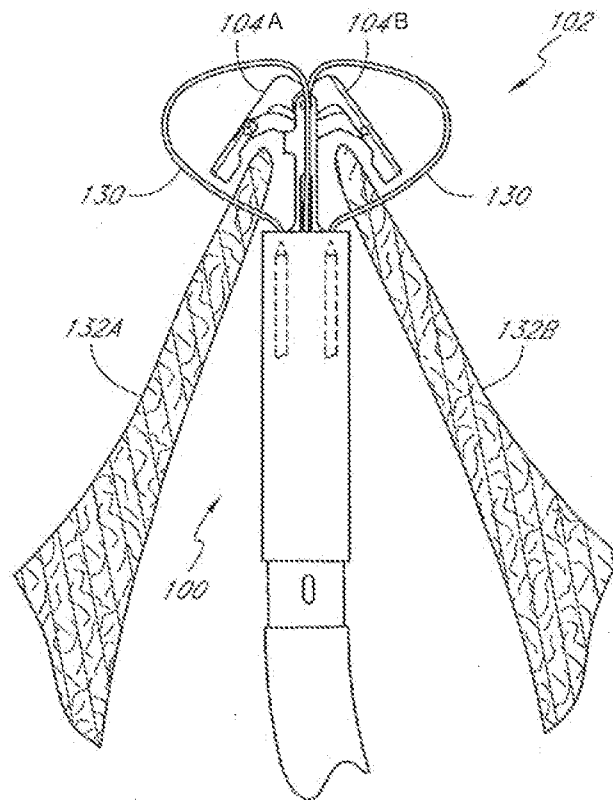


FIG. 14

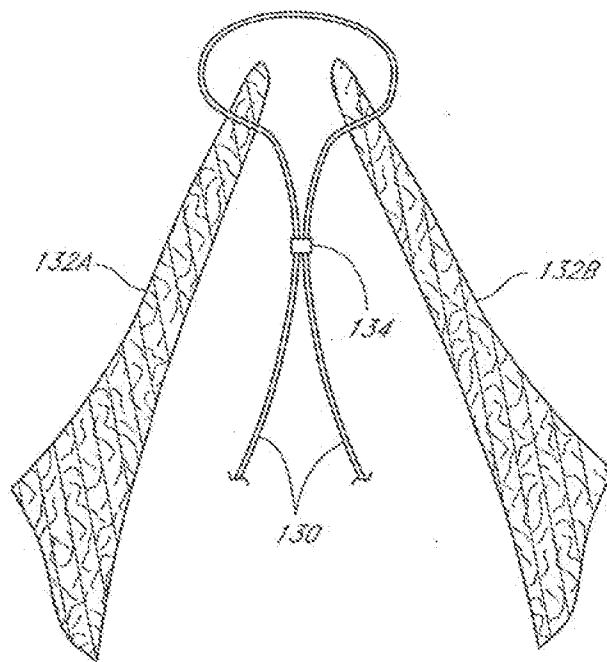


FIG. 15

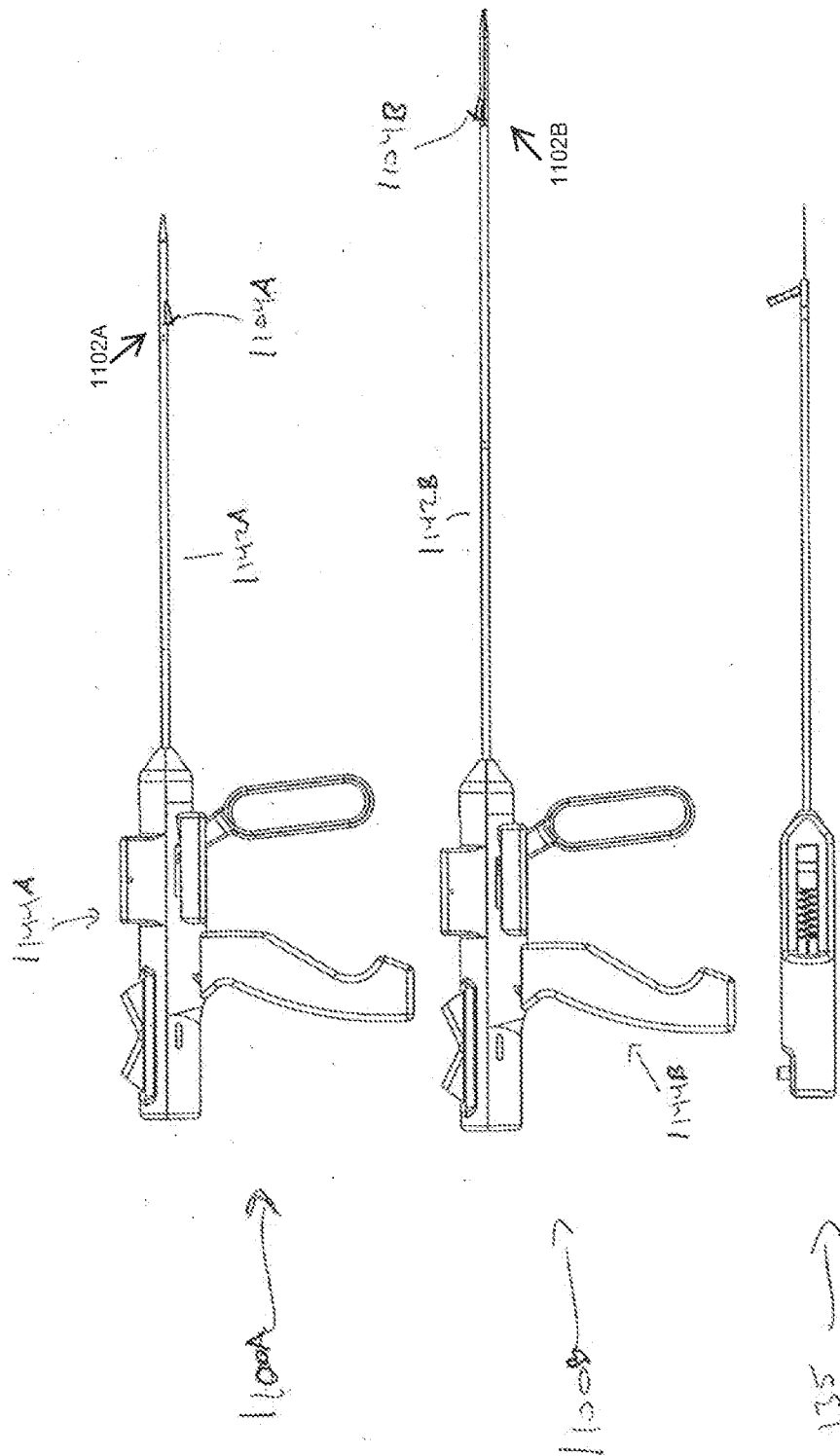


Figure 16

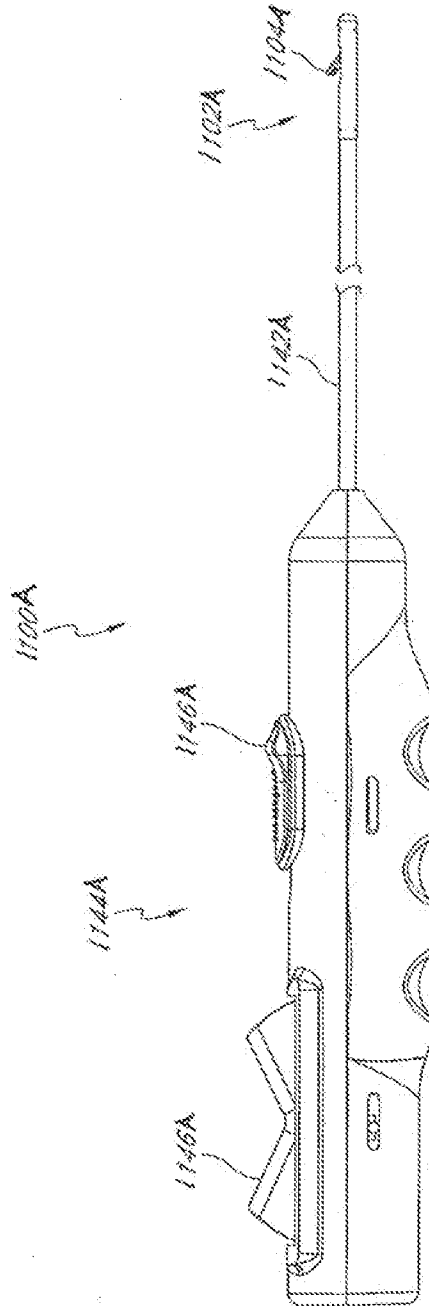


FIG. 17

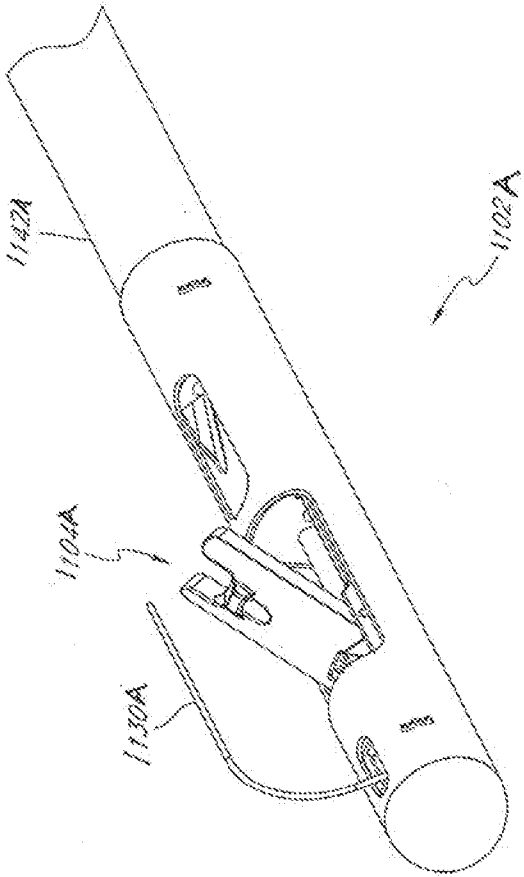


FIG. 18

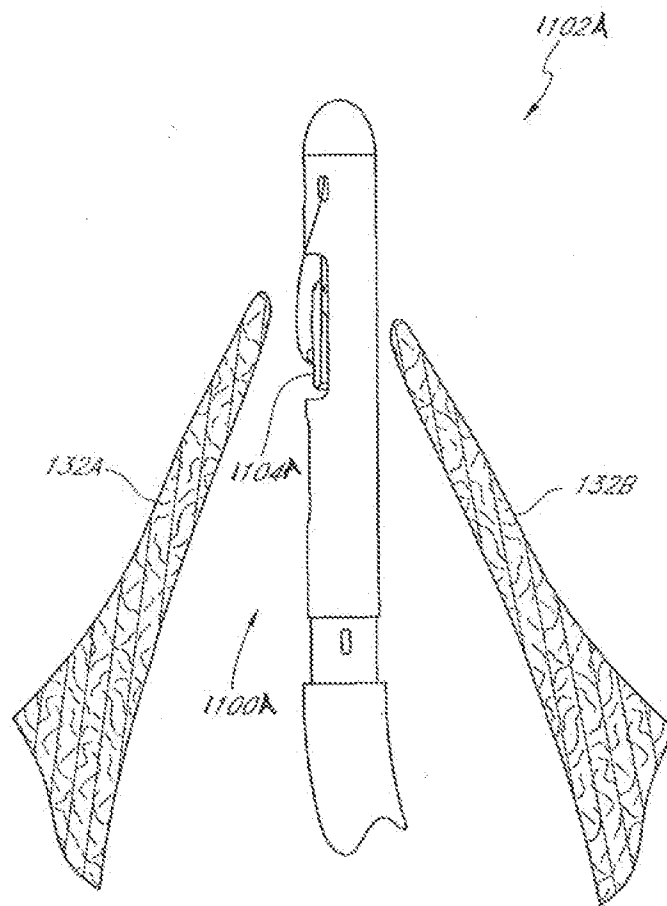


FIG. 19

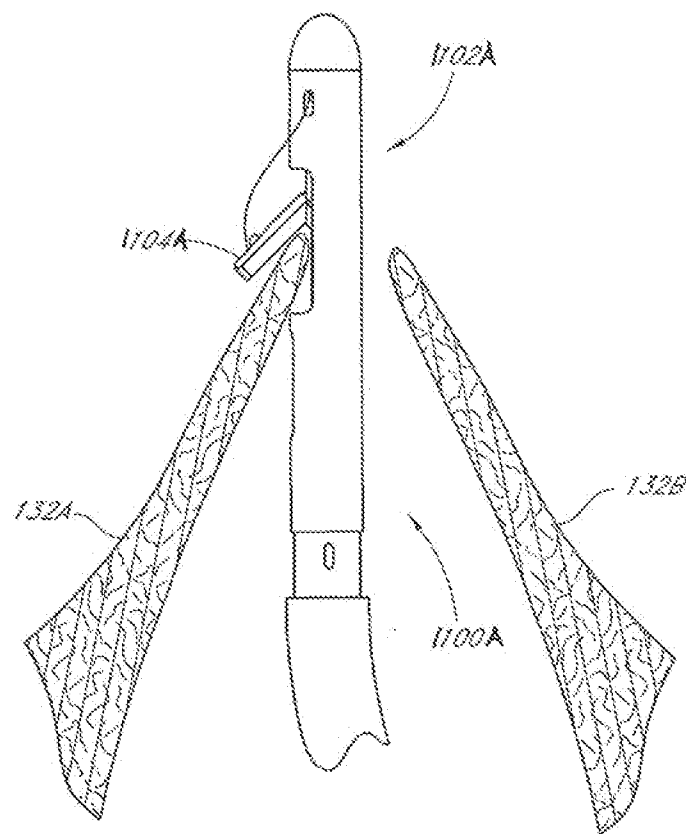


FIG. 20

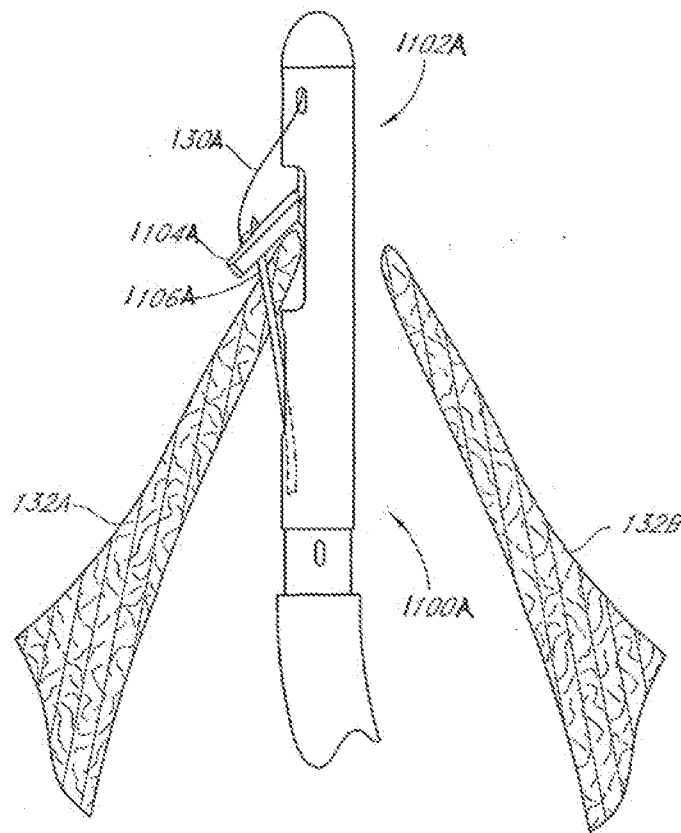


FIG. 21

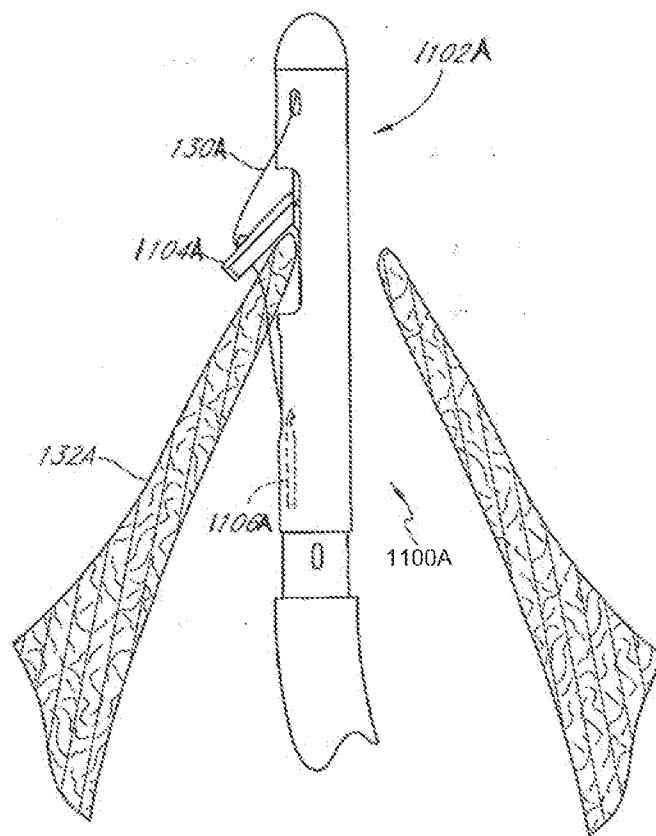


FIG. 22

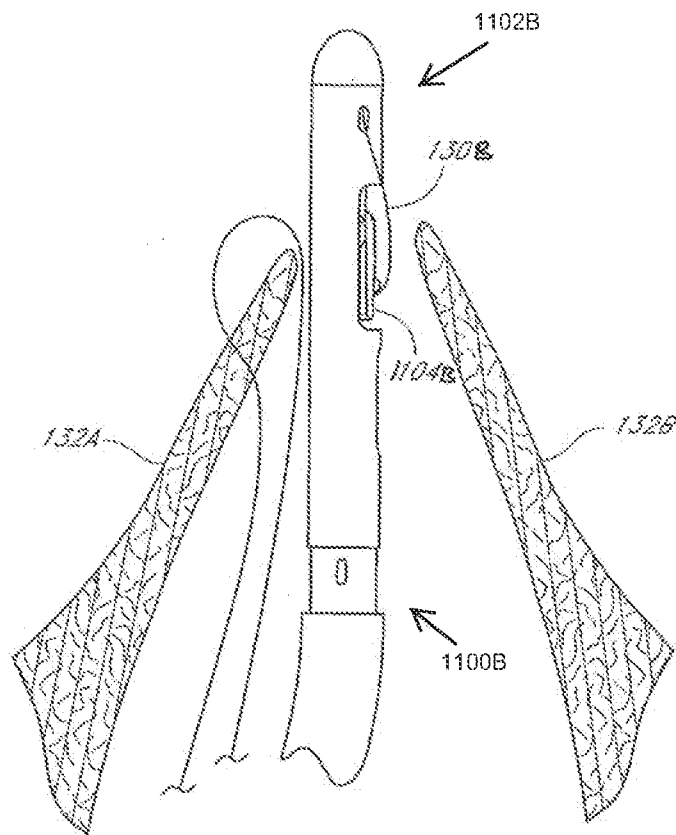


FIG. 23

