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Bishop et al.

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(54) **PROSTHETIC IMPLANT DELIVERY
DEVICE WITH INTRODUCER CATHETER**

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CPC **A61F 2/2436** (2013.01); **A61F 2/2412**
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2250/0003 (2013.01)

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CPC .. **A61F 2/2427**; **A61F 2/2466**; **A61F 2/2418**;
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2017/00292; A61B 17/12109; A61B
2017/22001; A61B 2017/22051; A61B
17/12131; A61M 25/104; A61M 29/00
USPC 623/2.11
See application file for complete search history.

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Primary Examiner — Katherine M Shi

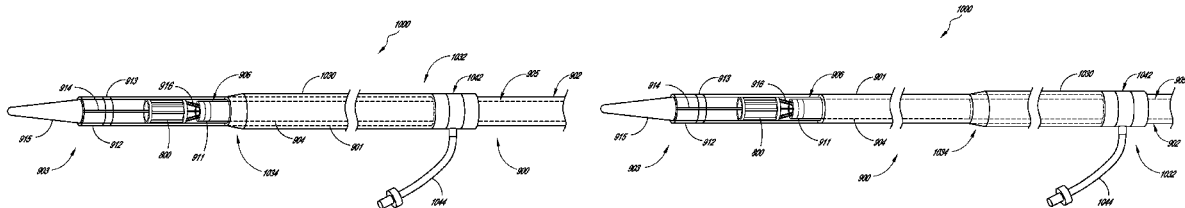
Assistant Examiner — Mohamed Gabr

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(57) **ABSTRACT**

A delivery system and a method for deploying a cardiovas-
cular prosthetic implant using a minimally invasive proce-
dure are disclosed. The delivery system comprises an intro-
ducer catheter, a delivery catheter having a proximal end and
a distal end, and a seal assembly, wherein an outer diameter
of the distal end of the delivery catheter is greater than an
inner diameter of the distal end of the introducer catheter.

24 Claims, 19 Drawing Sheets



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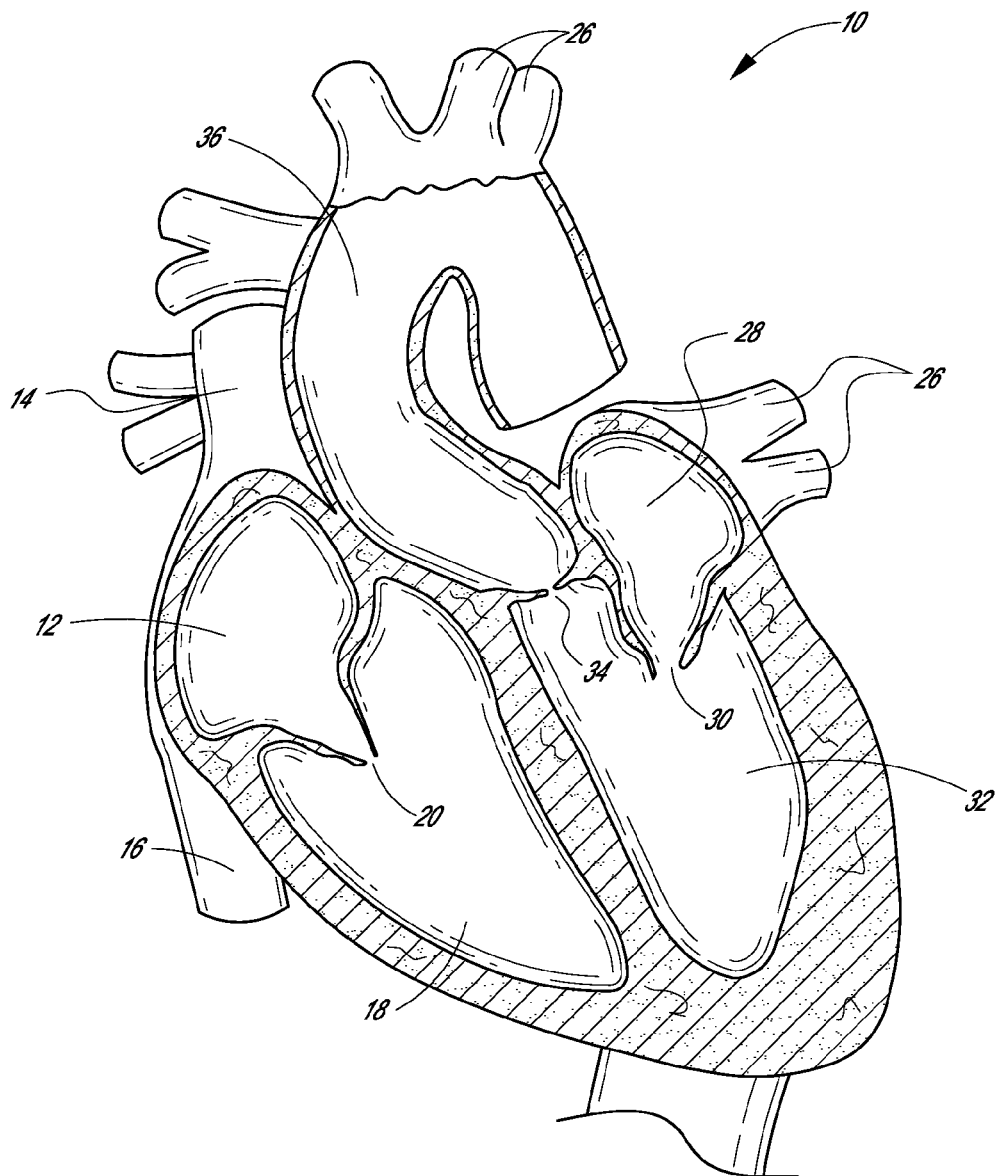