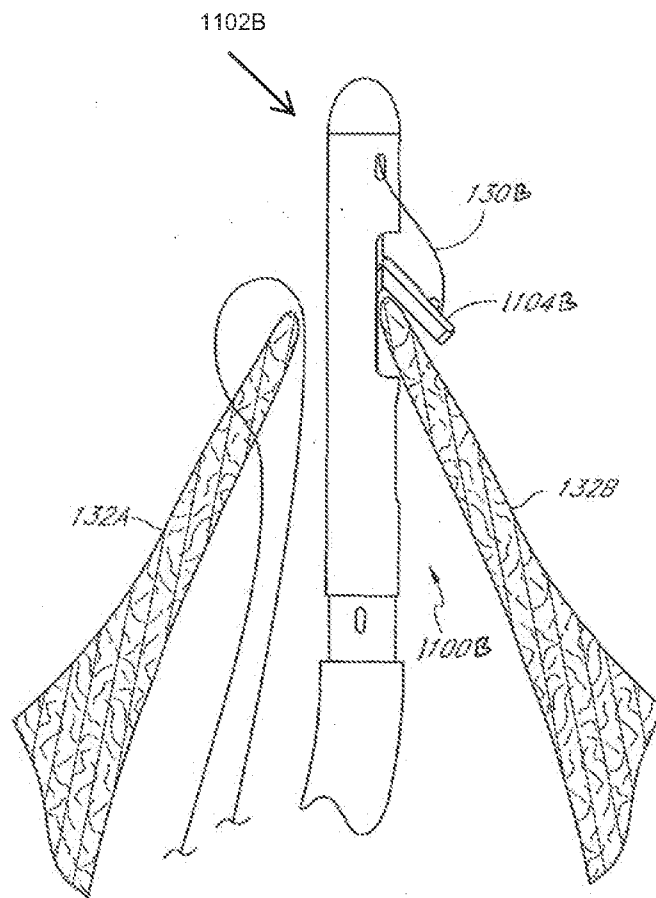


FIG. 24

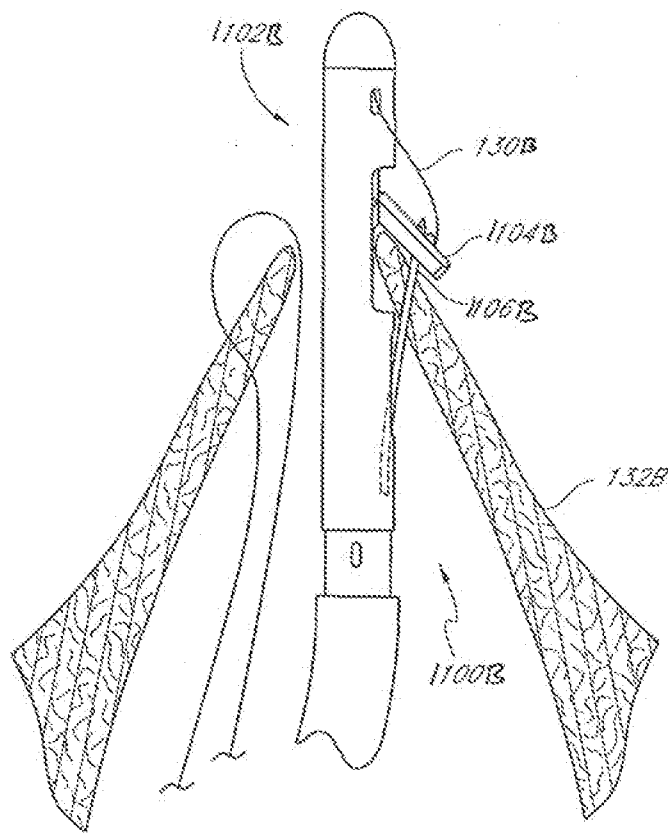


FIG. 25

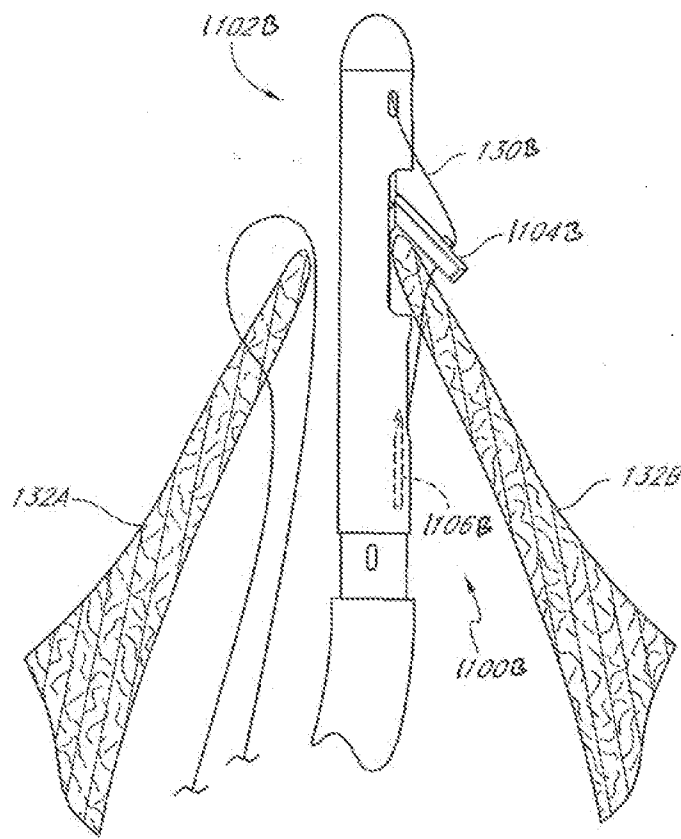


FIG. 26

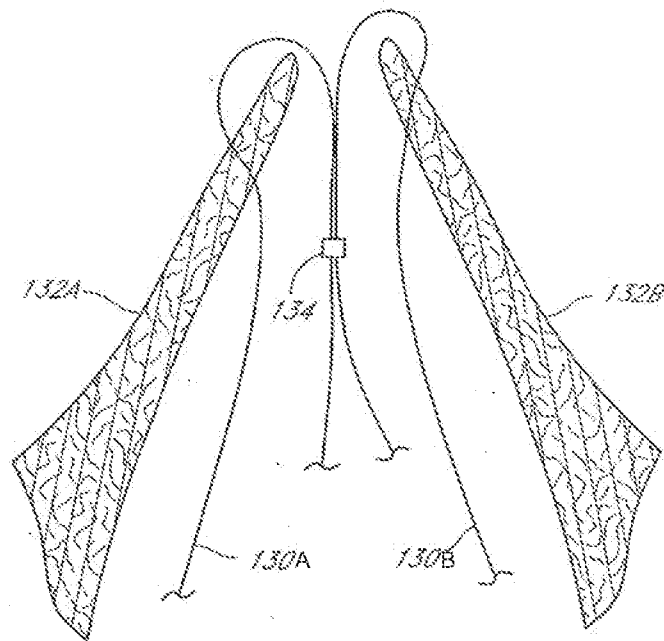


FIG. 27

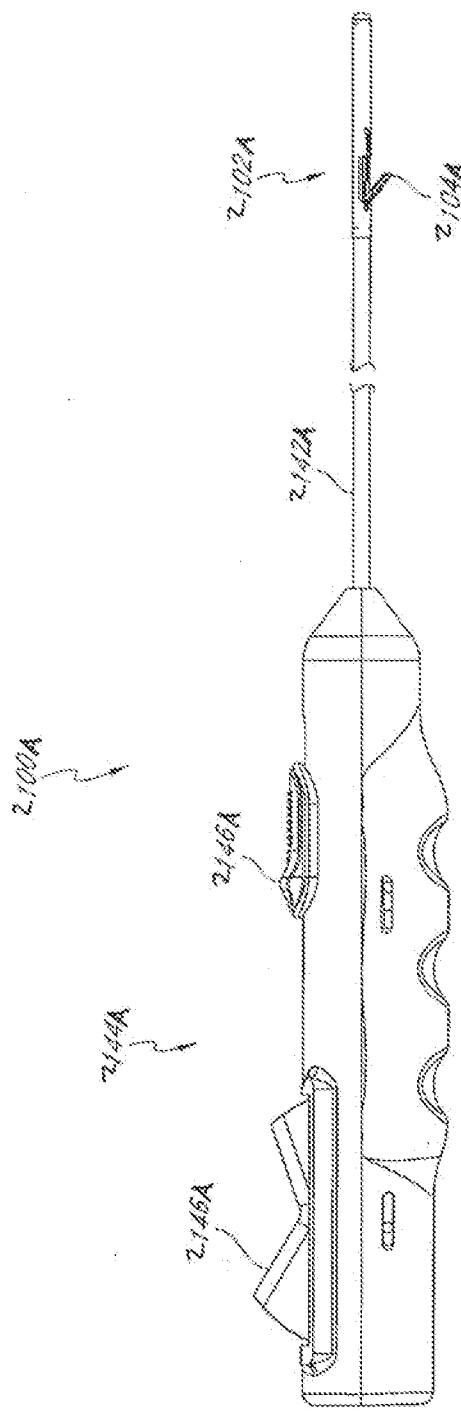


FIG. 28

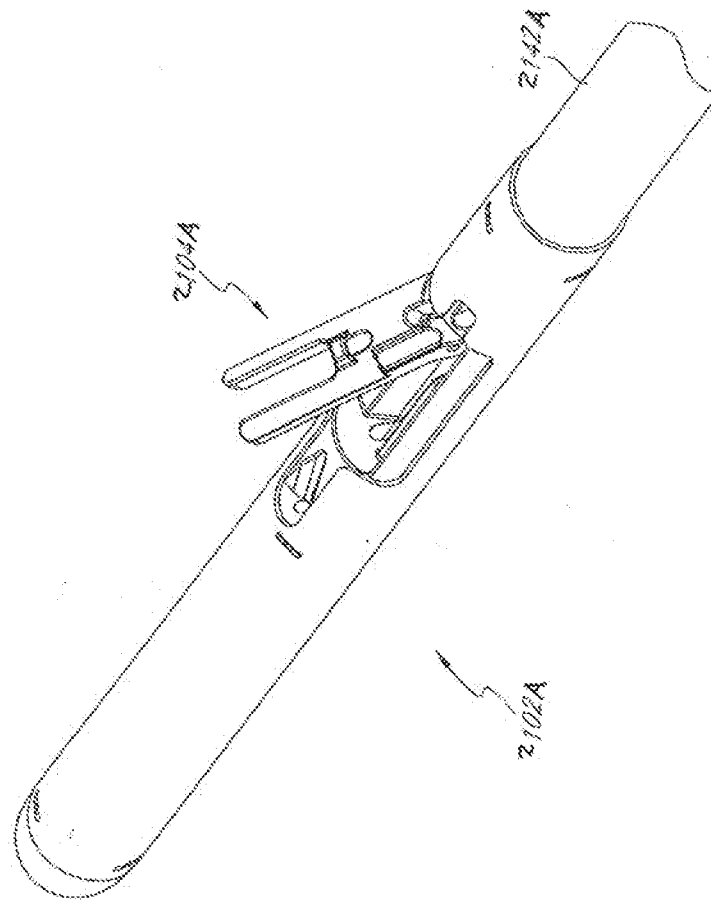


FIG. 29

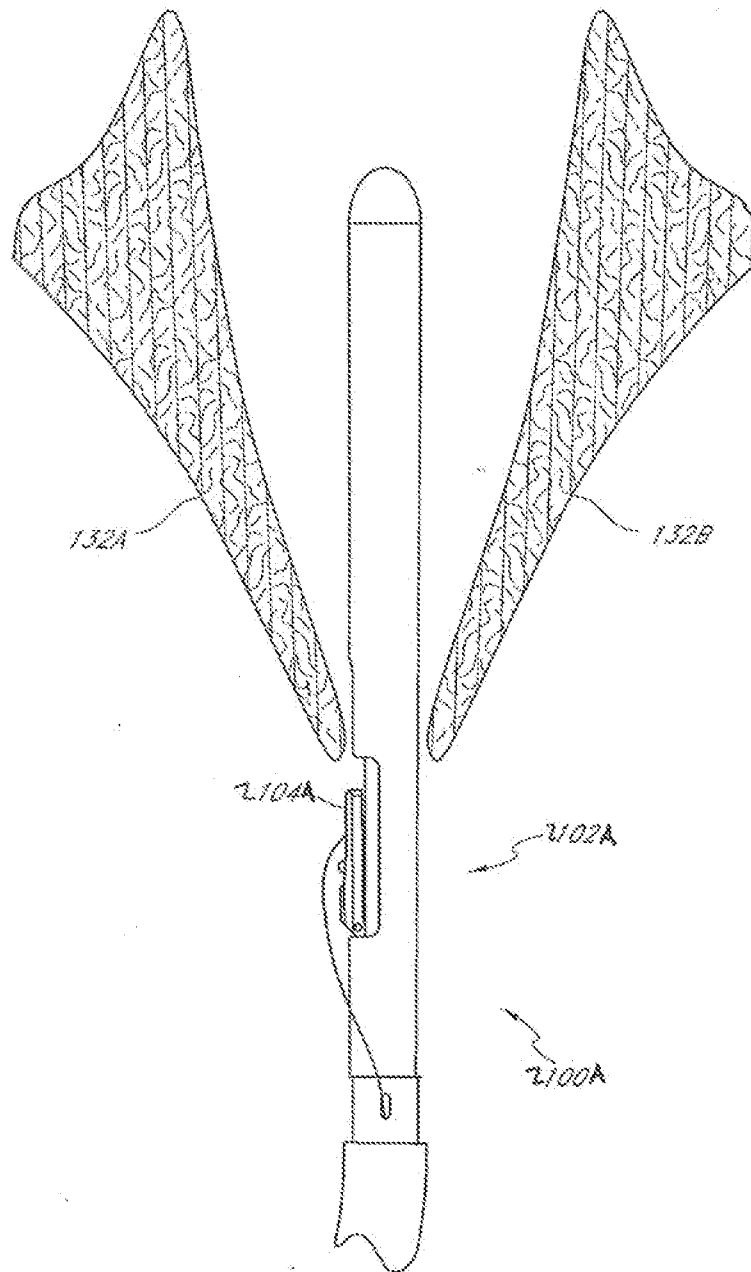


FIG. 30

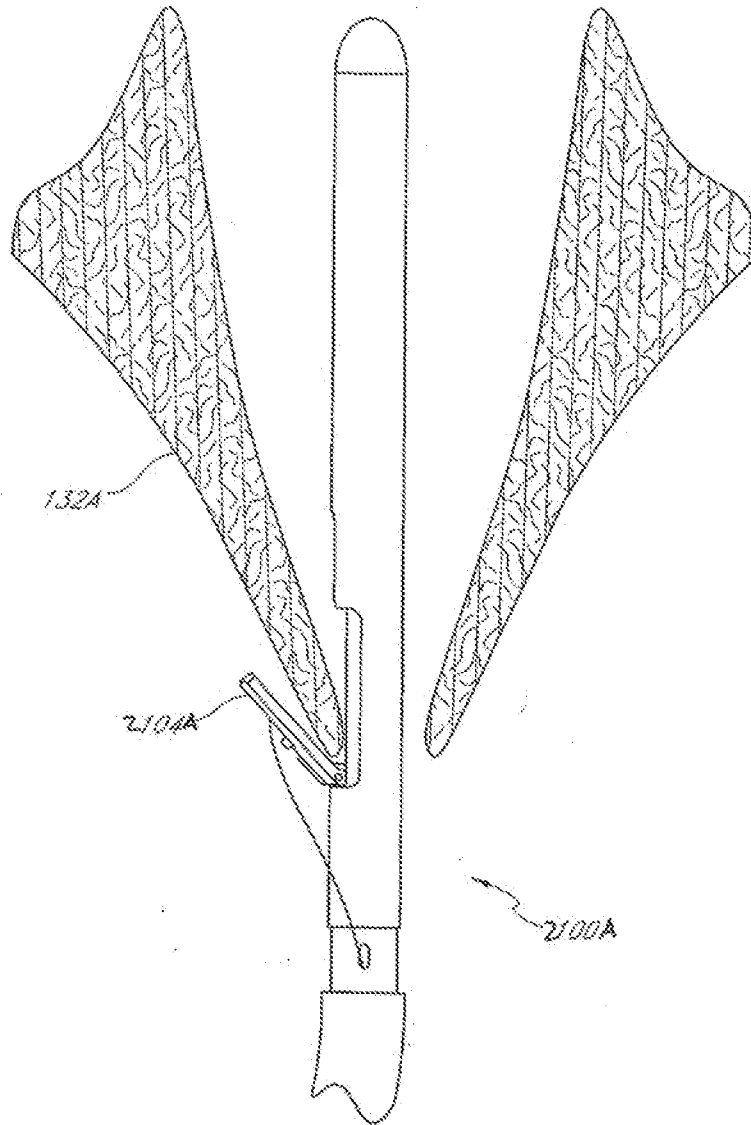


FIG. 31

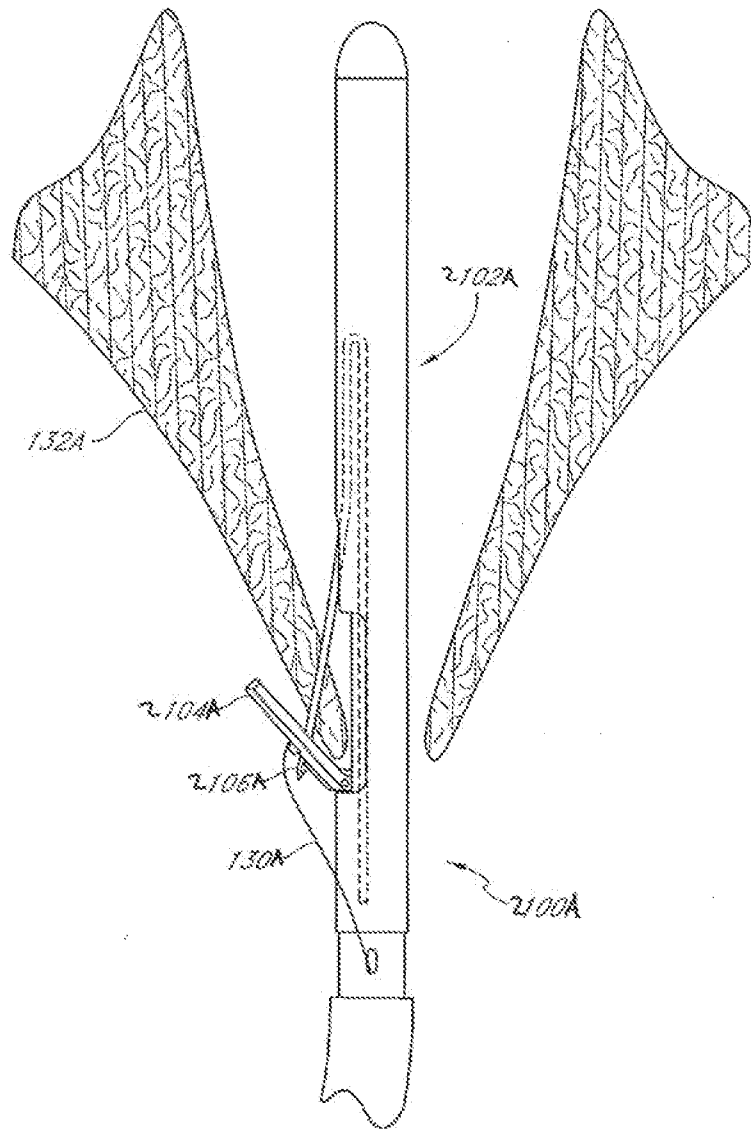


FIG. 32

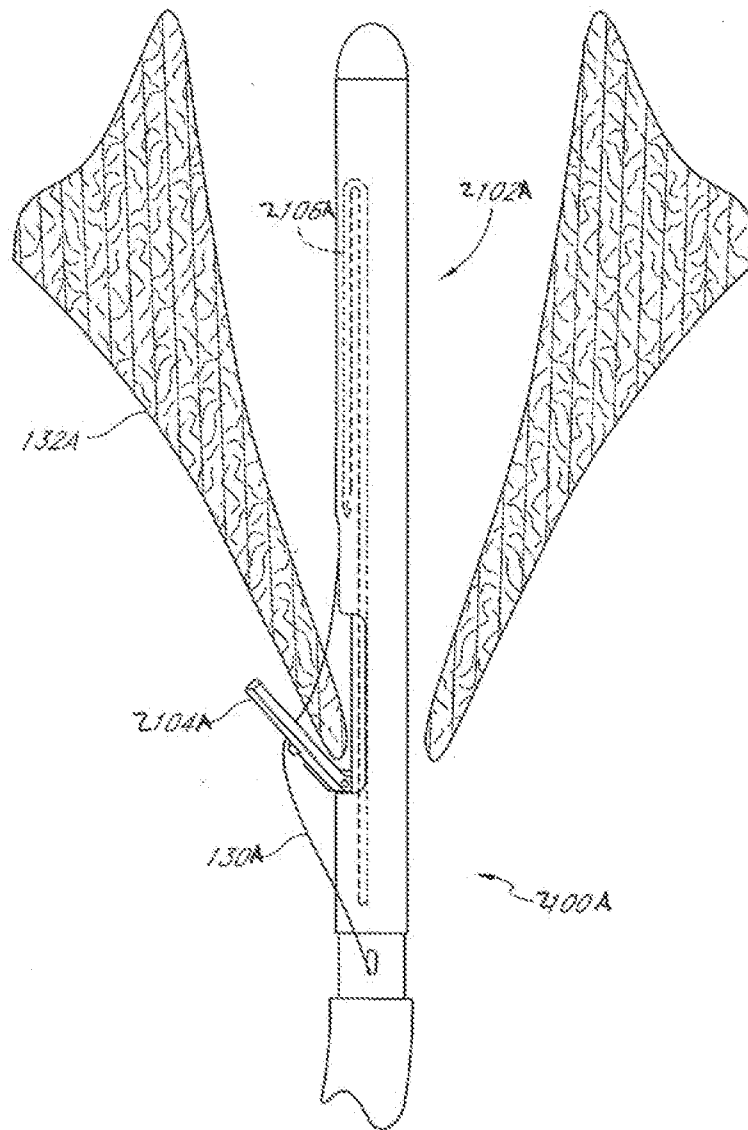


FIG. 33

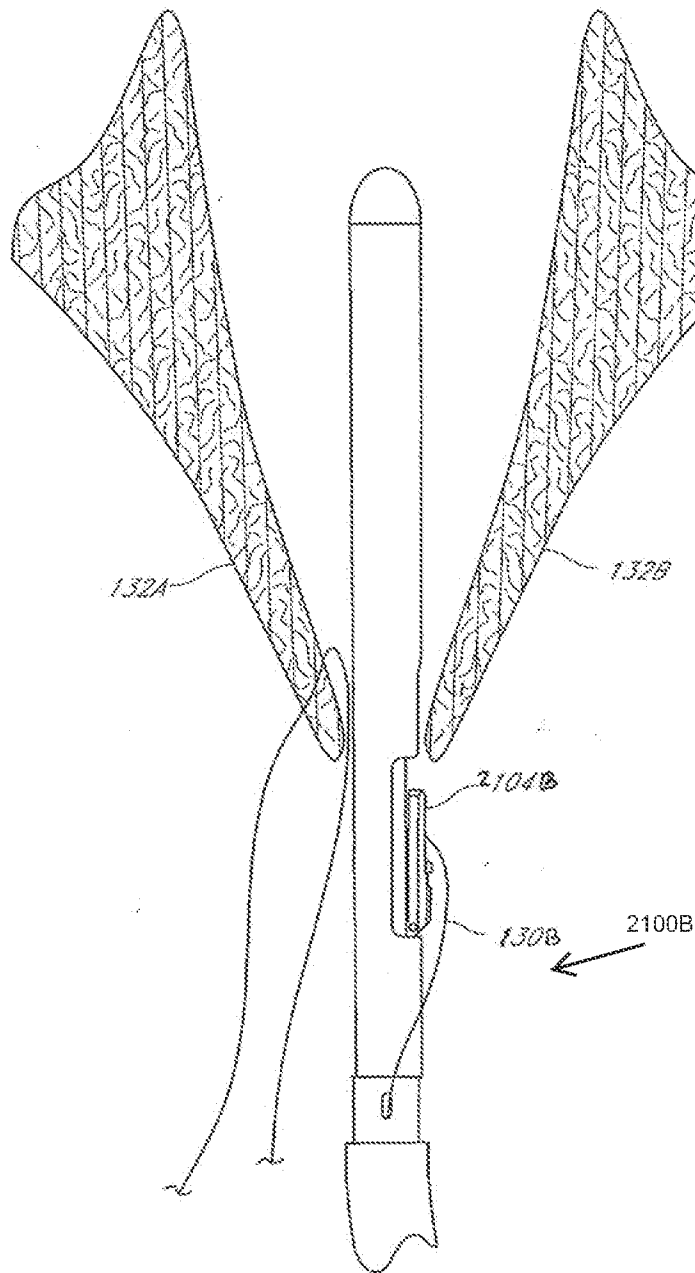


FIG. 34

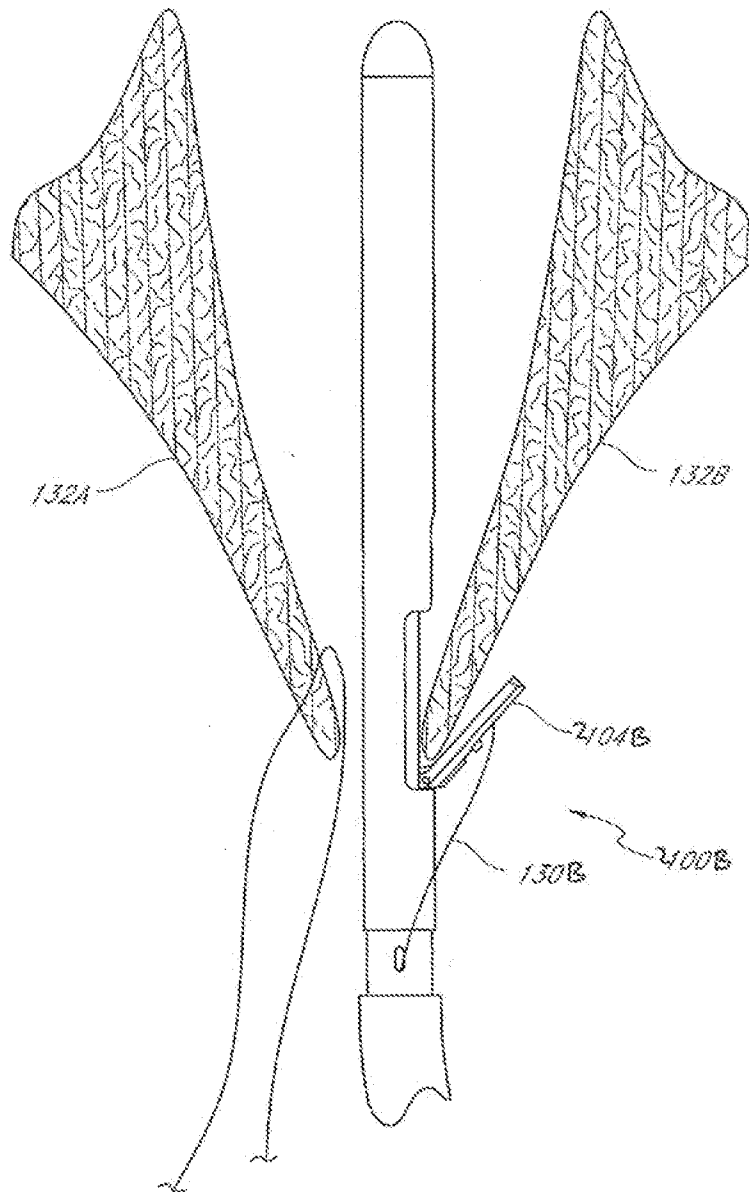


FIG. 35

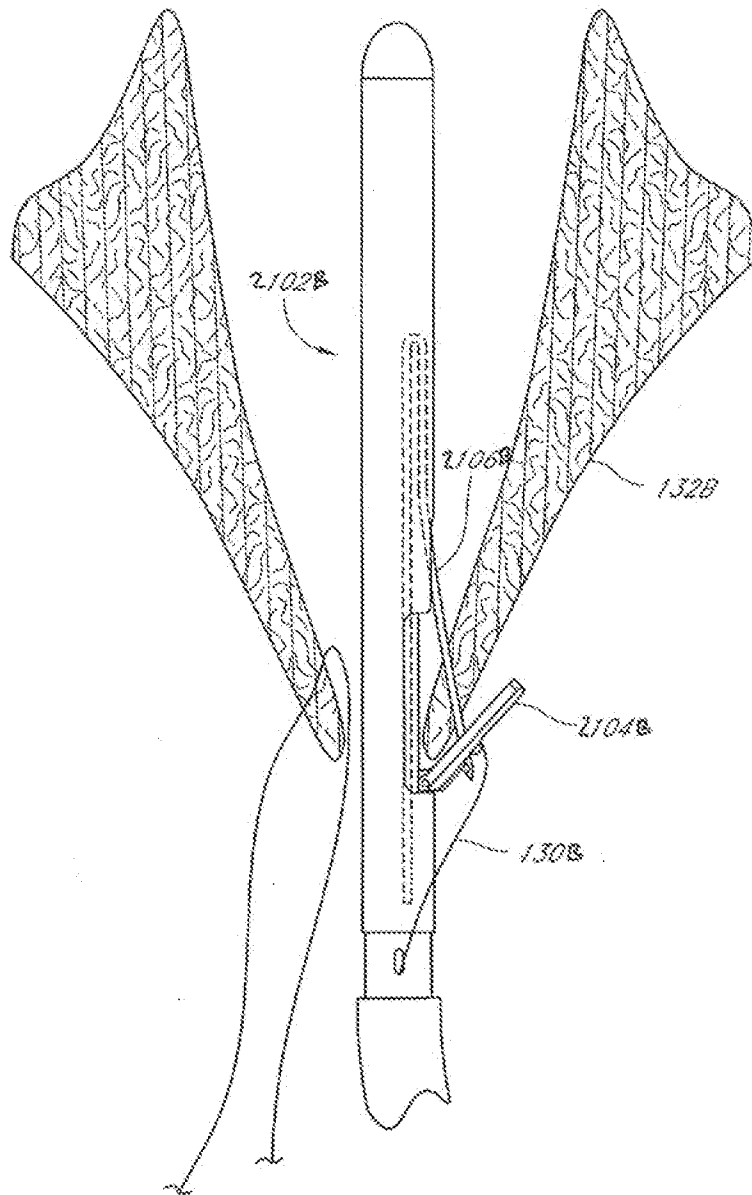


FIG. 36

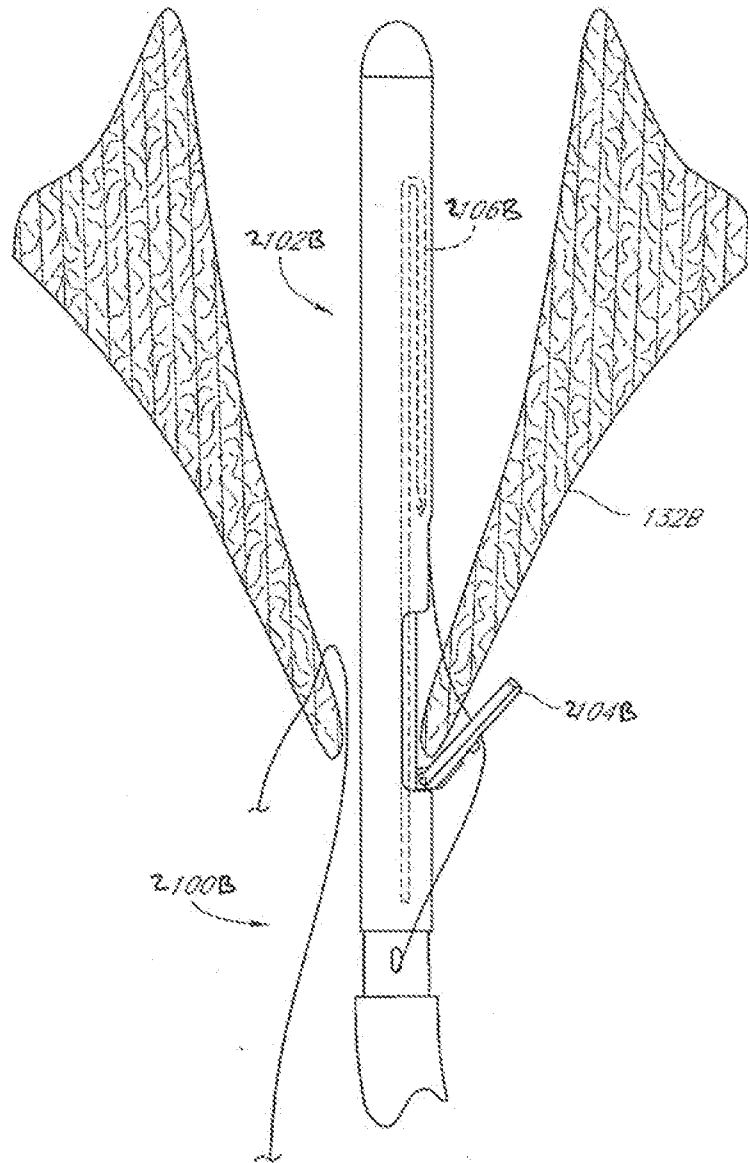


FIG. 37

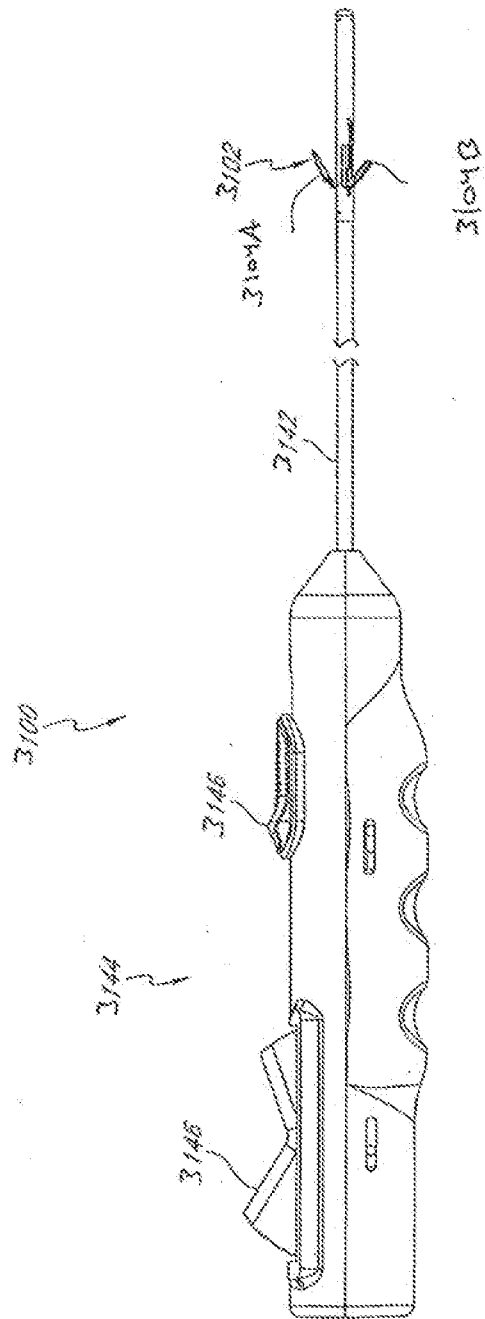


FIG. 38A

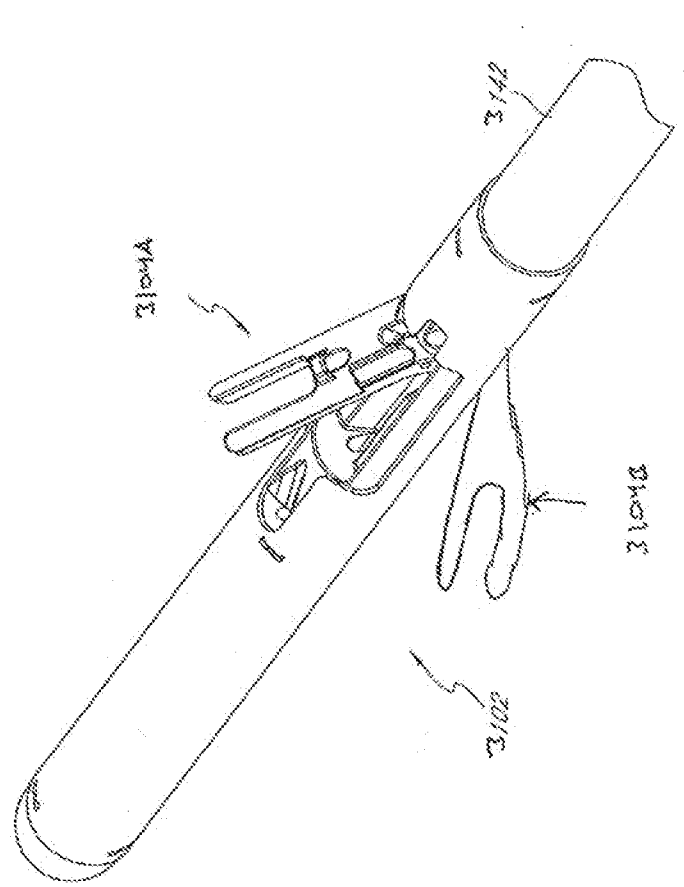


FIG. 38B

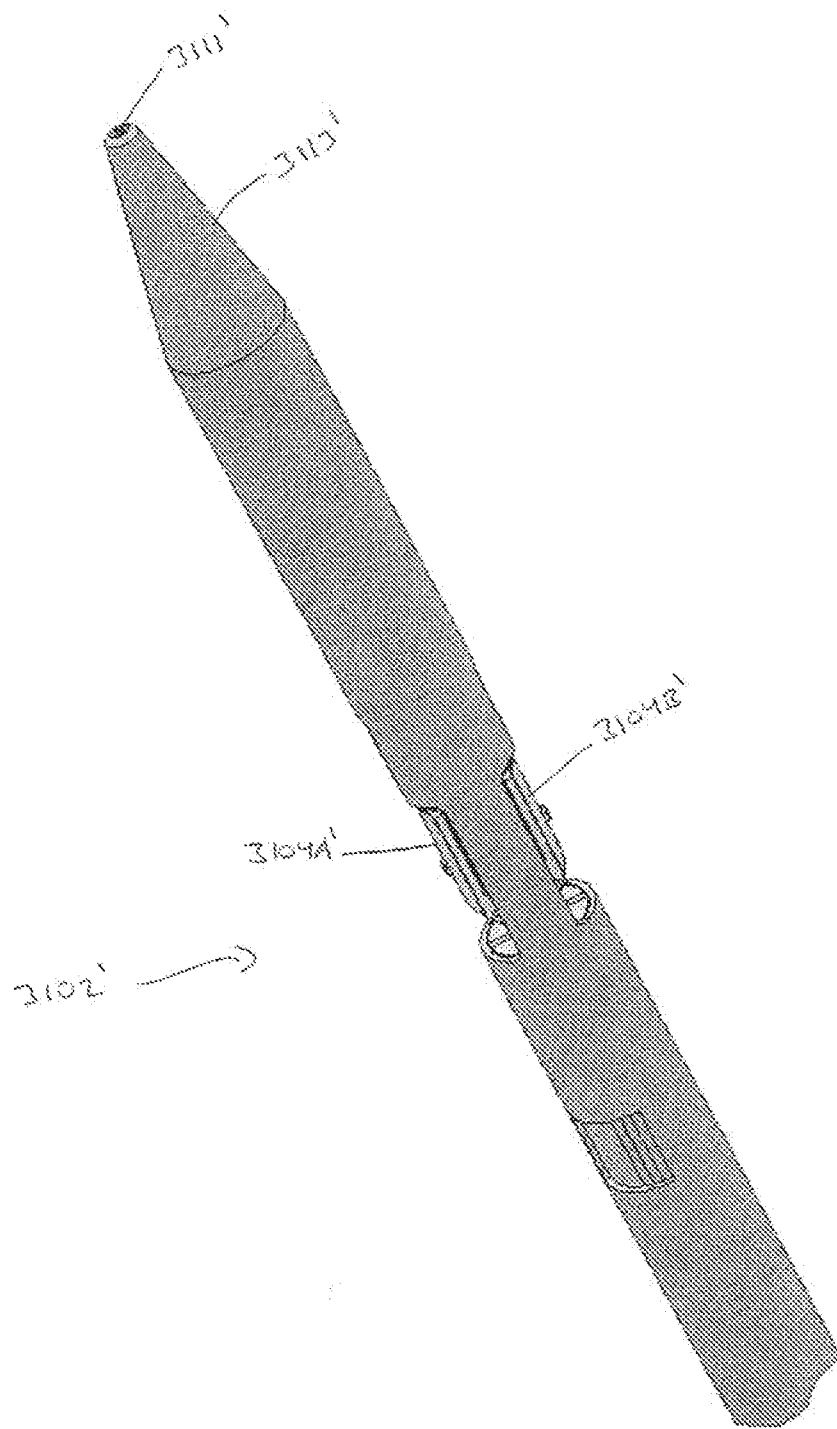


Fig. 39A

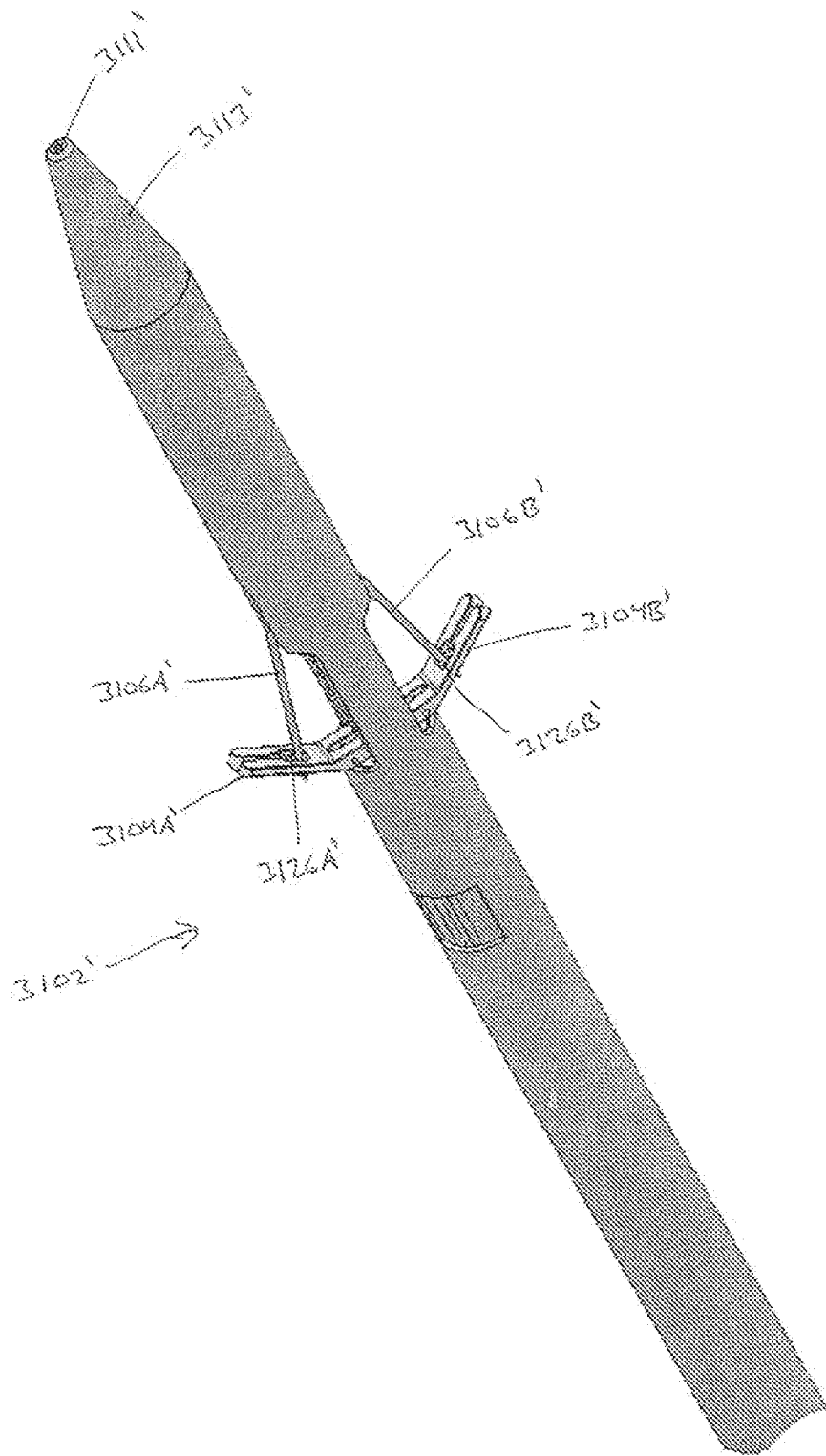


Fig. 31B

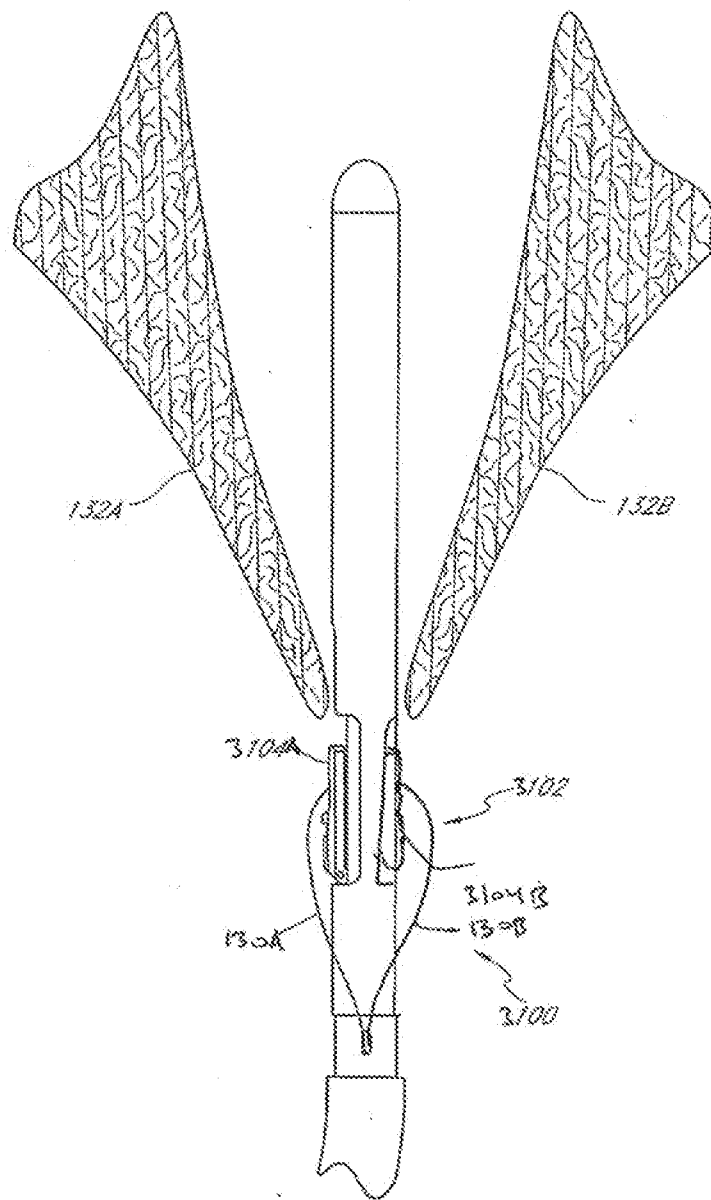


FIG. 40

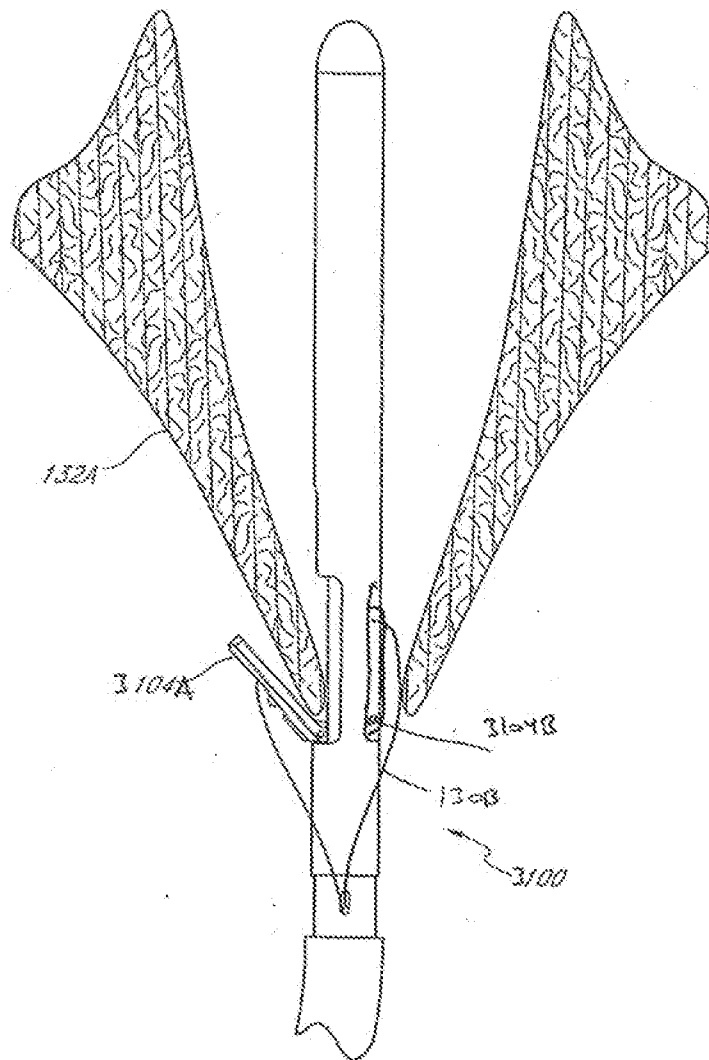


FIG. 41