FIG. 1

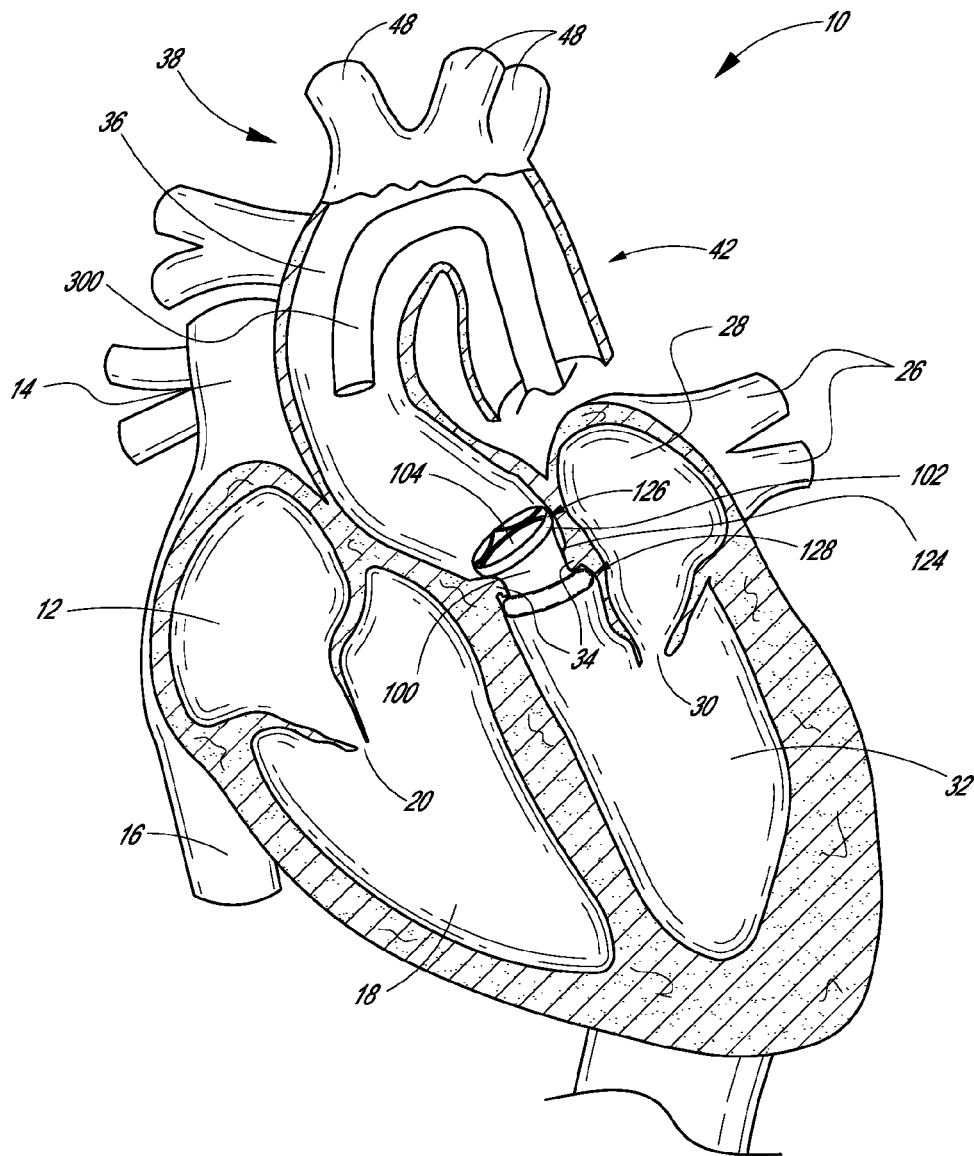


FIG. 2A

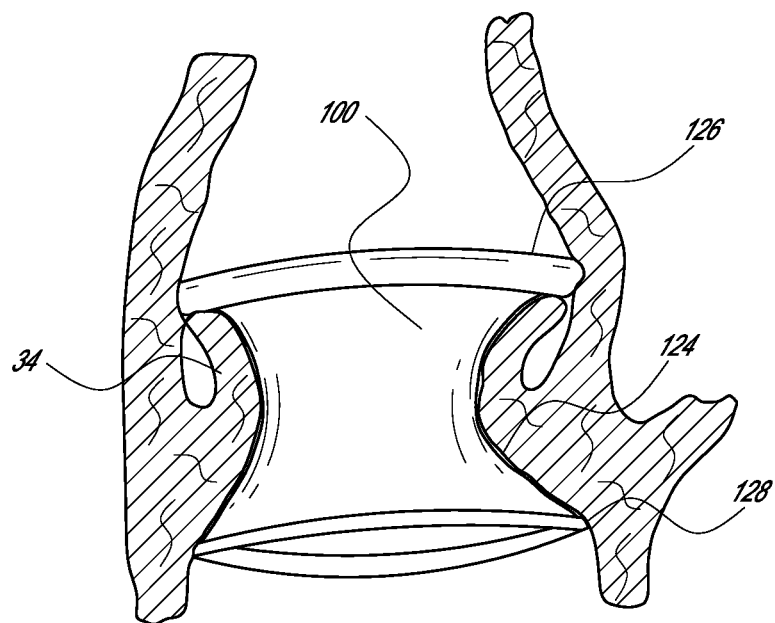


FIG. 2B

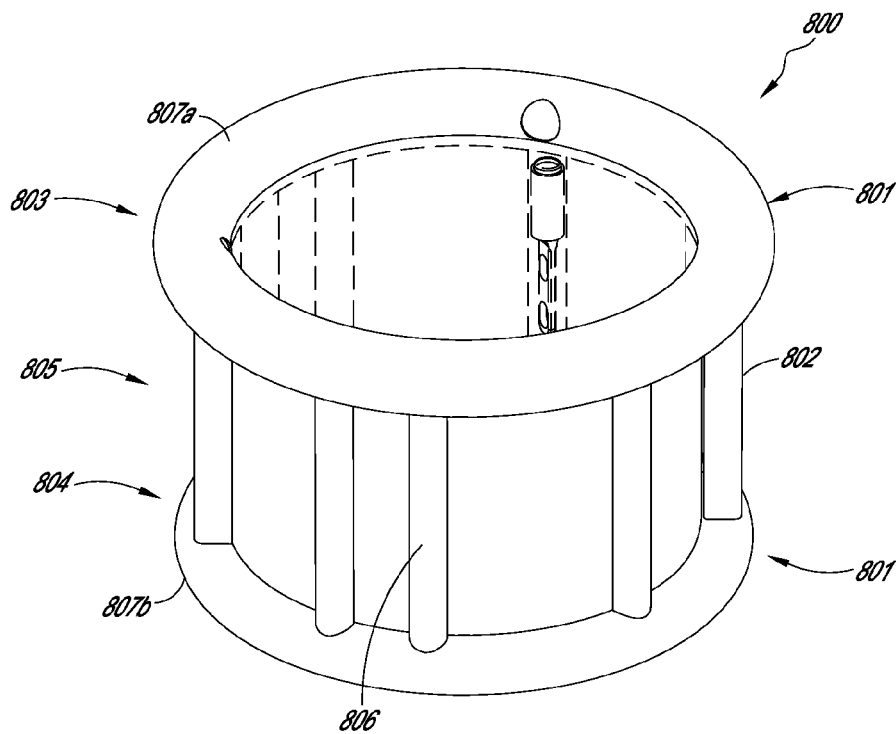


FIG. 3A

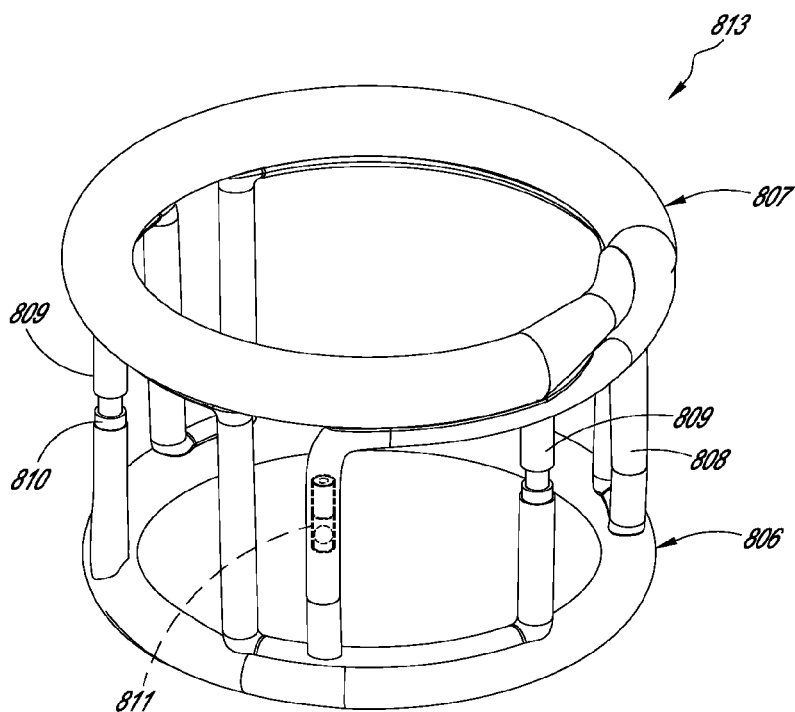