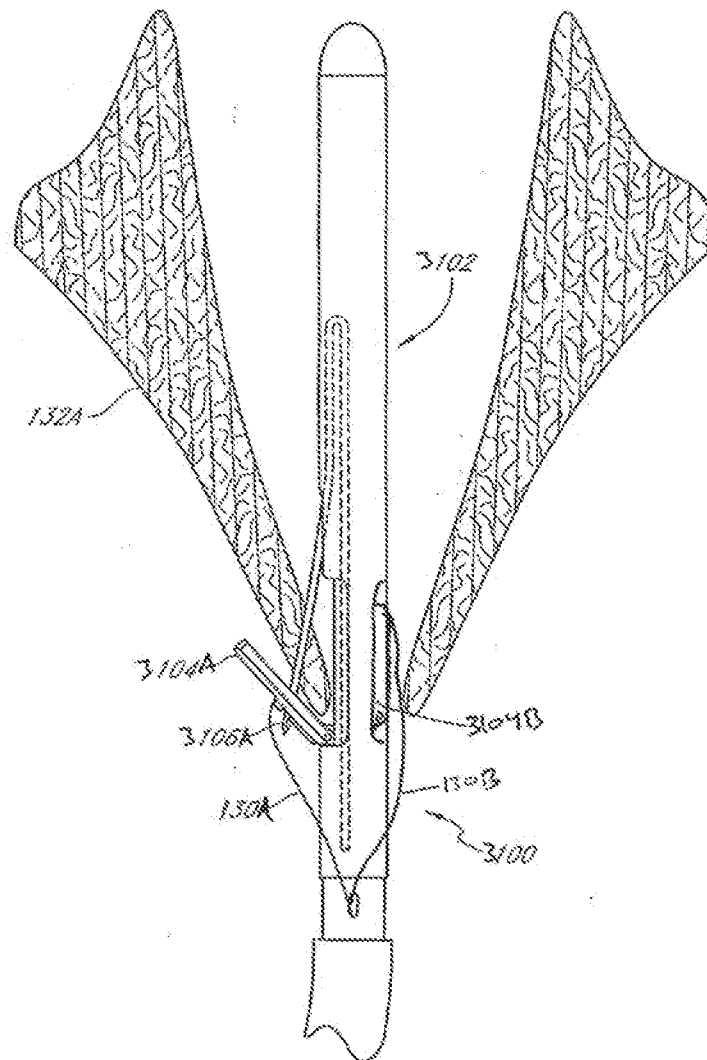


FIG. 42

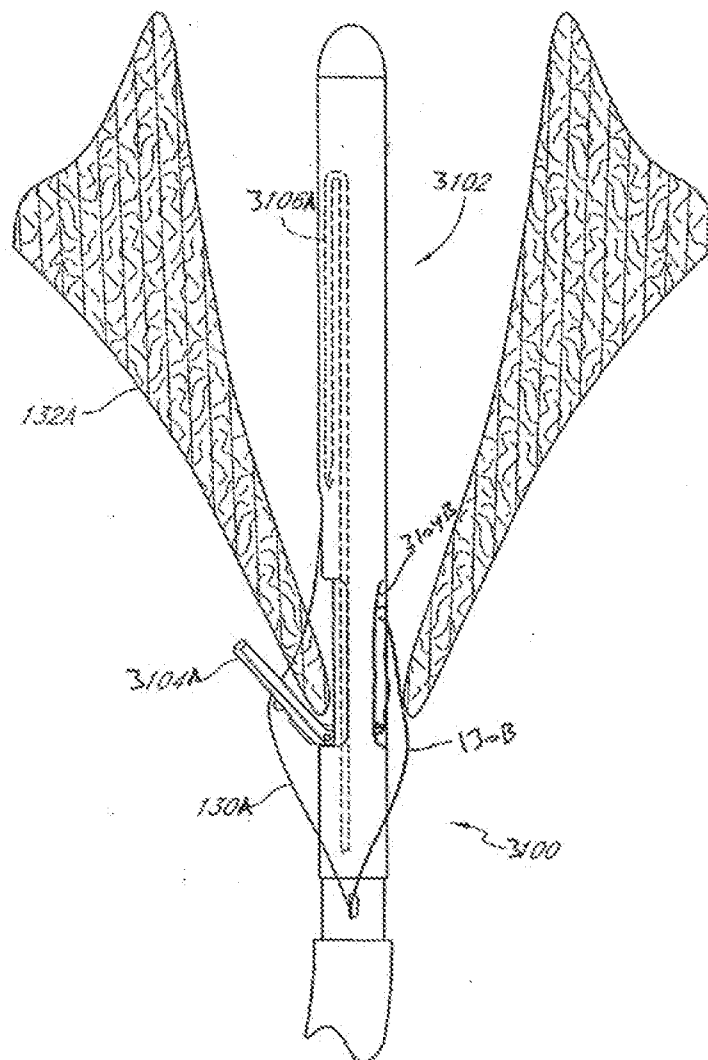


FIG. 43

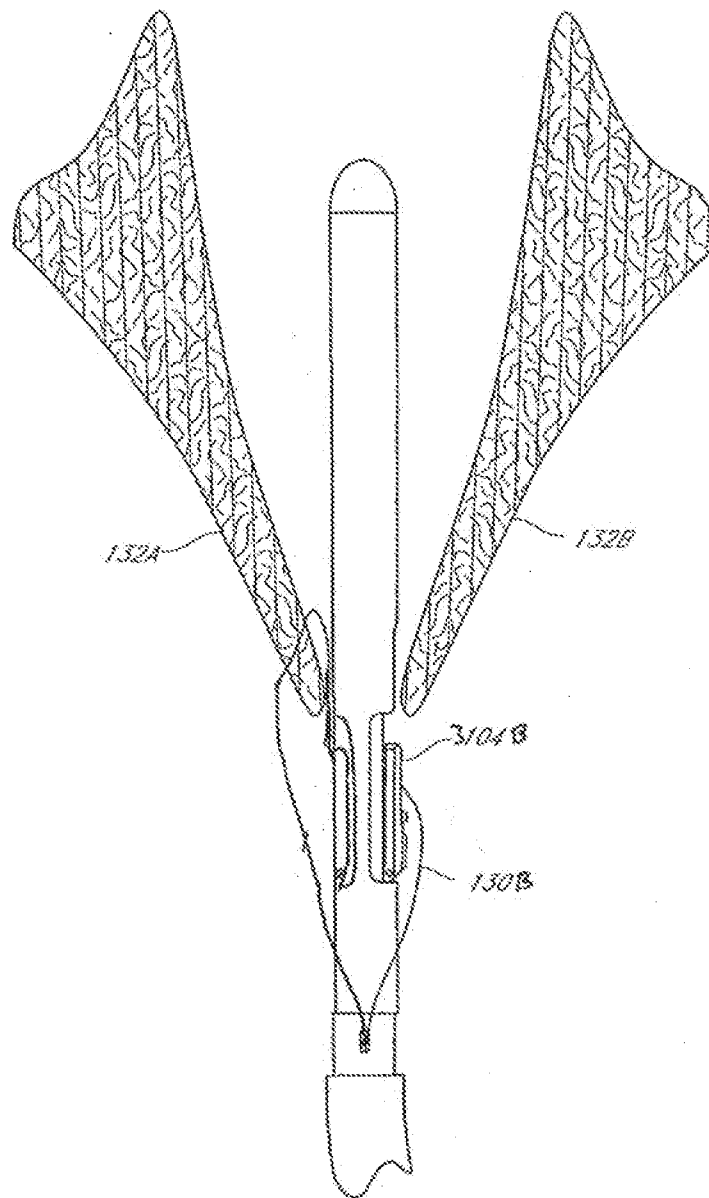


FIG. 44

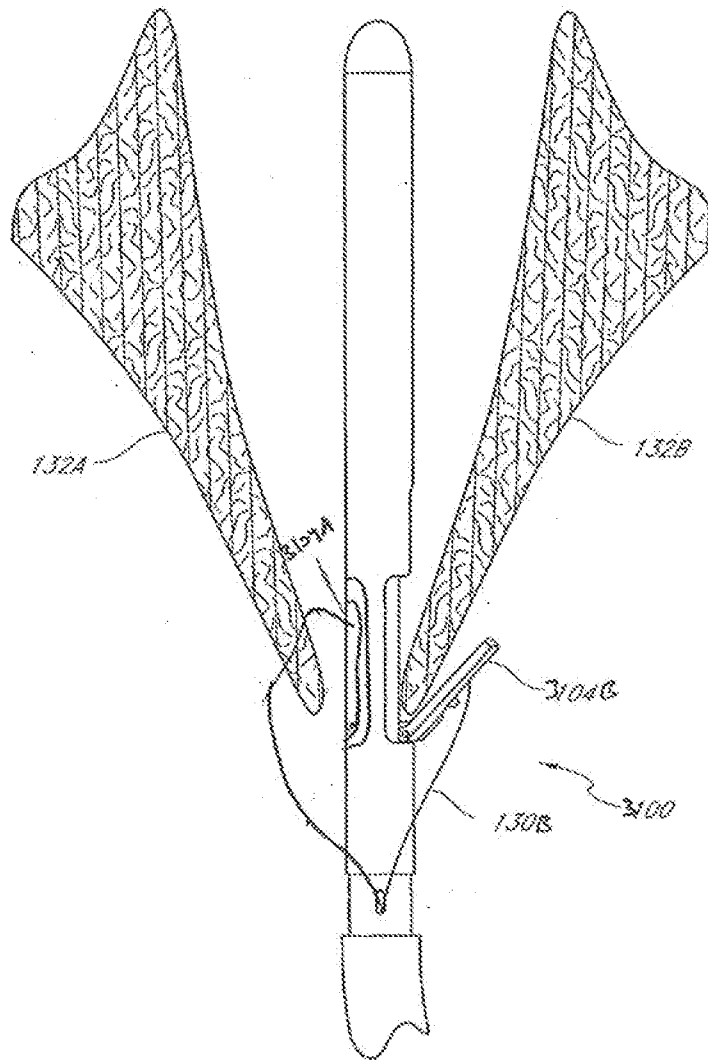


FIG. 45

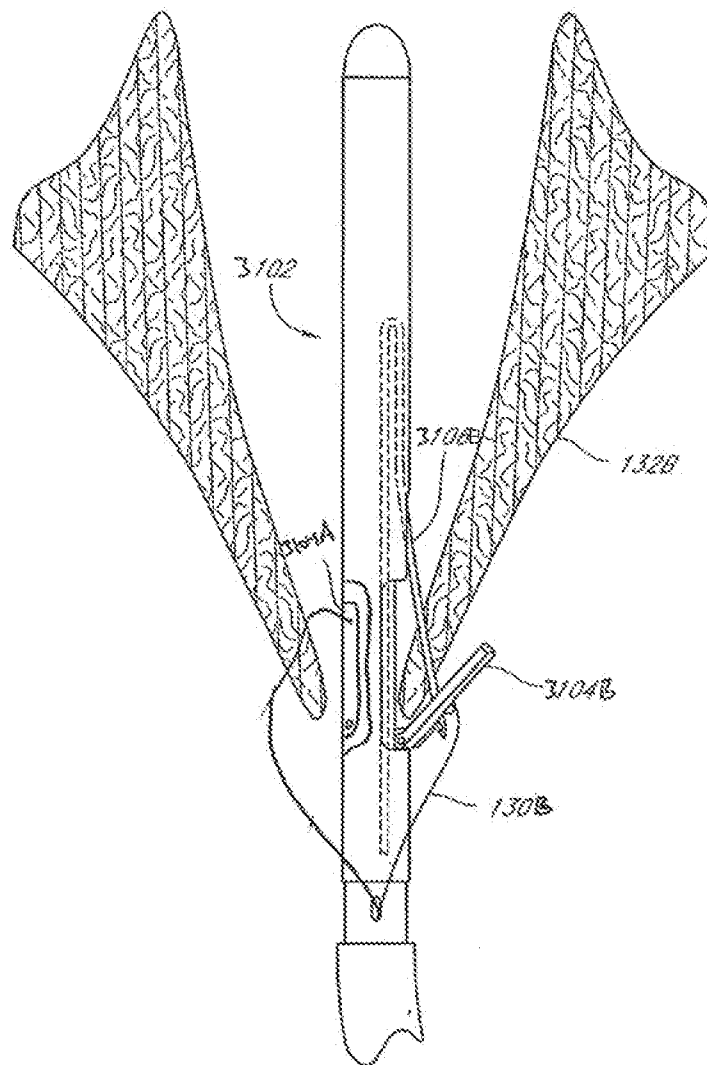
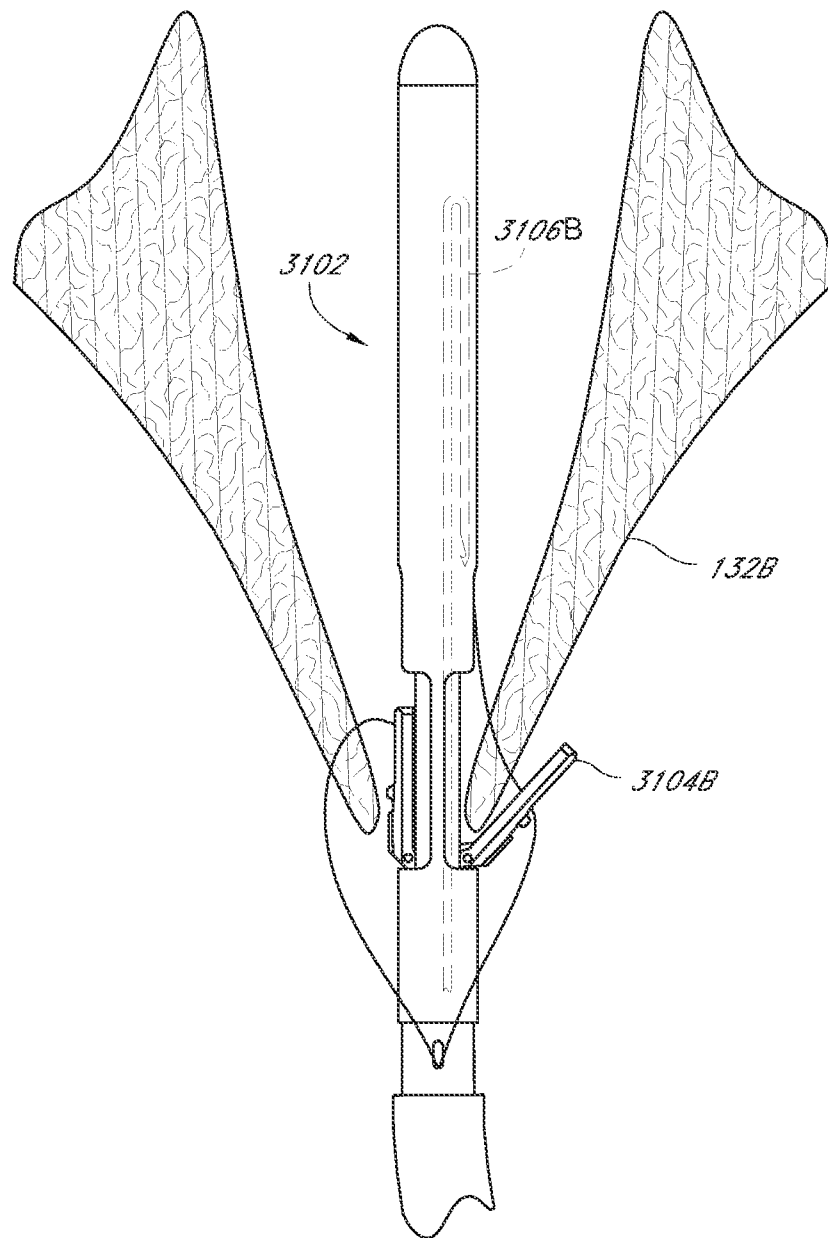


FIG 46

*FIG. 47*

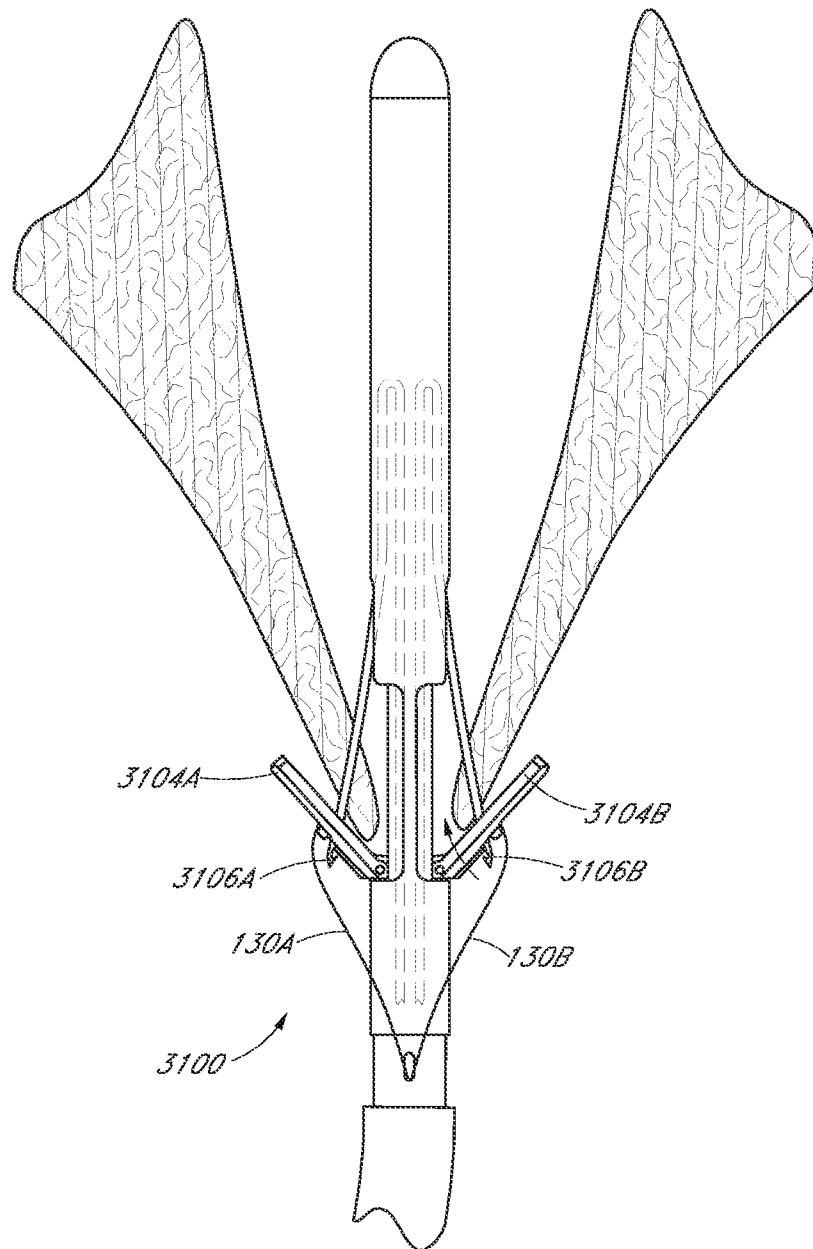
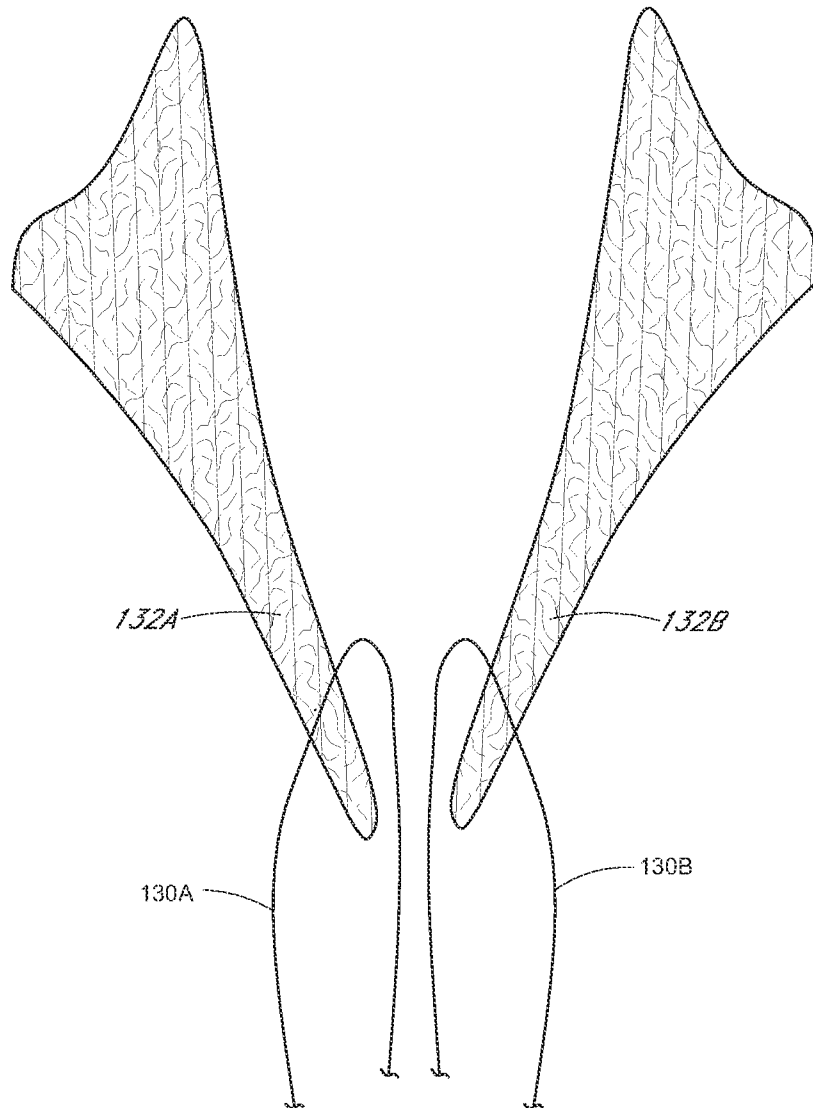
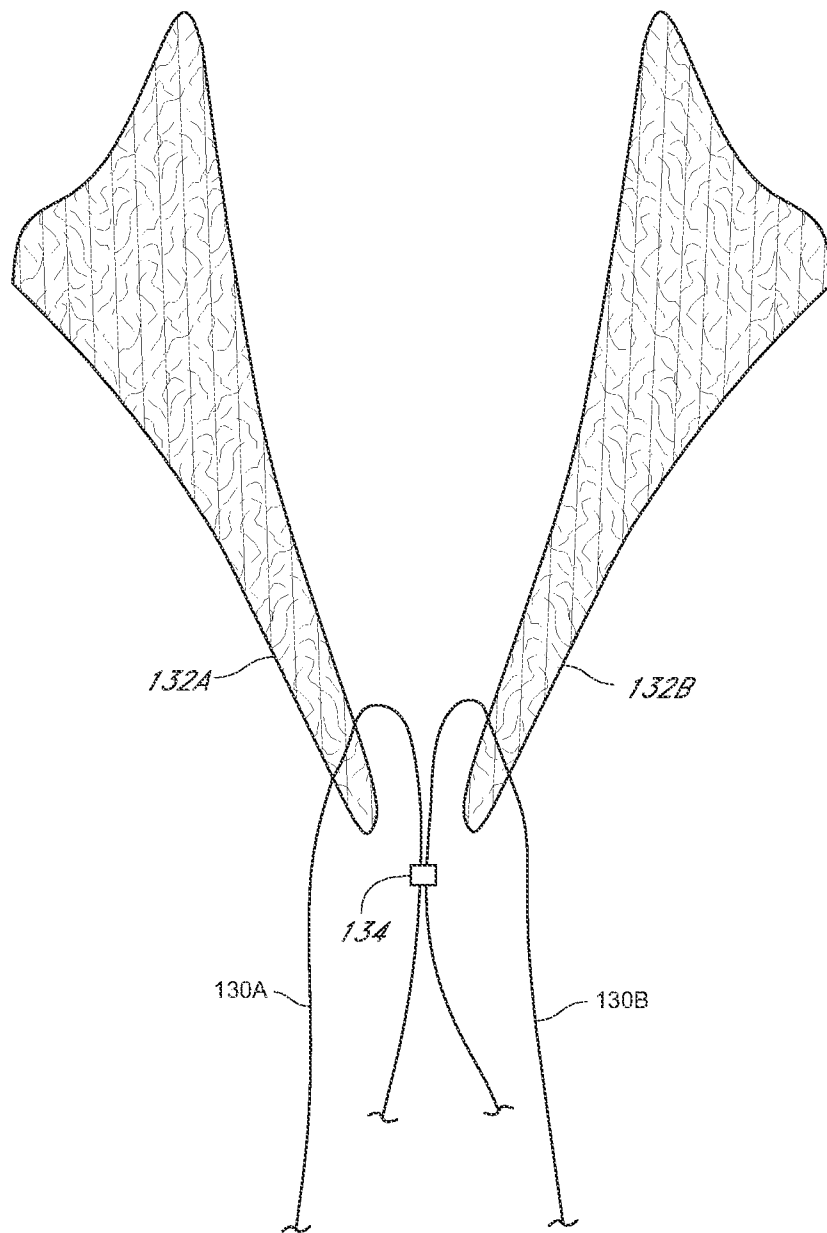
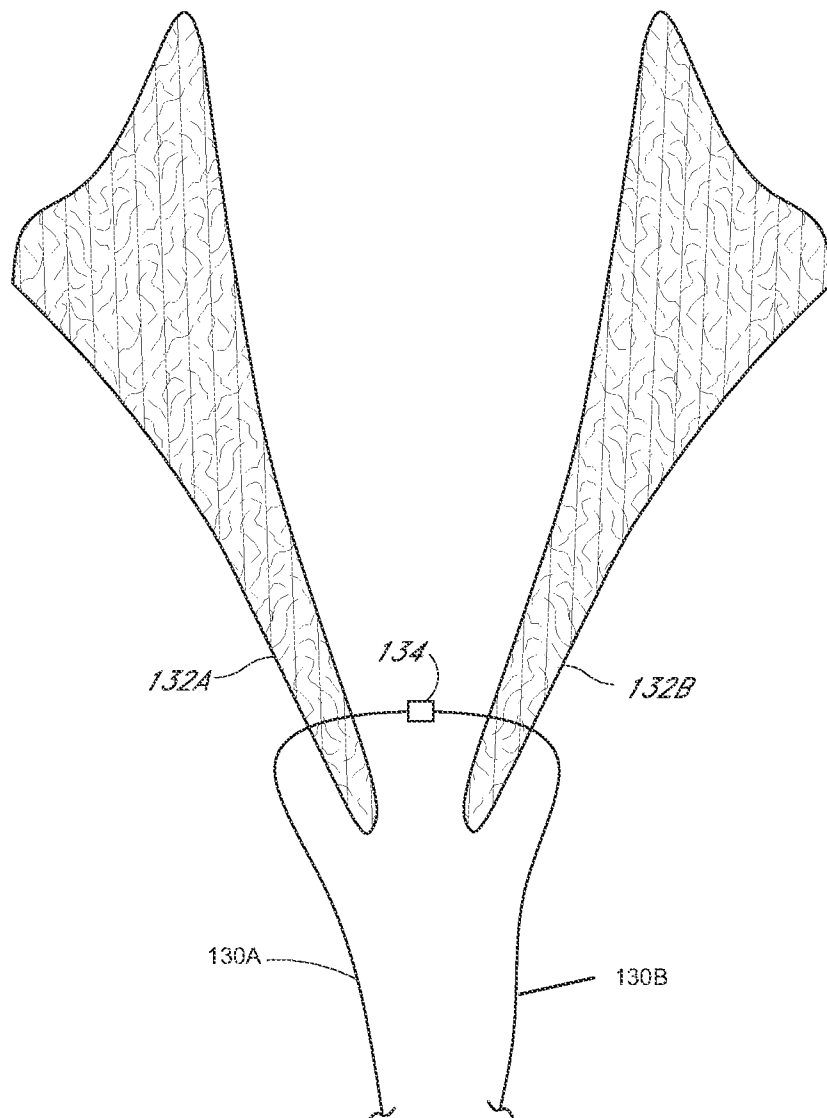
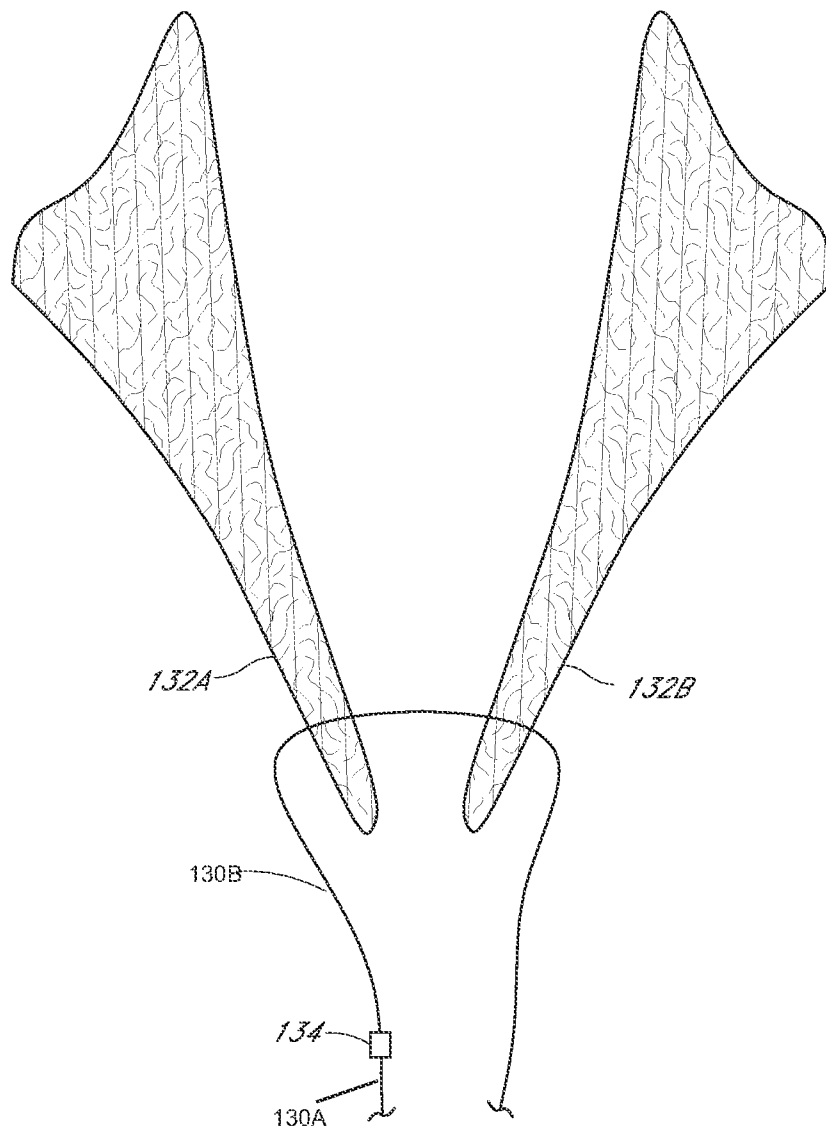