FIG. 3B

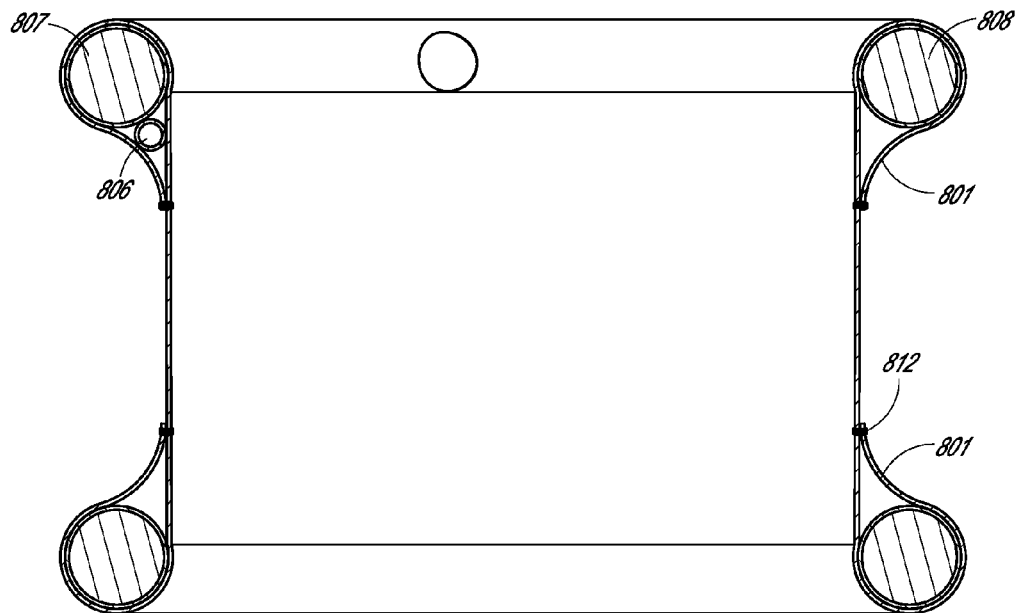


FIG. 3C

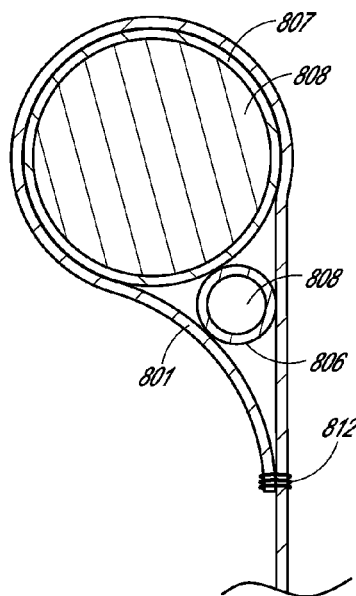


FIG. 3D

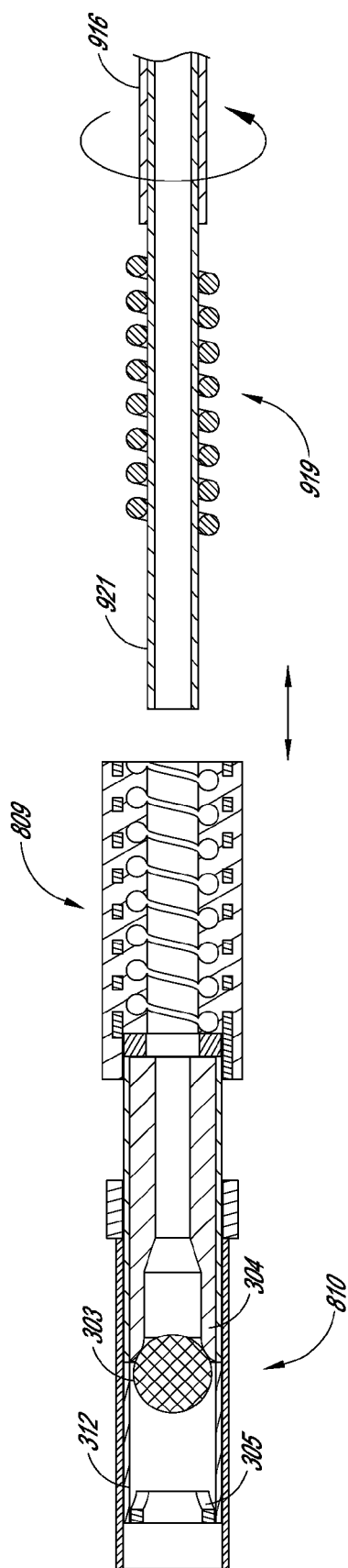


FIG. 4