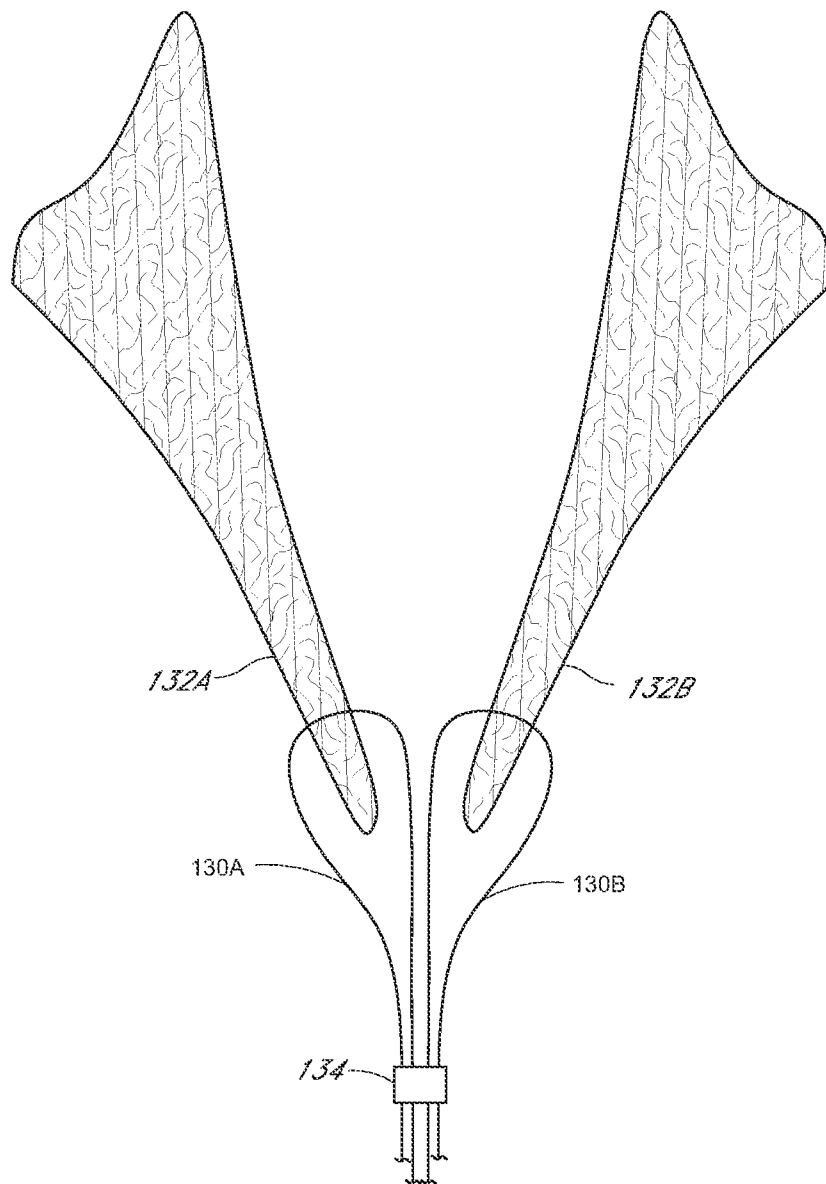
FIG. 48

*FIG. 49*

*FIG. 50*

*FIG. 51*

*FIG. 52*

*FIG. 53*

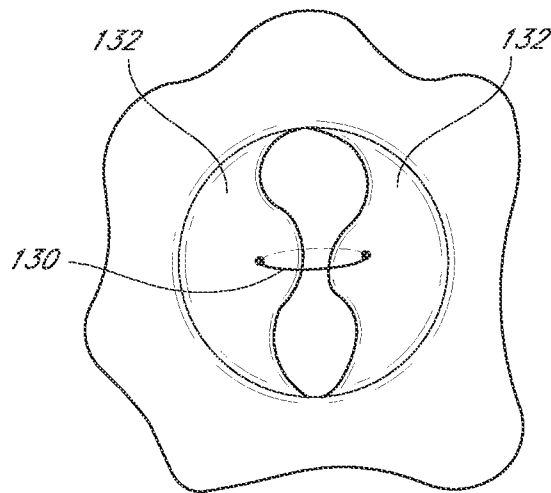


FIG. 54

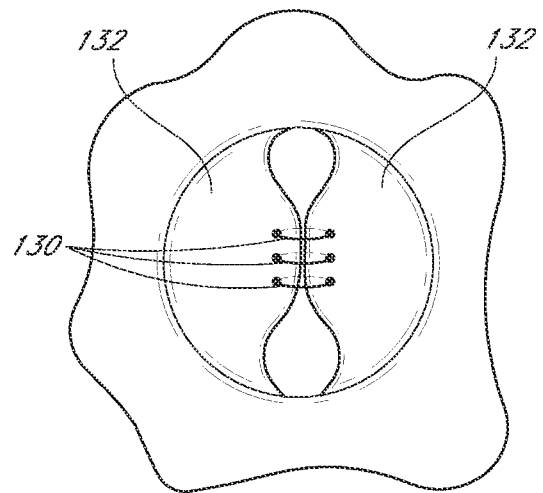


FIG. 55

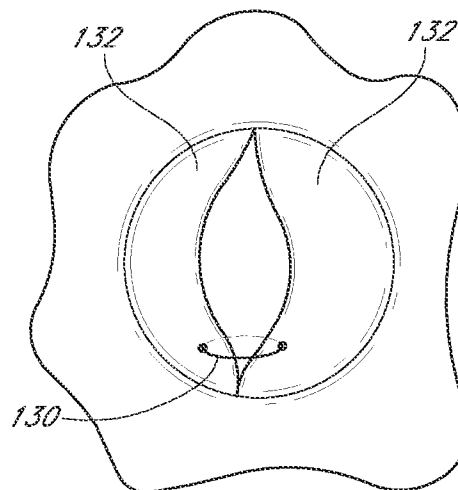


FIG. 56

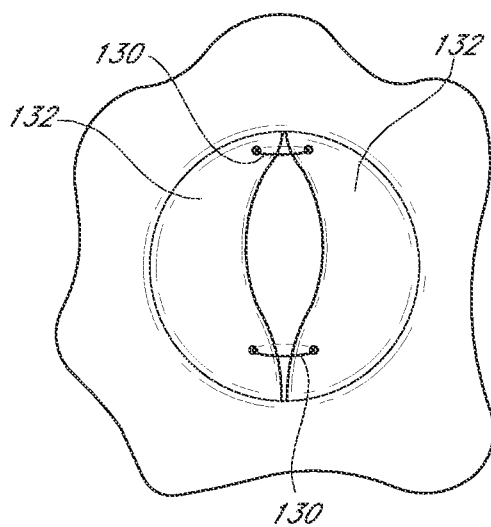


FIG. 57

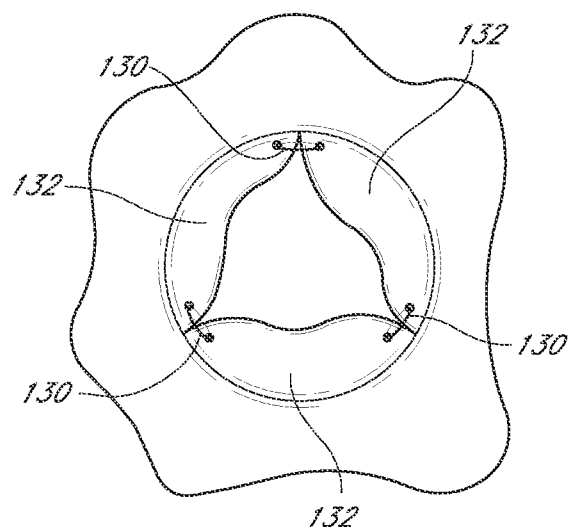
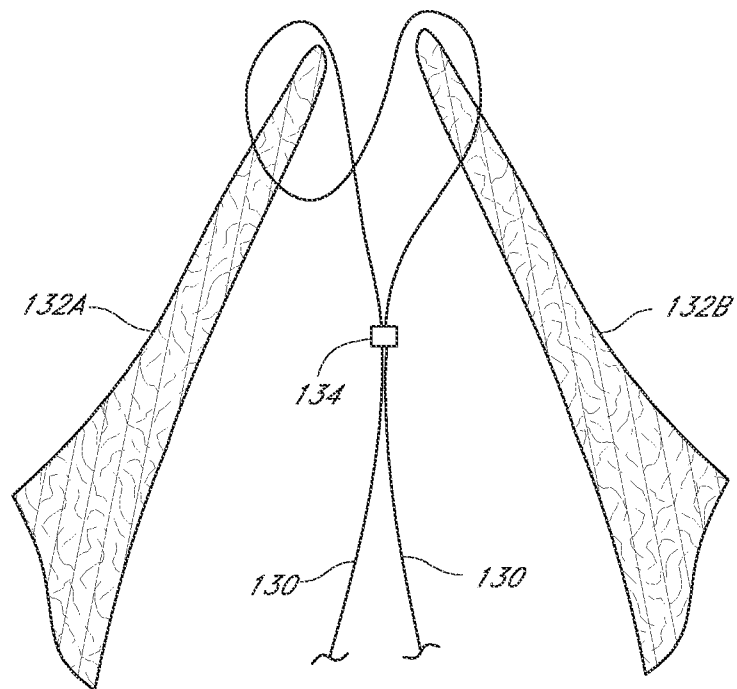


FIG. 58

*FIG. 59*

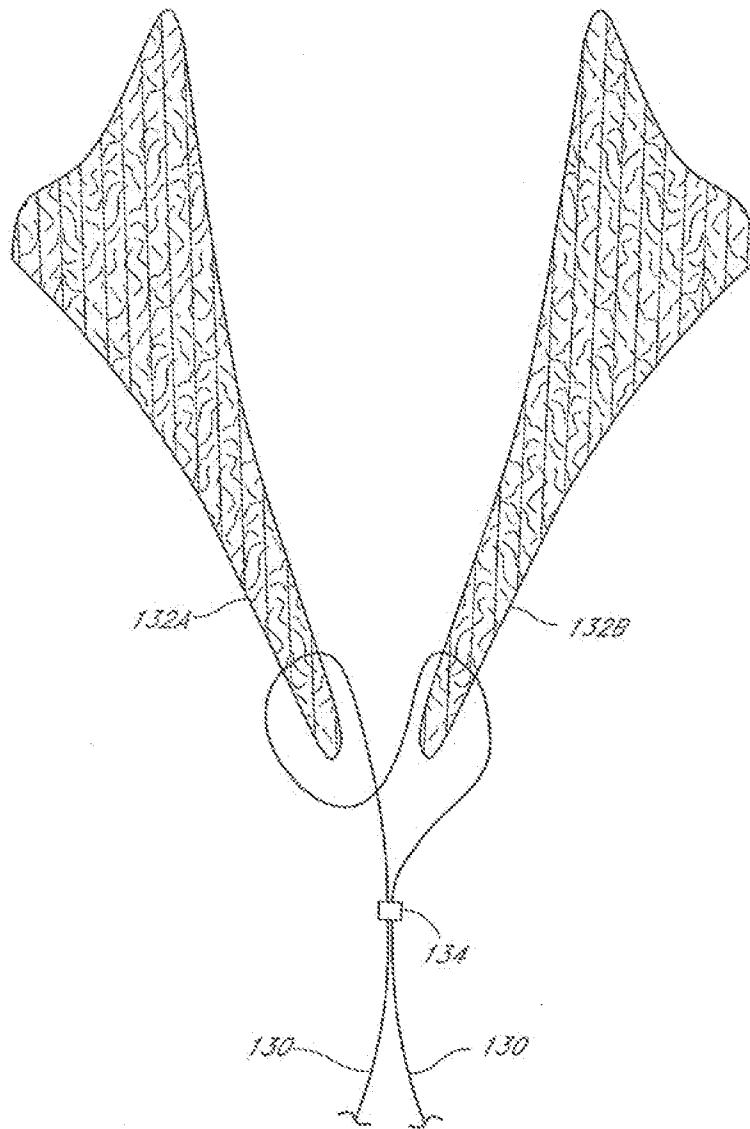


FIG. 60

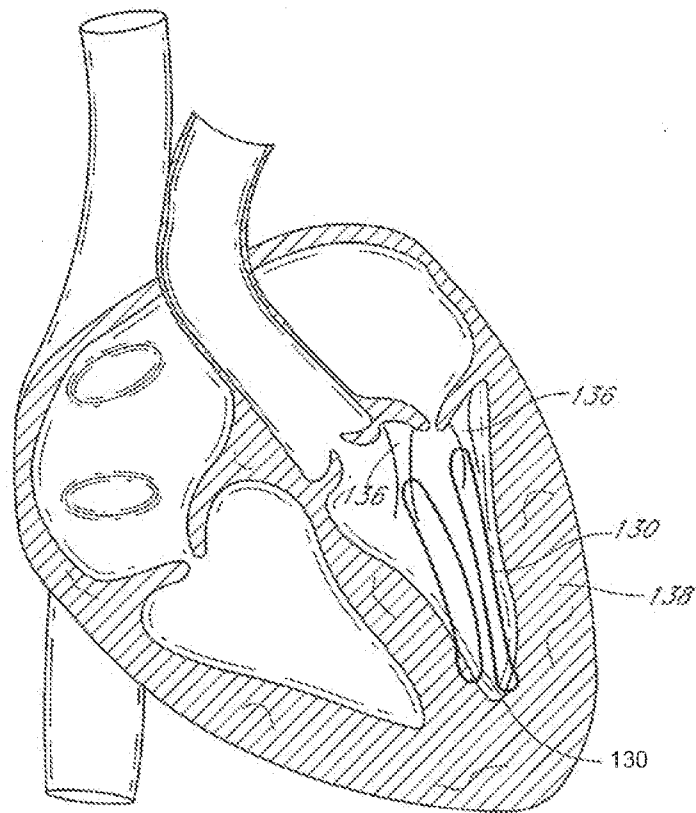
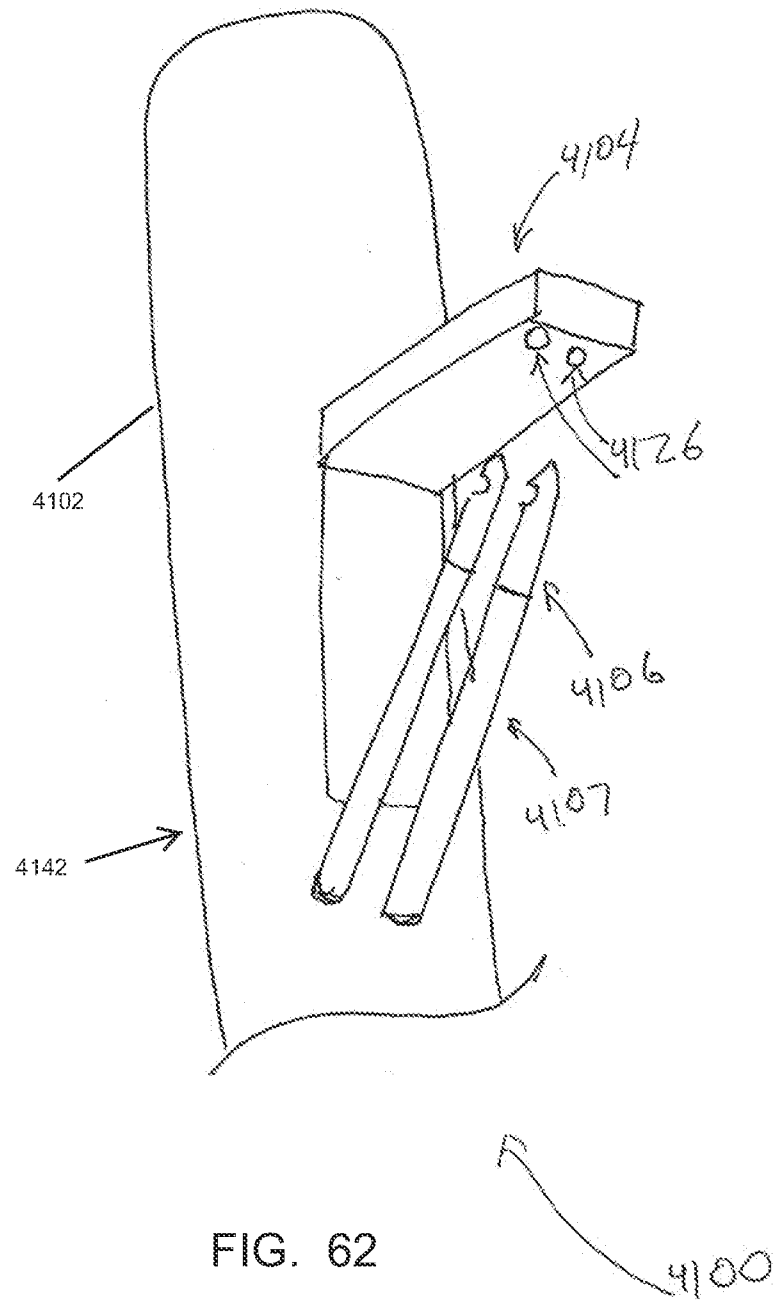


FIG. 61



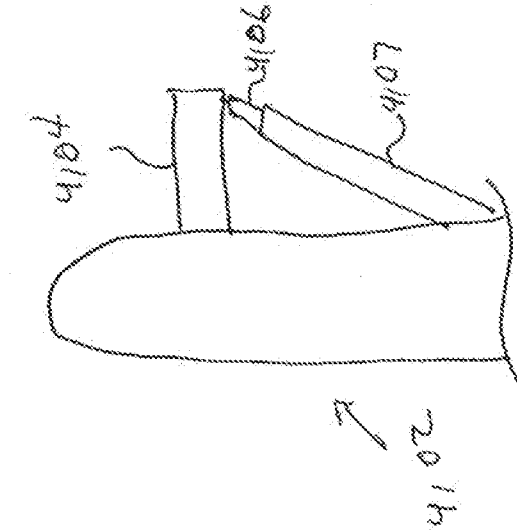


FIG. 63

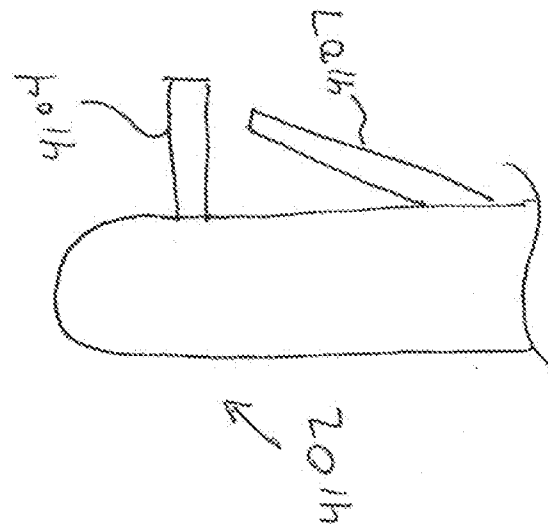


FIG. 64

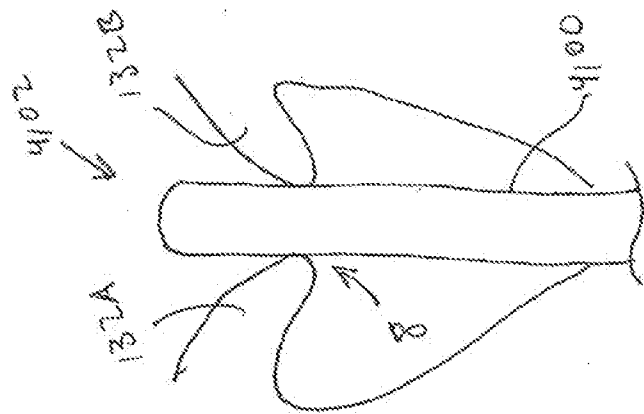


FIG. 65

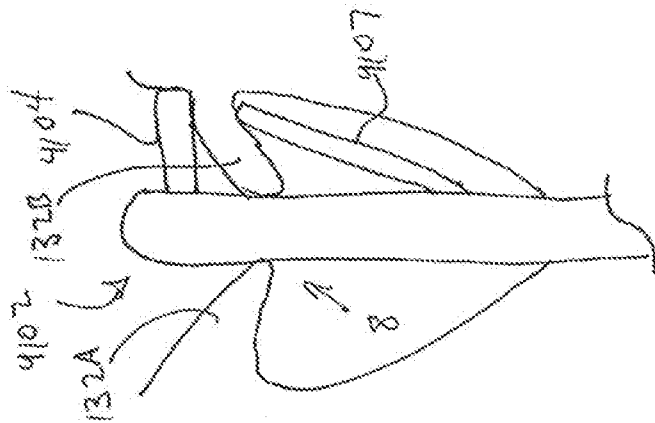


FIG. 66

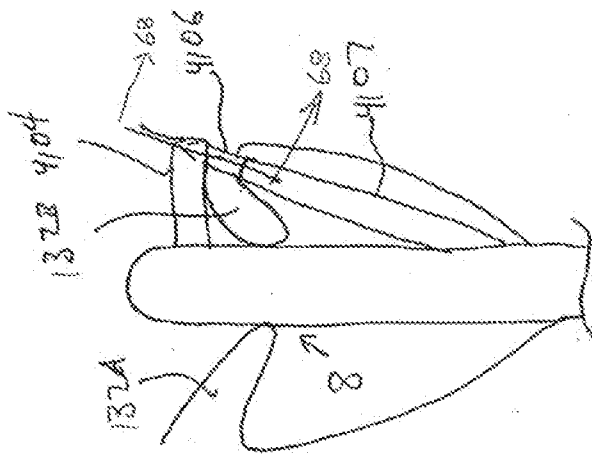


FIG. 67

FIG. 68

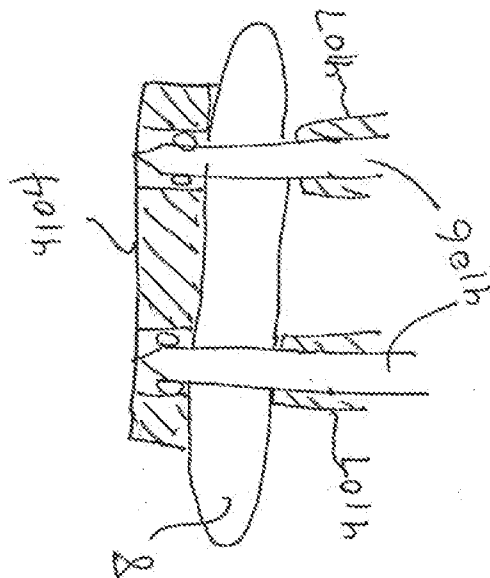


FIG. 69

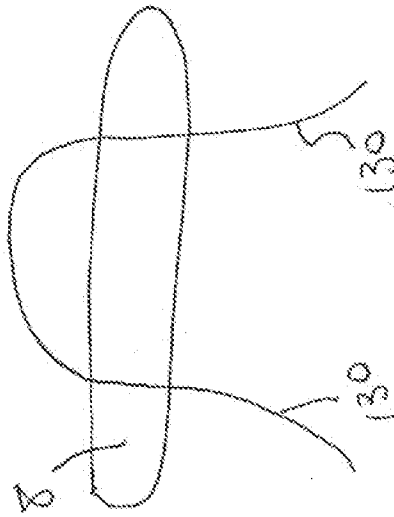


FIG. 70

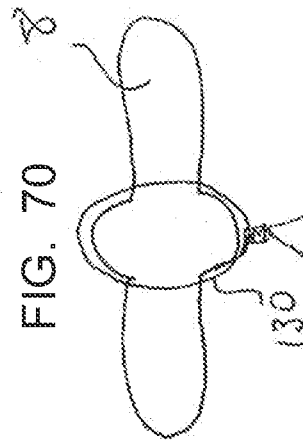


FIG. 71

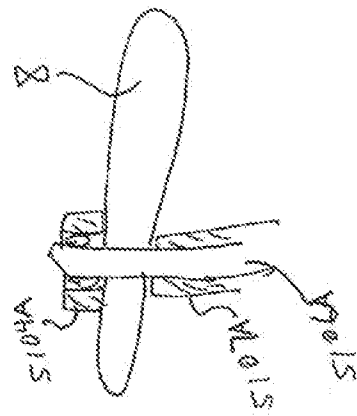


FIG. 72

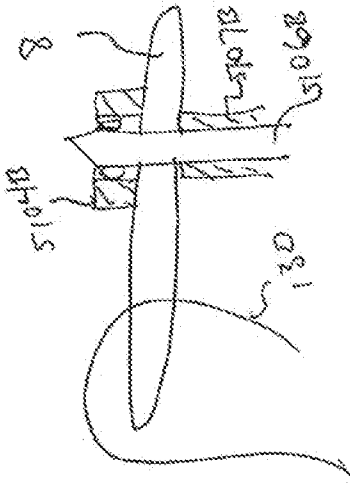


FIG. 73

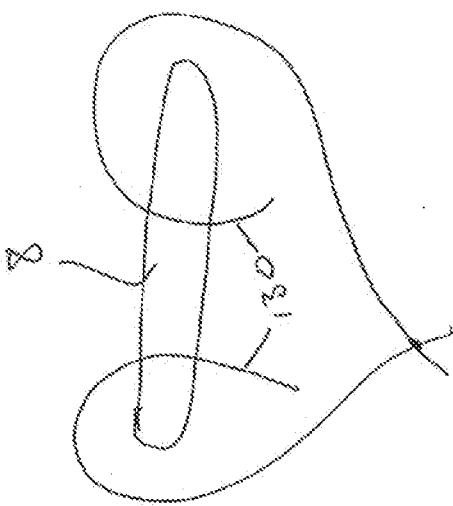


FIG. 74

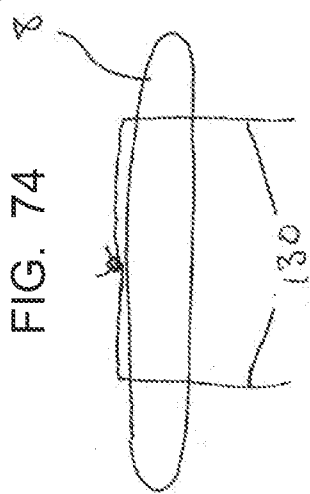


FIG. 75

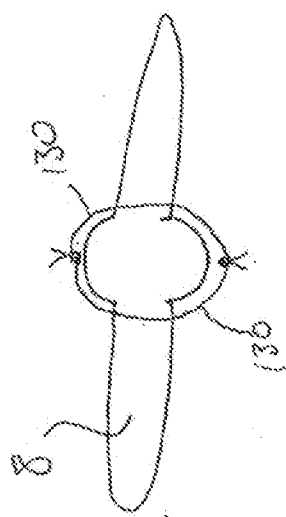
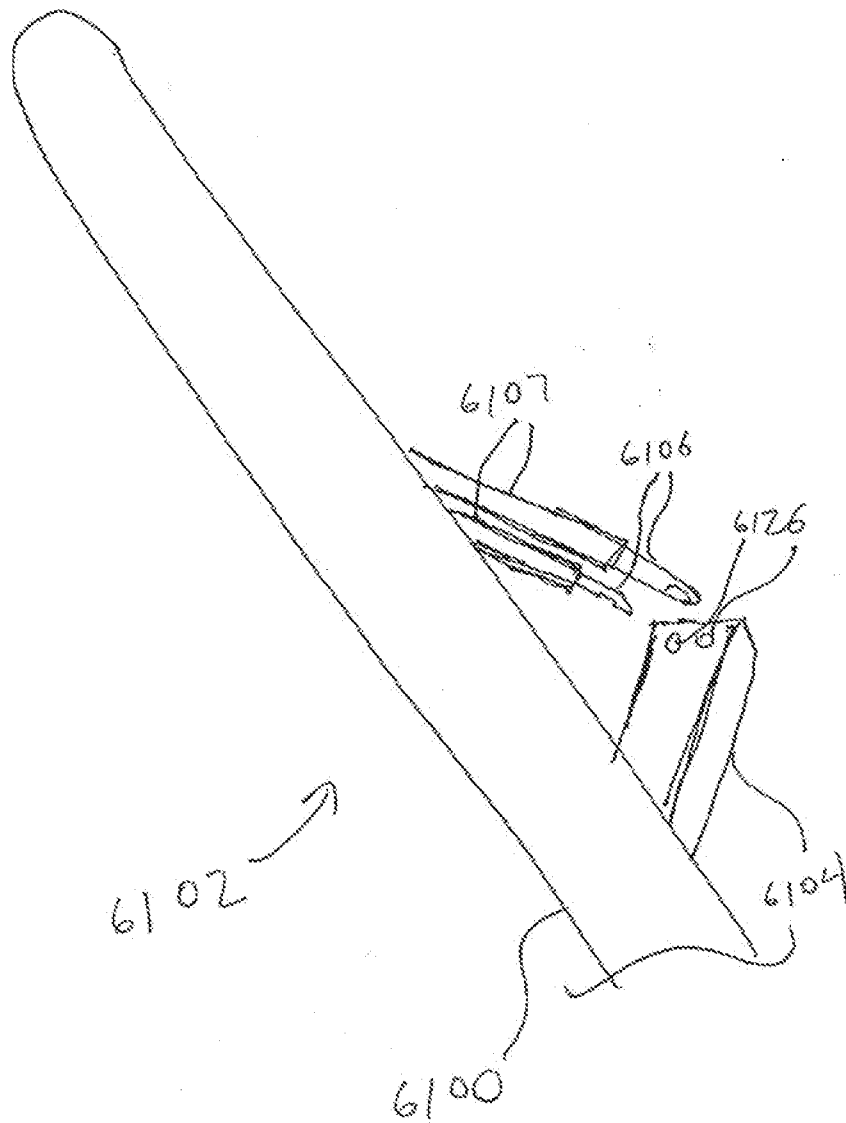


FIG. 76



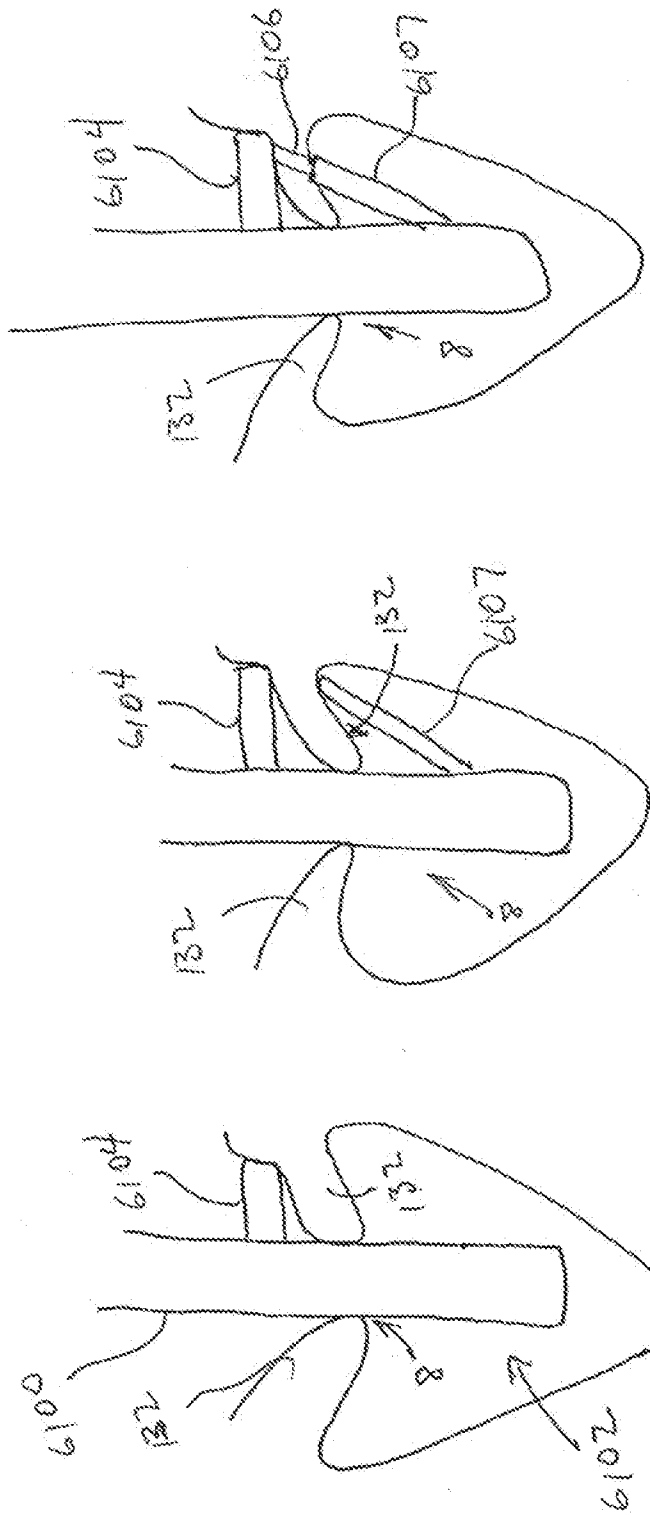
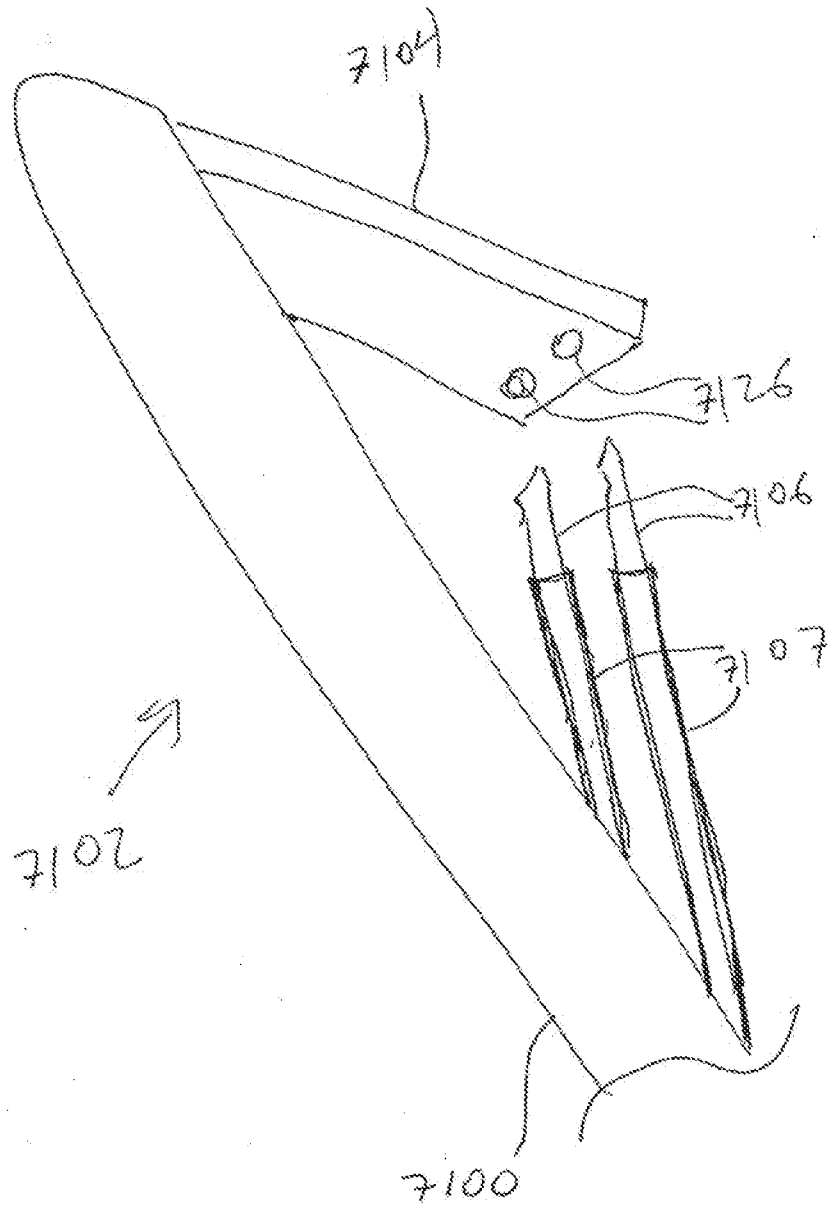


FIG. 77

FIG. 78

FIG. 79

FIG. 80



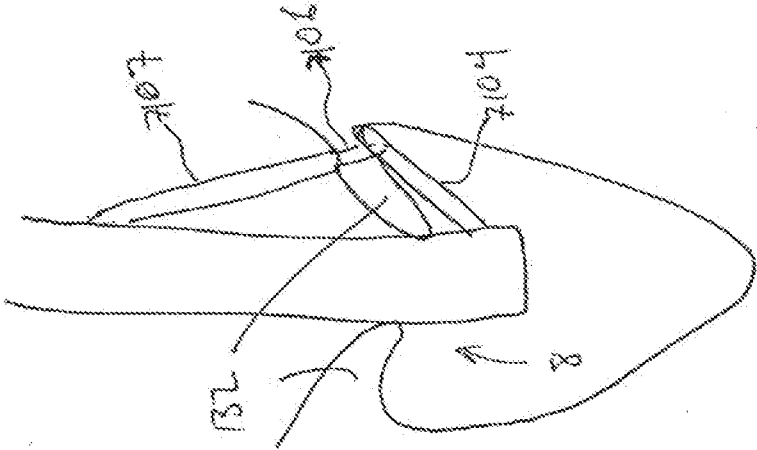


FIG. 81

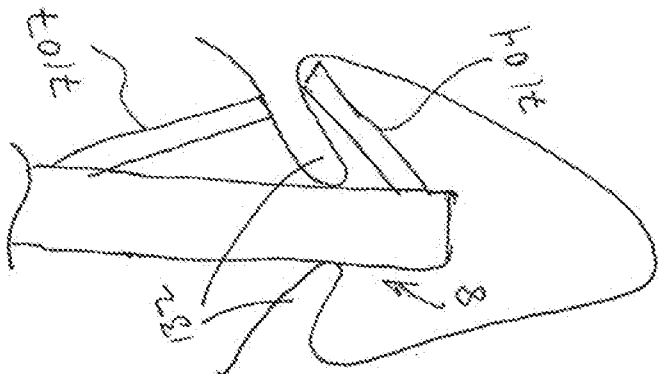


FIG. 82

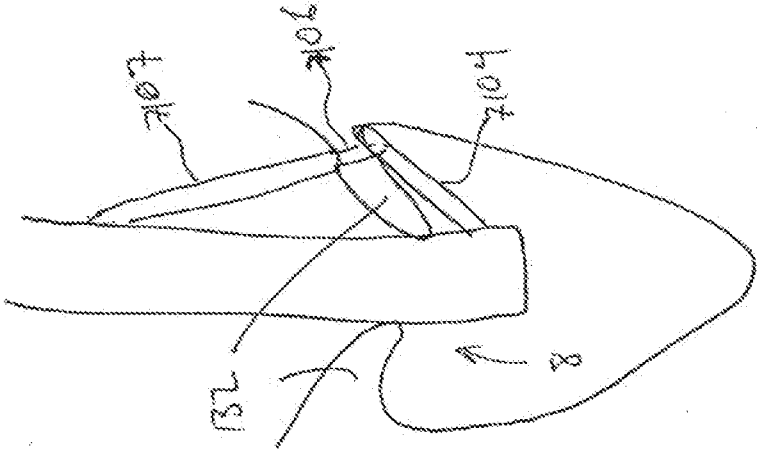


FIG. 83

FIG. 84

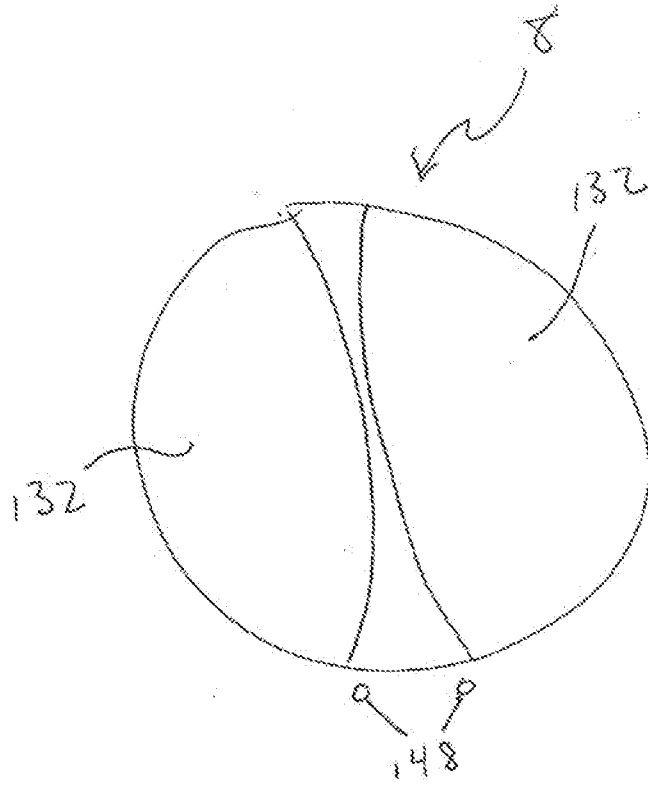
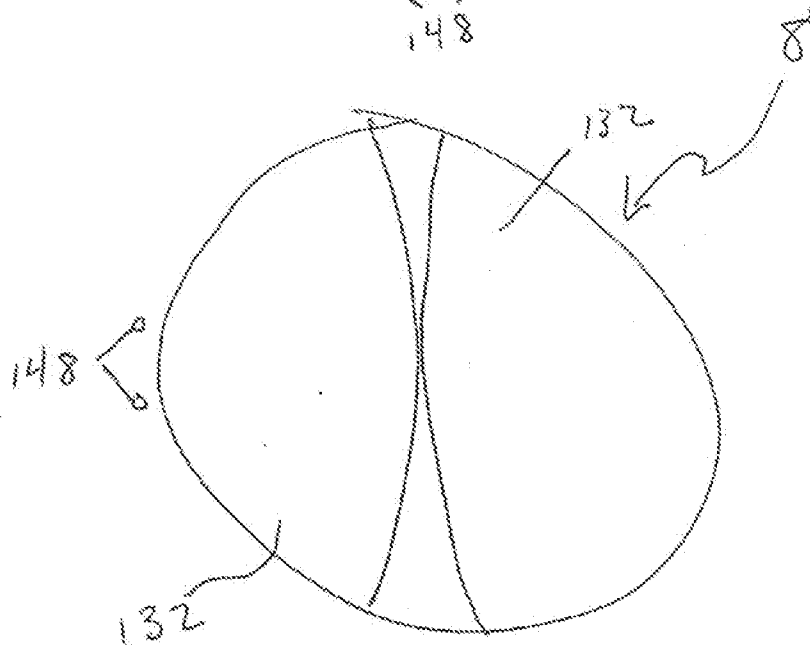


FIG. 85



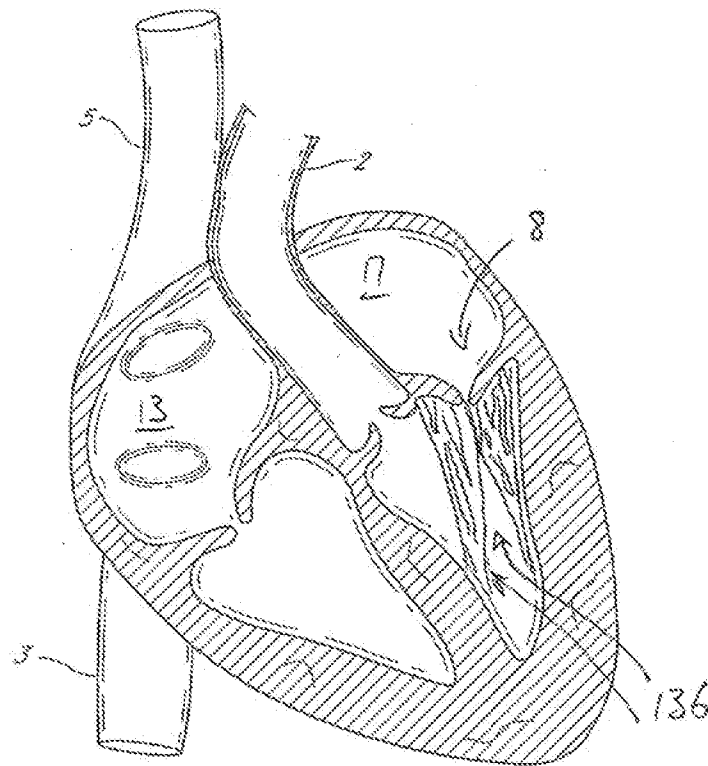


FIG. 86

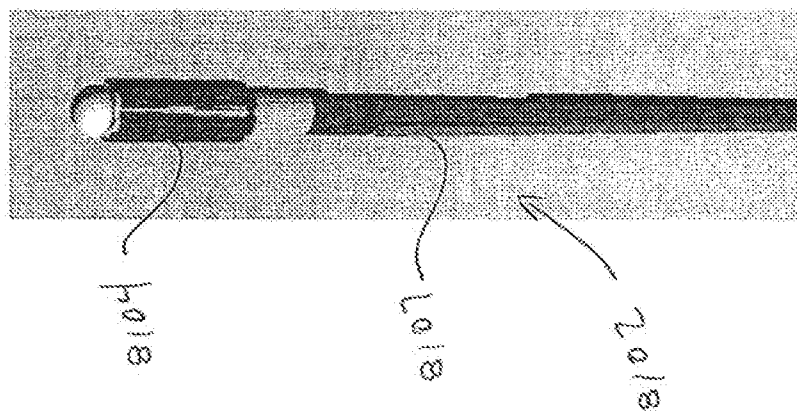


Fig. 87

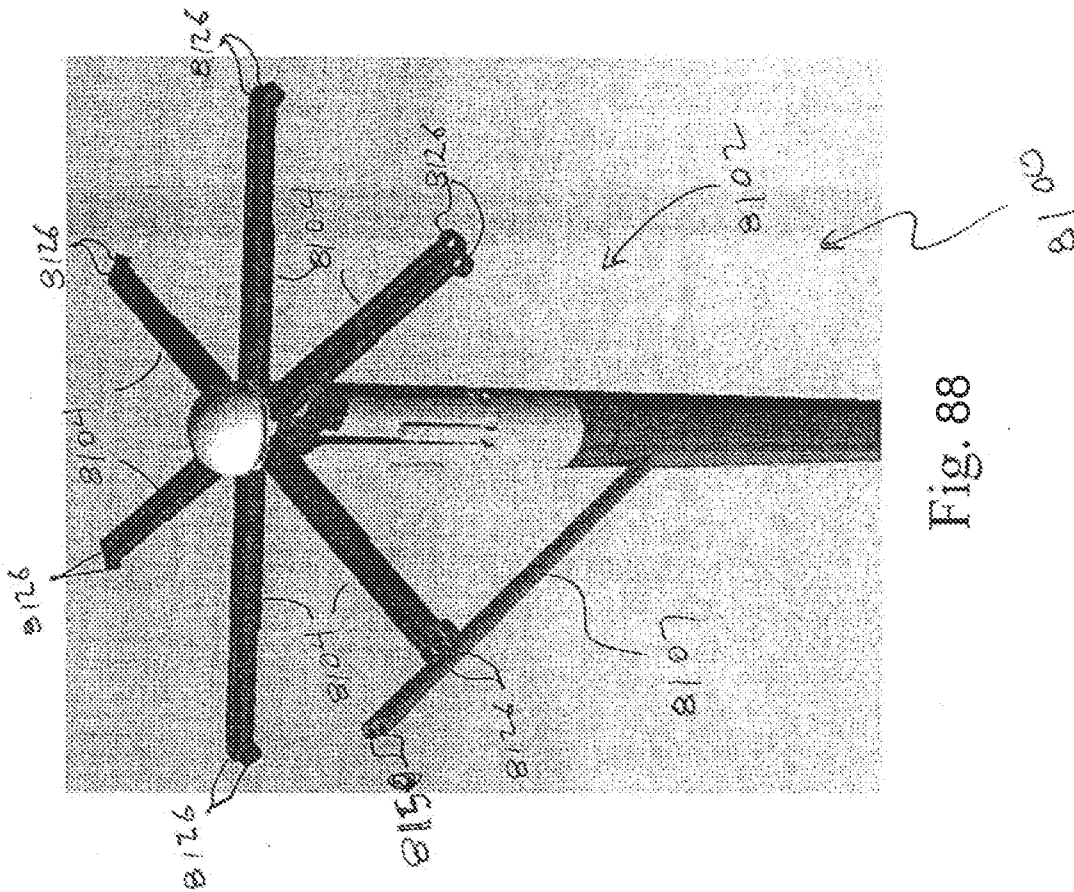
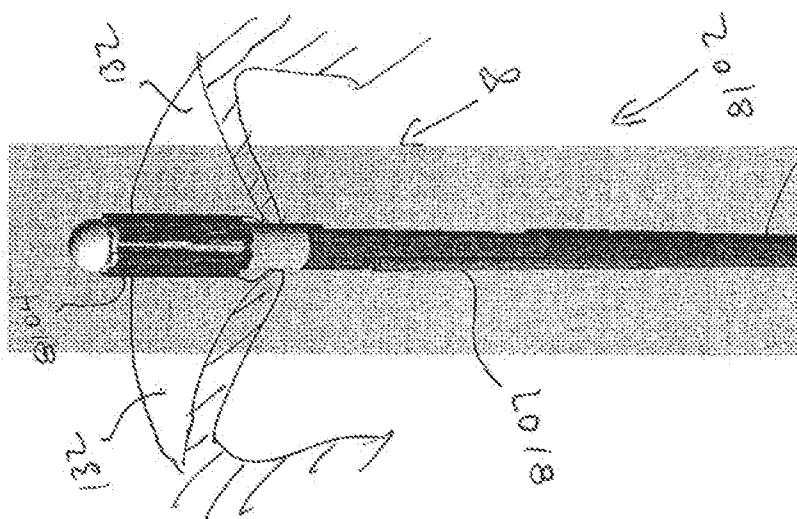
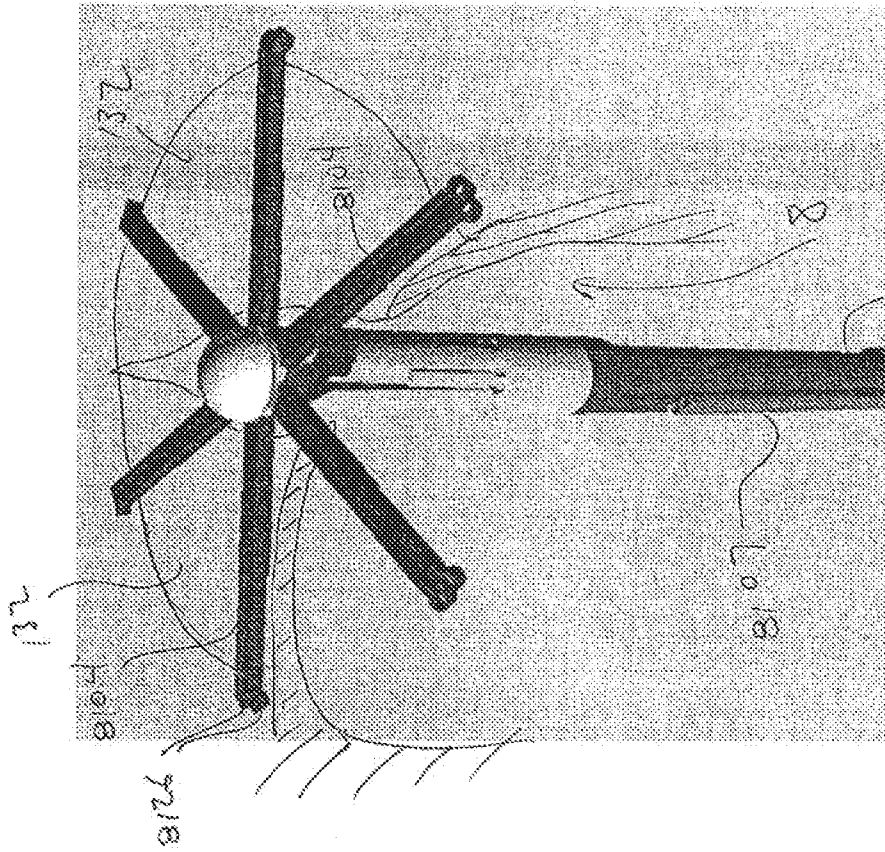