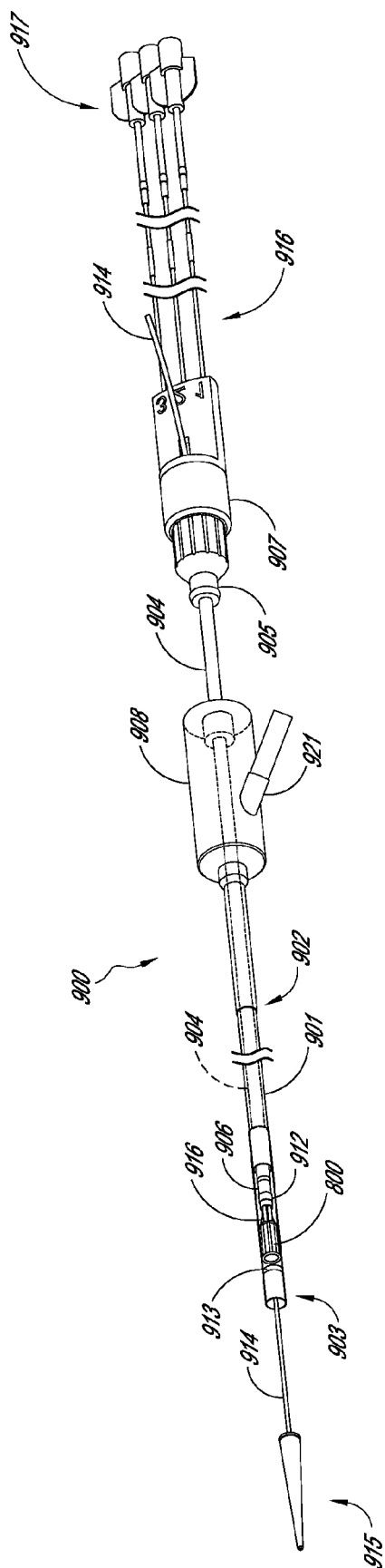


FIG. 5A

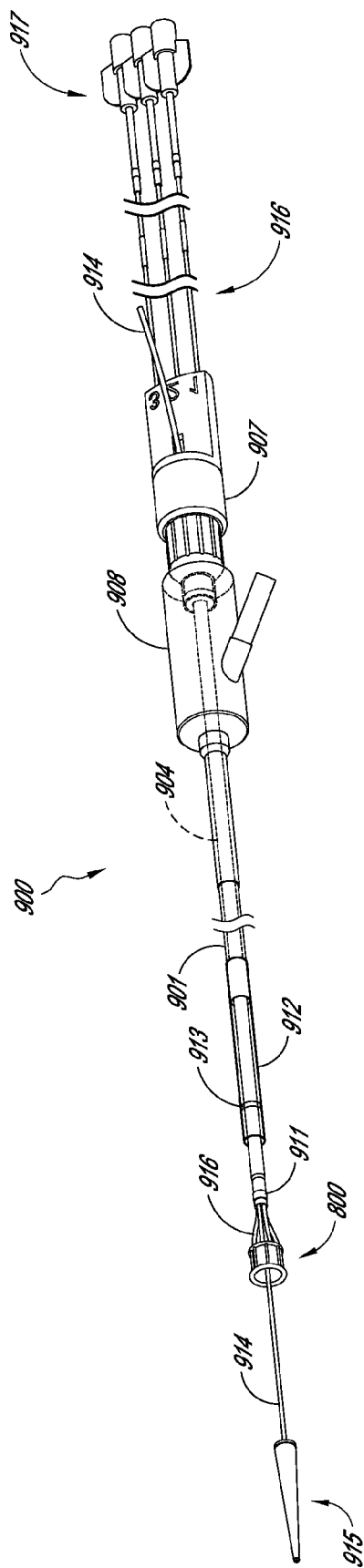


FIG. 5B