Fig. 88



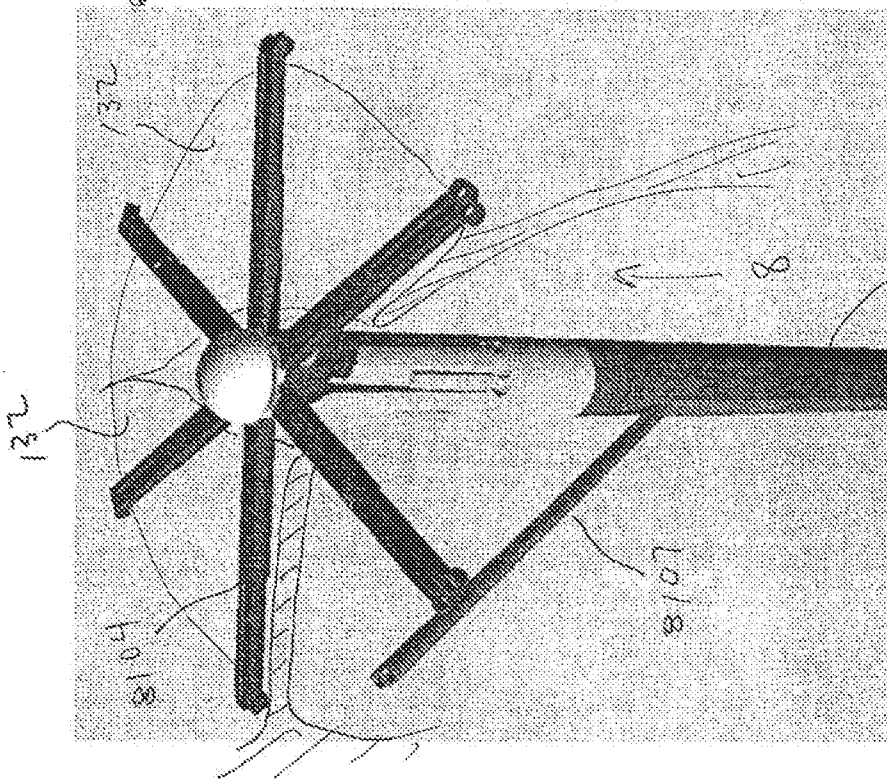


Fig. 91 8100

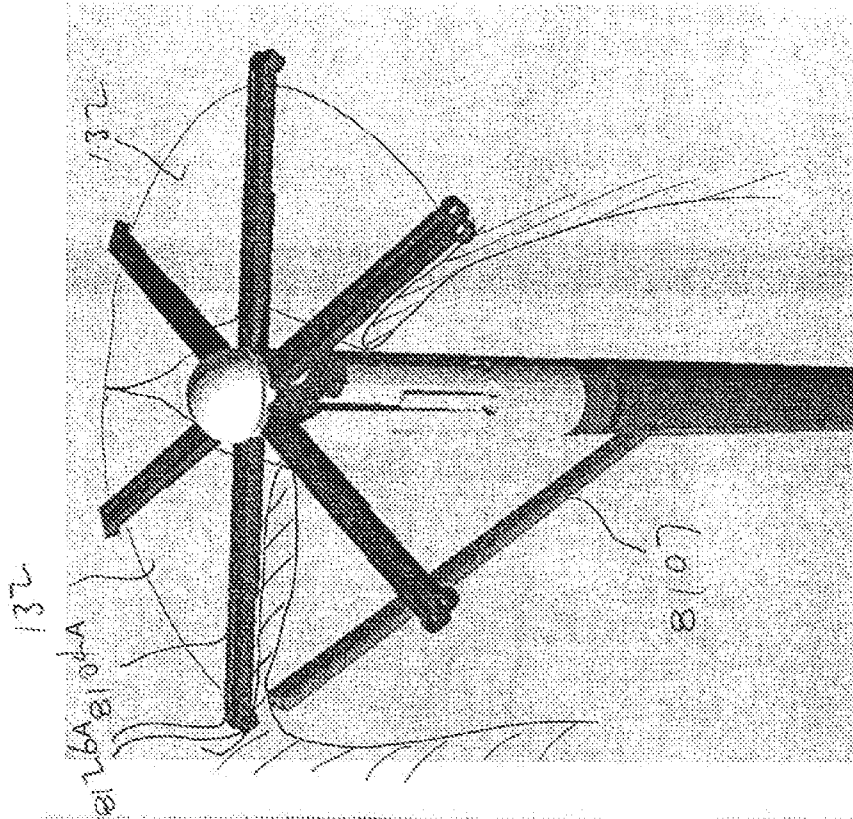


Fig. 92

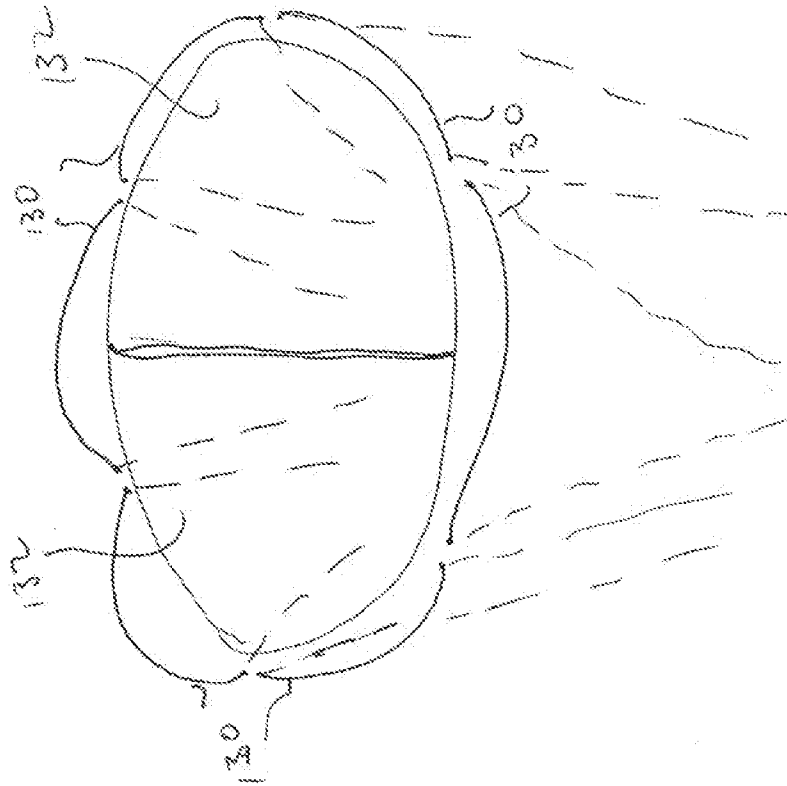


Fig. 94

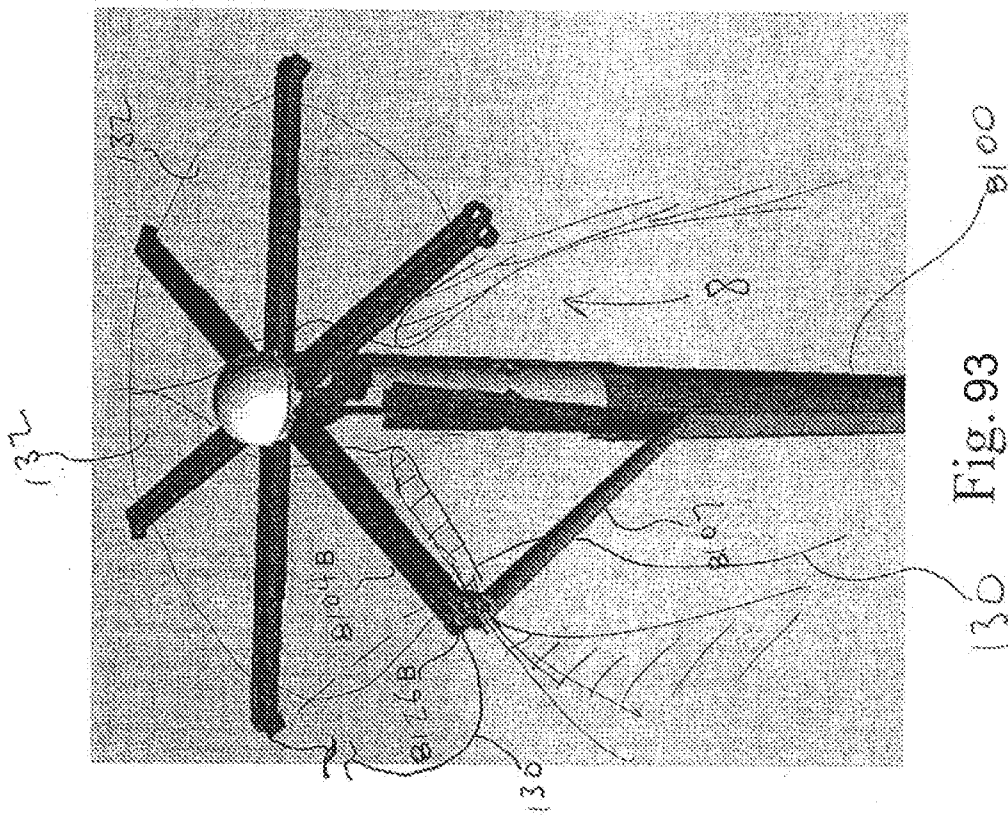


Fig. 93

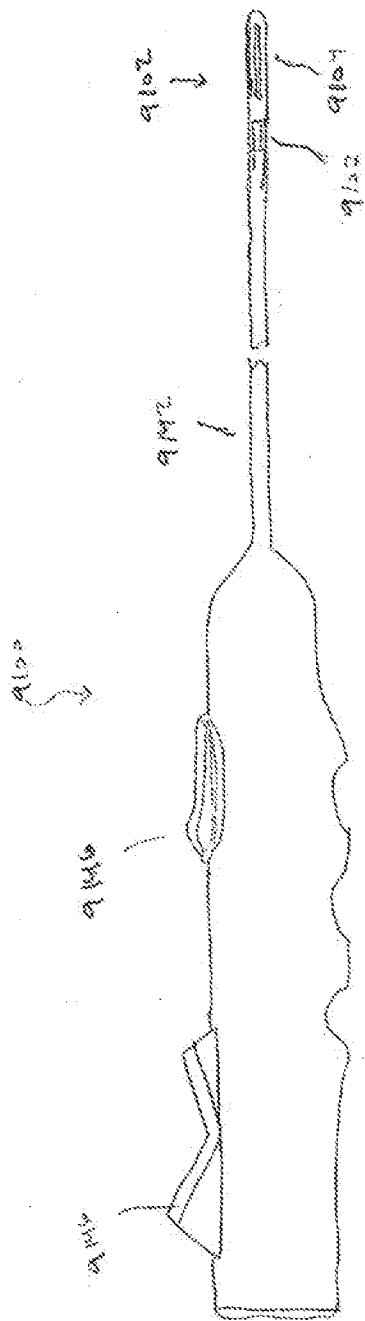


FIG. 95

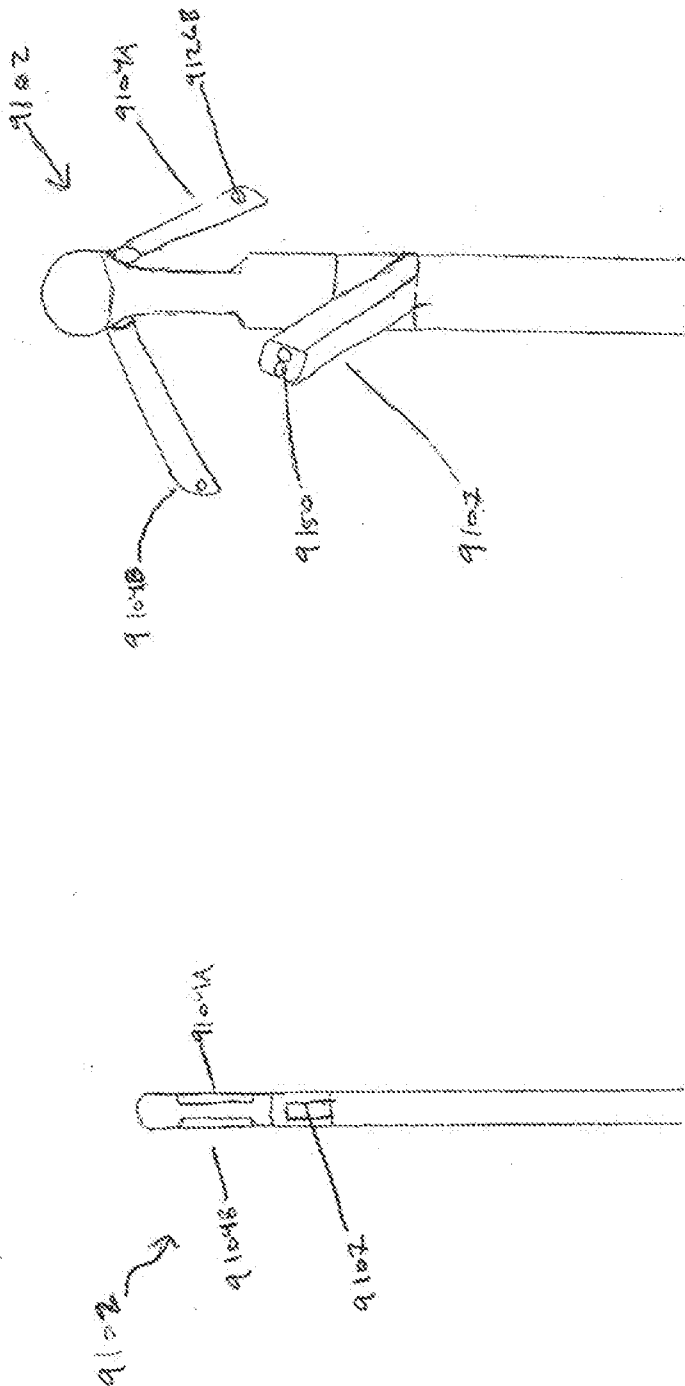


FIG. 96

FIG. 97

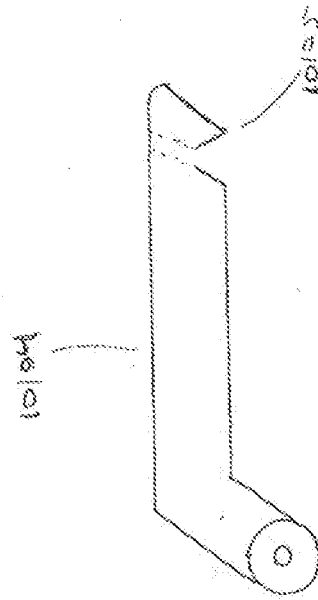


FIG. 98

(6/12/12 SAT)

79/93

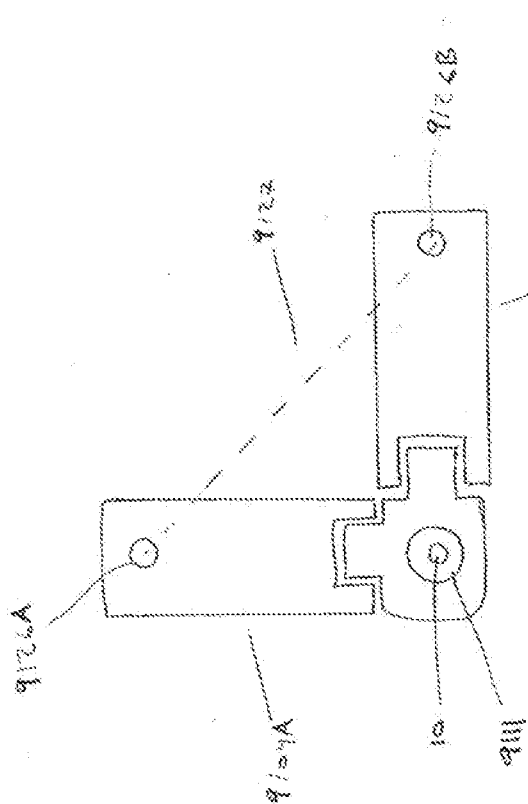


FIG. 100

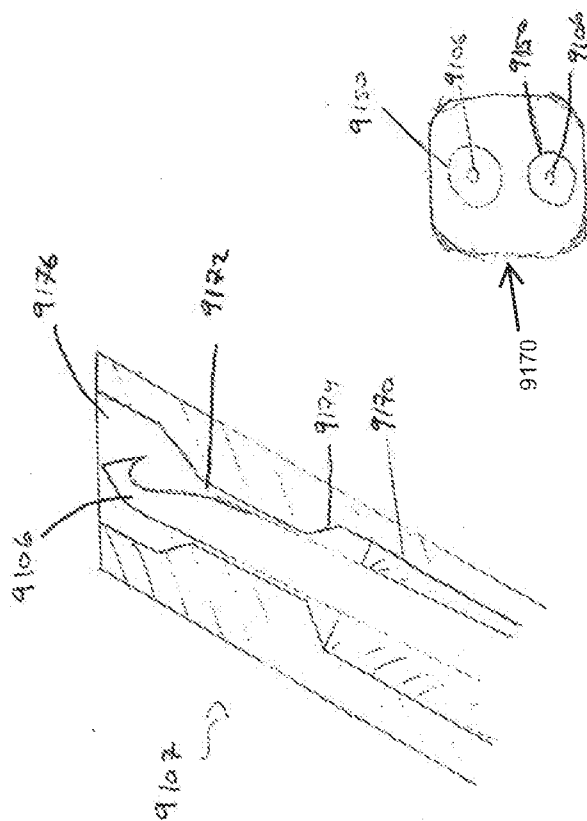


FIG. 101

FIG. 102

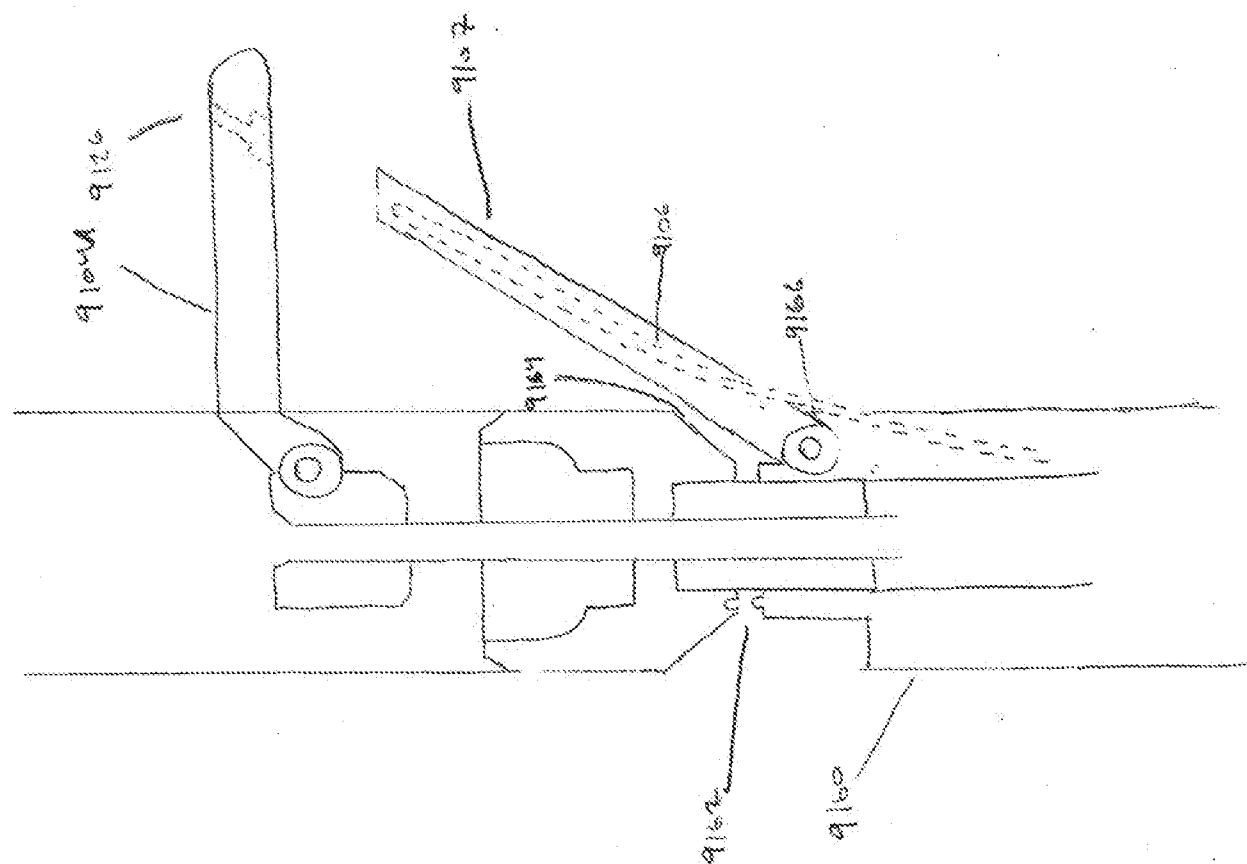


FIG. 99

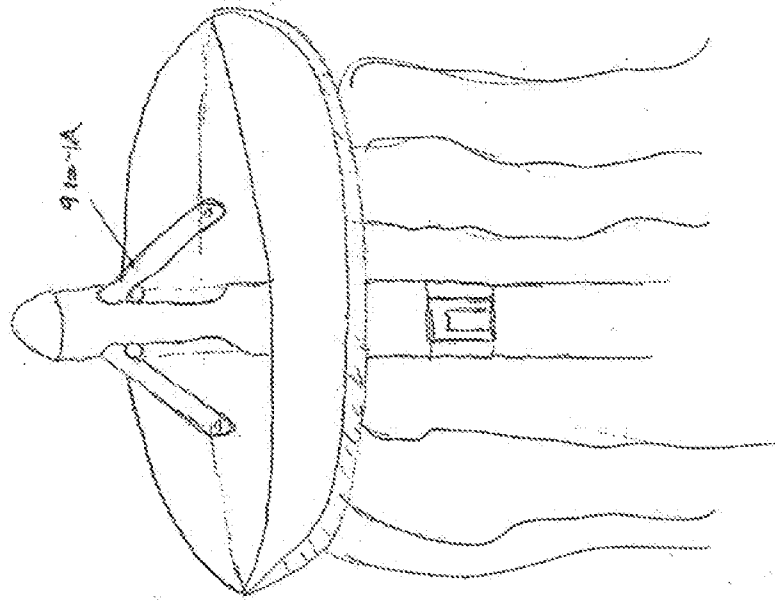


FIG. 103

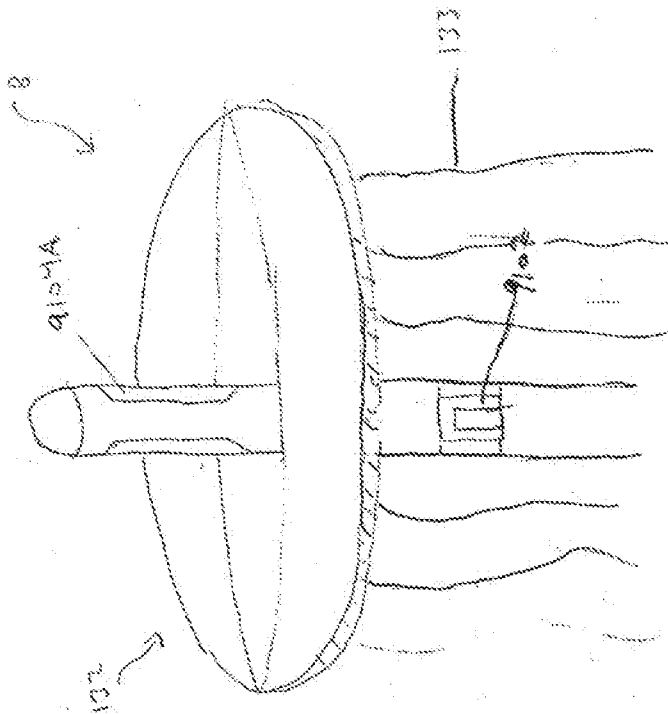
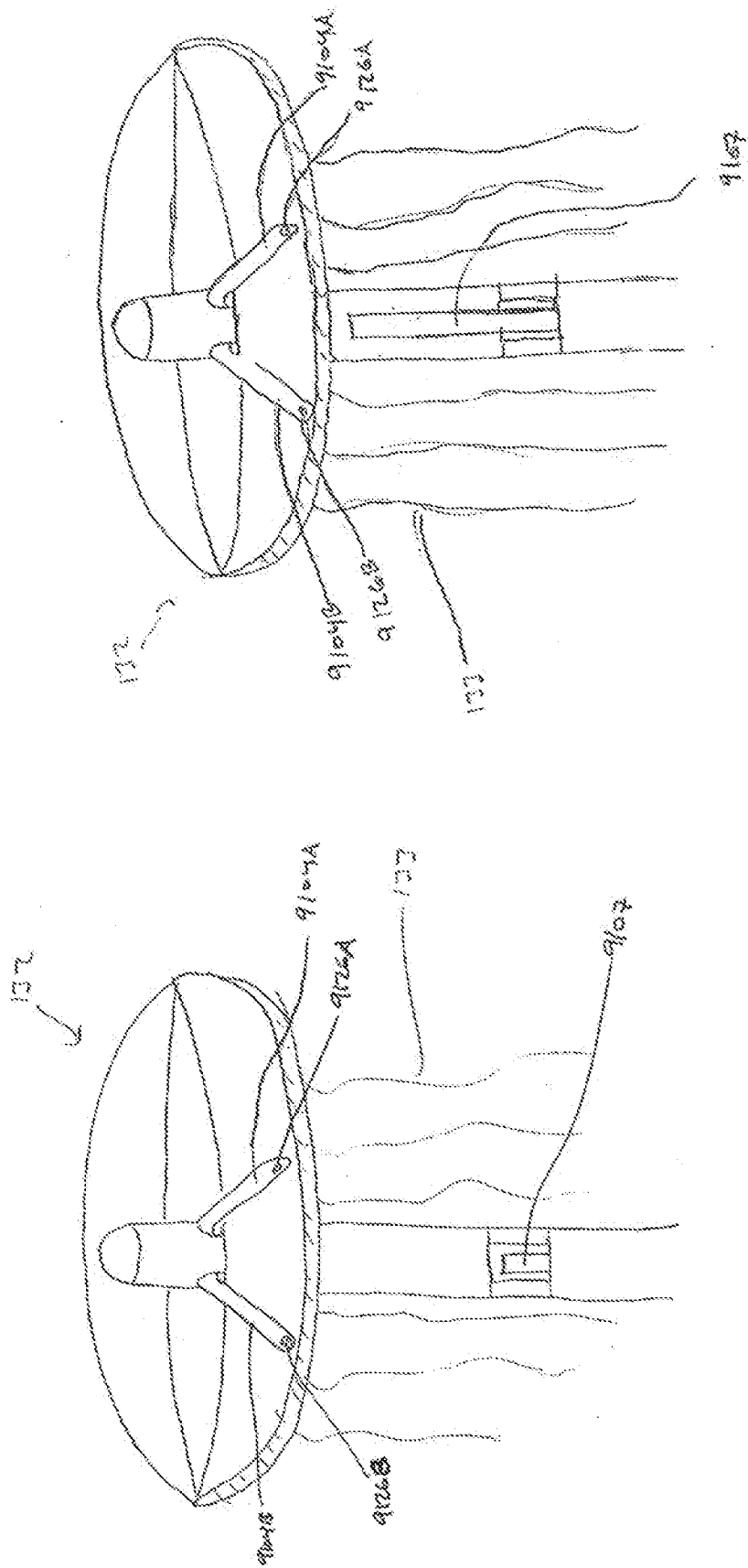
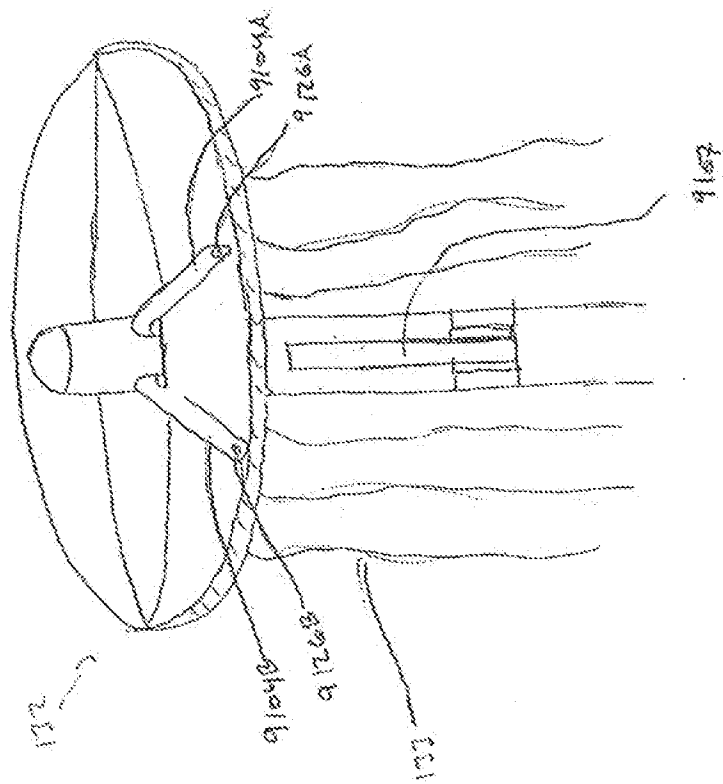


FIG. 104



1051



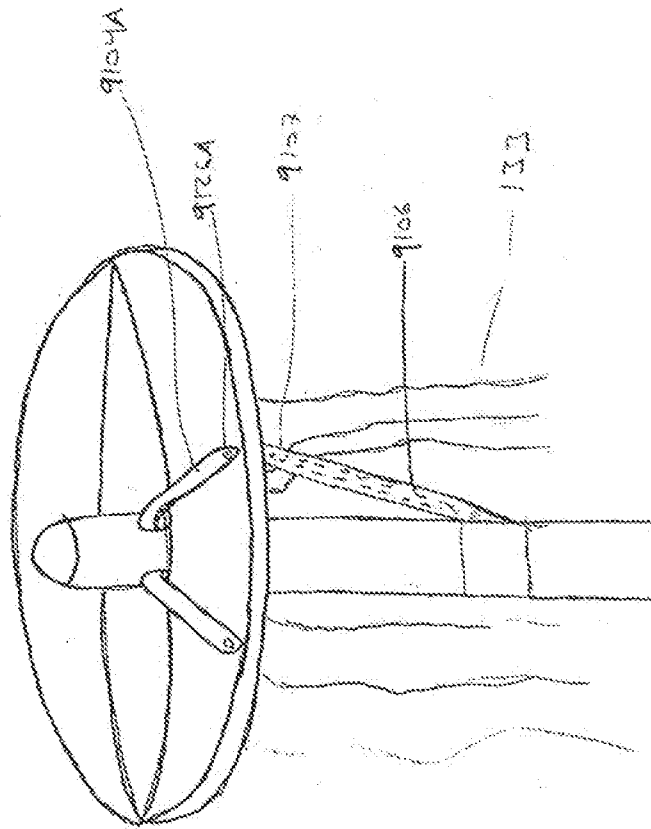


FIG. 107

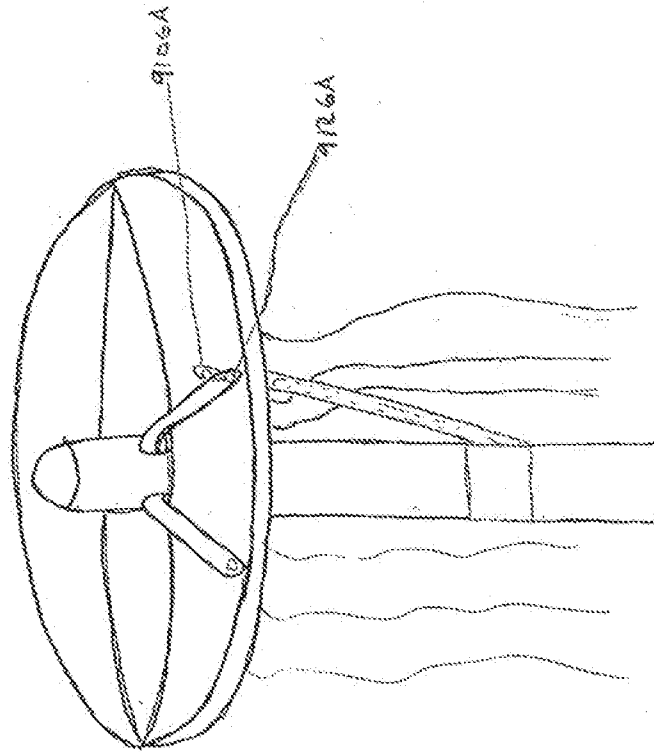


FIG. 108

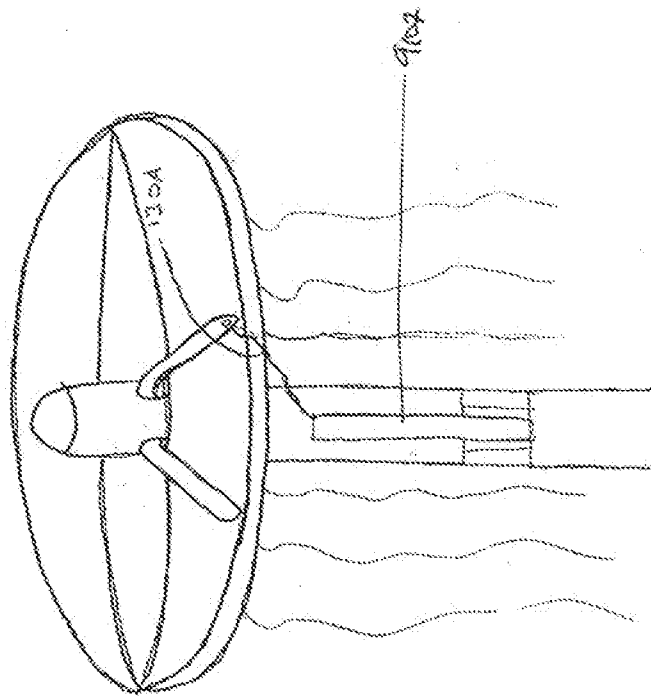


FIG. 109

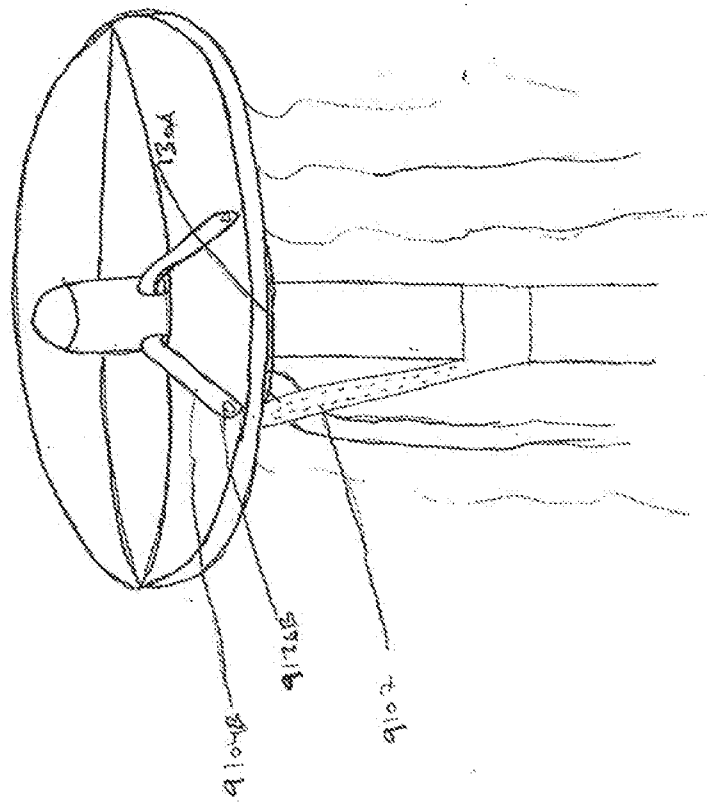


FIG. 110

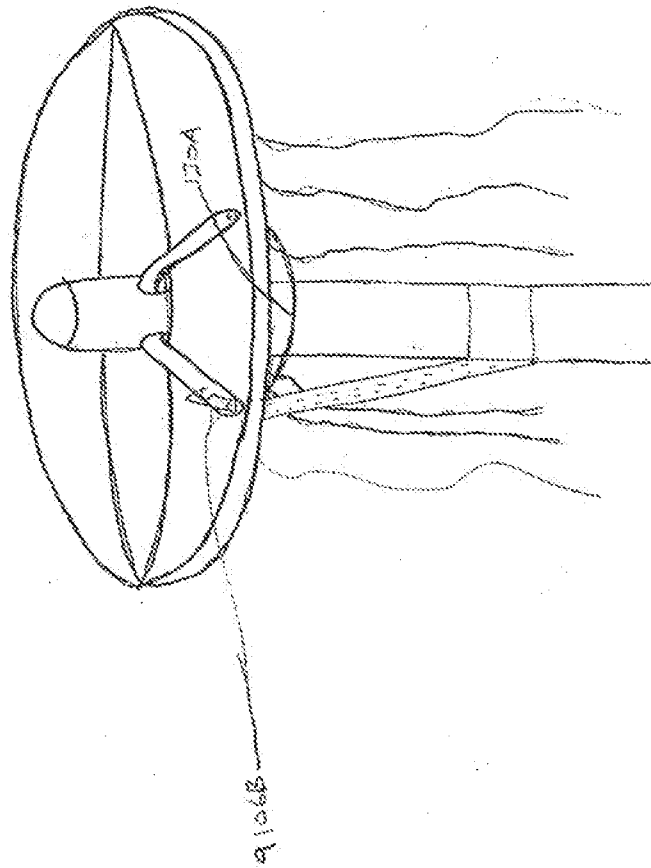


FIG. 111

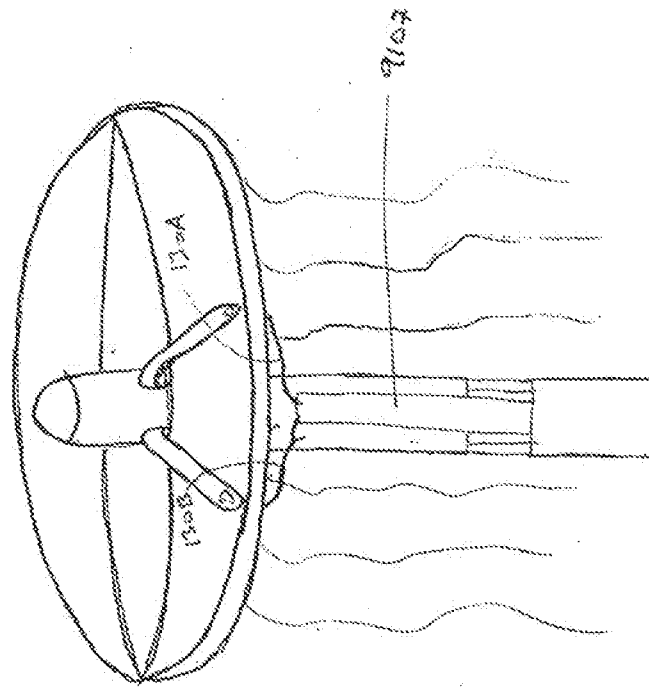
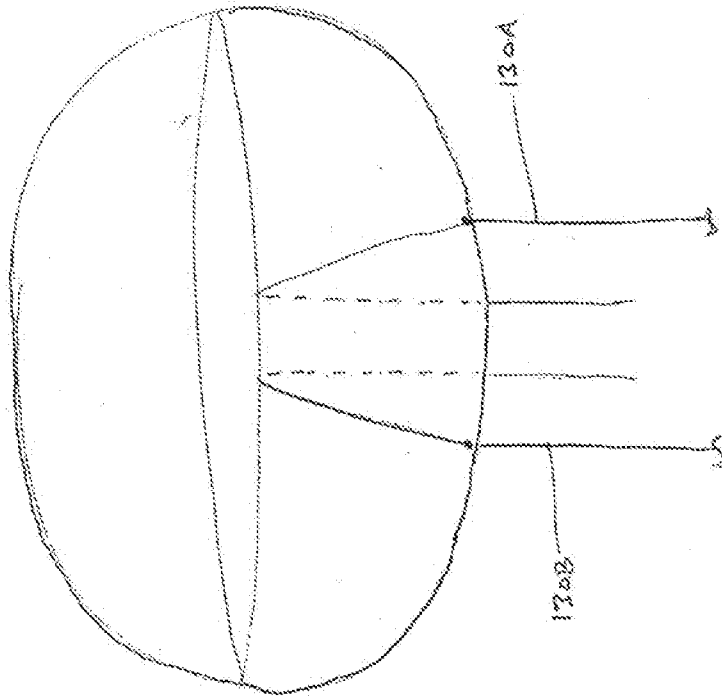


FIG. 112



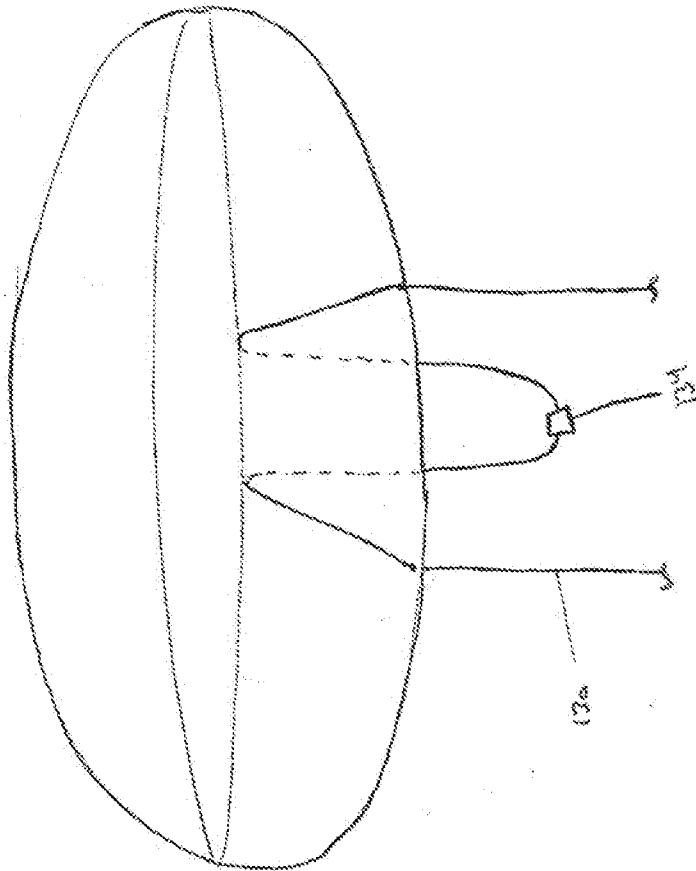


FIG. 114

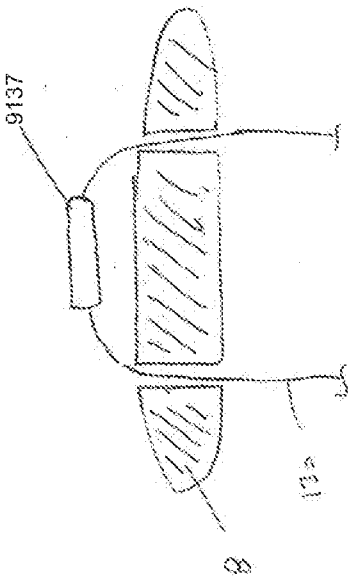


FIG. 115

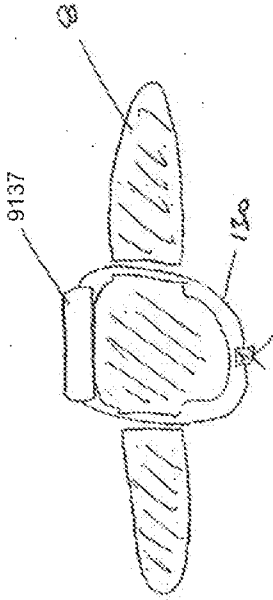
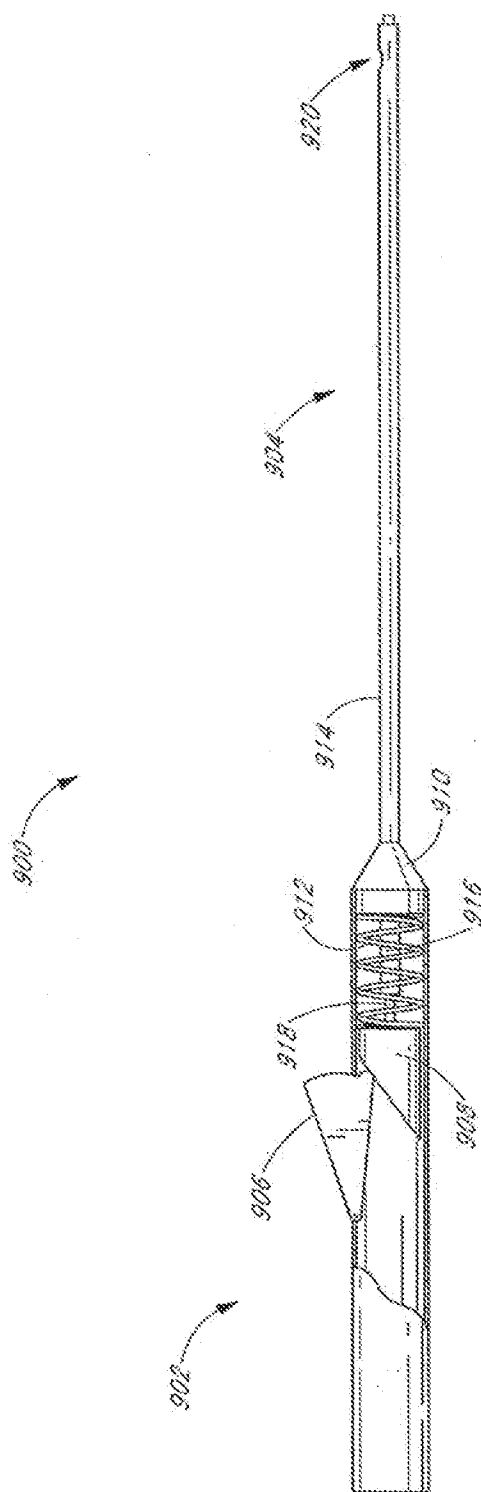


FIG. 116



115

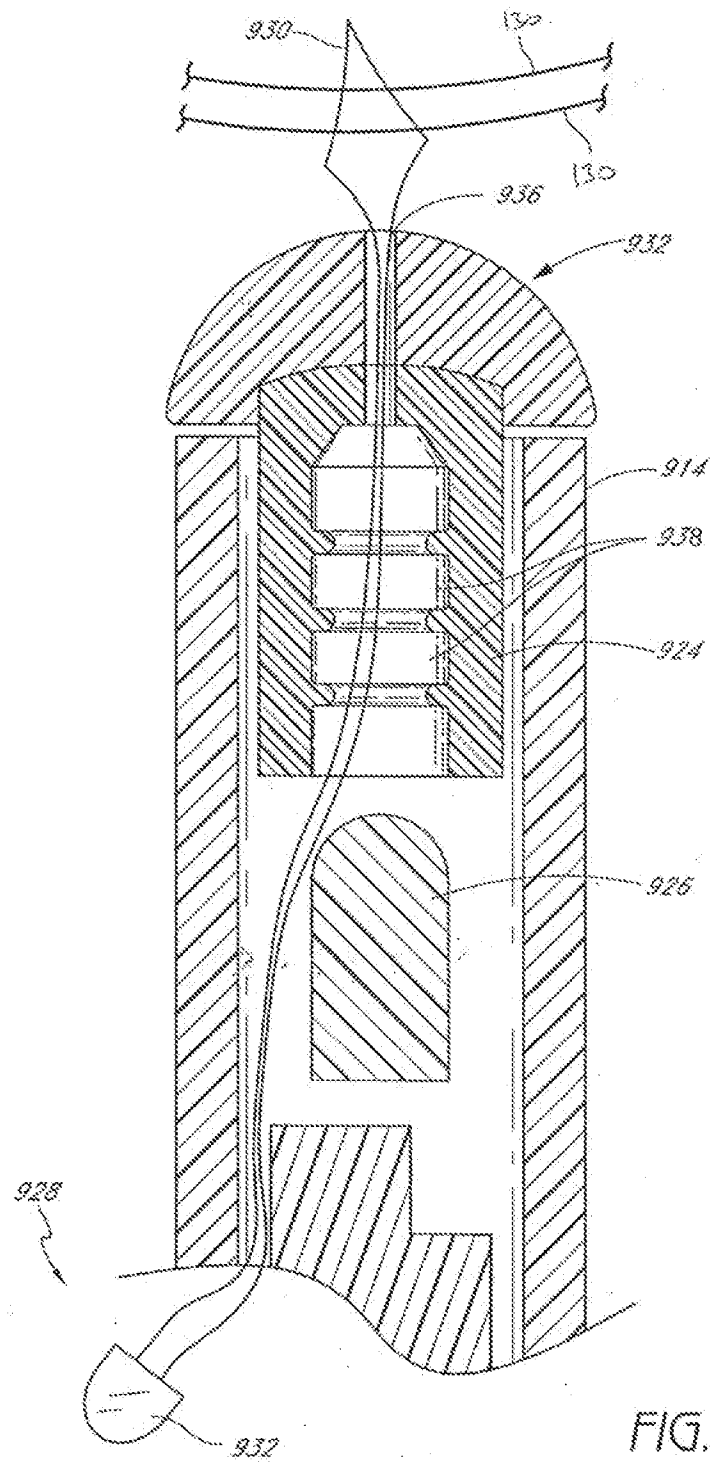


FIG. 118

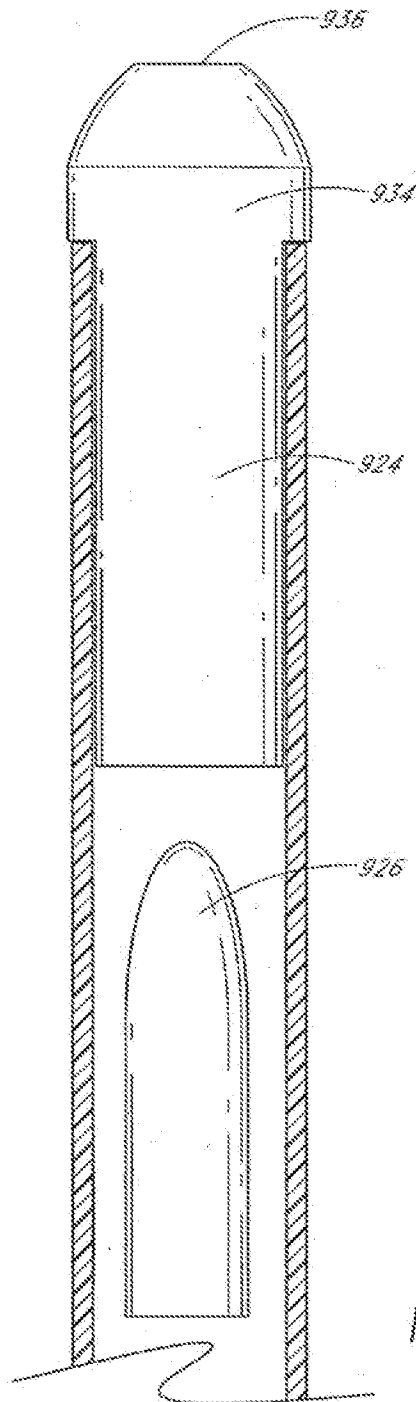


FIG. 119