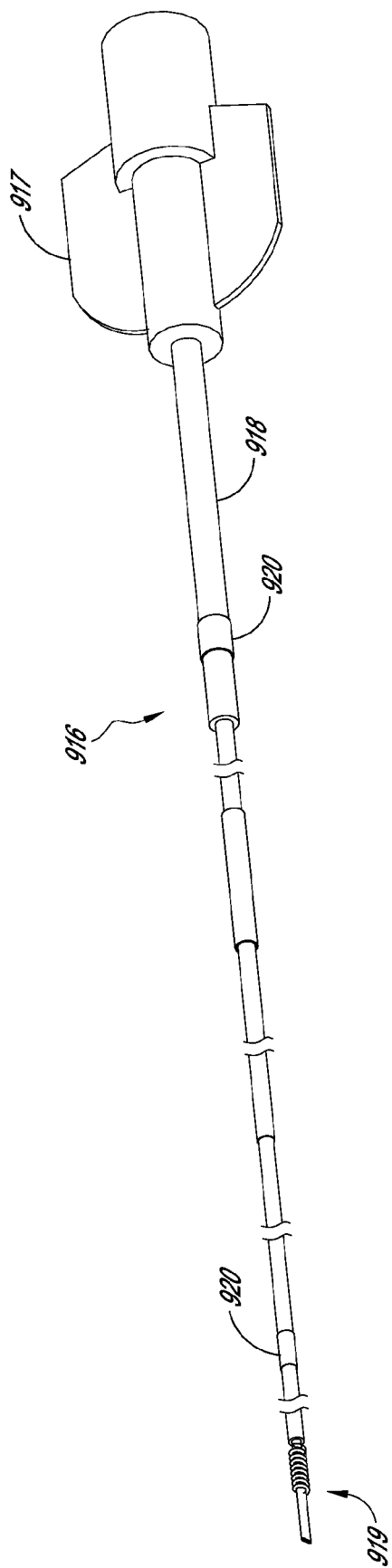


FIG. 5C

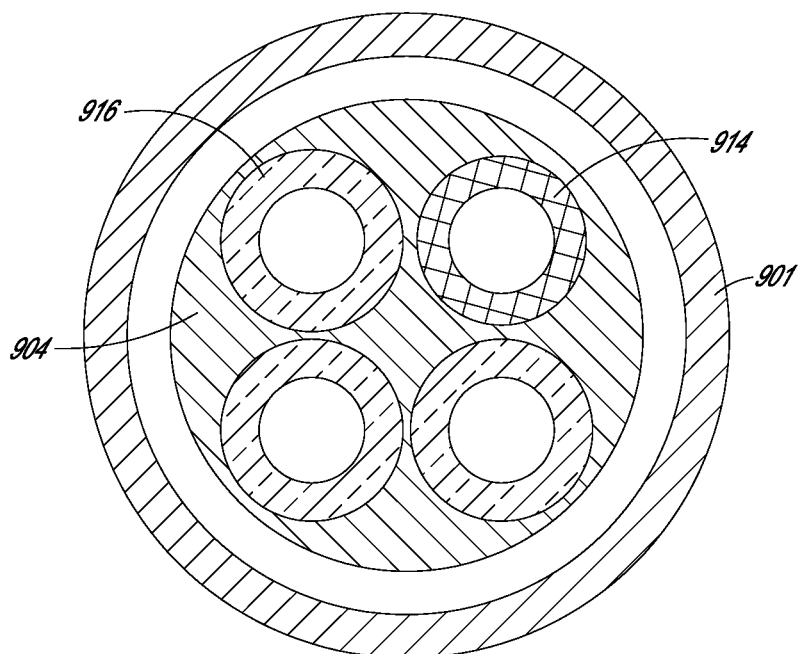


FIG. 6

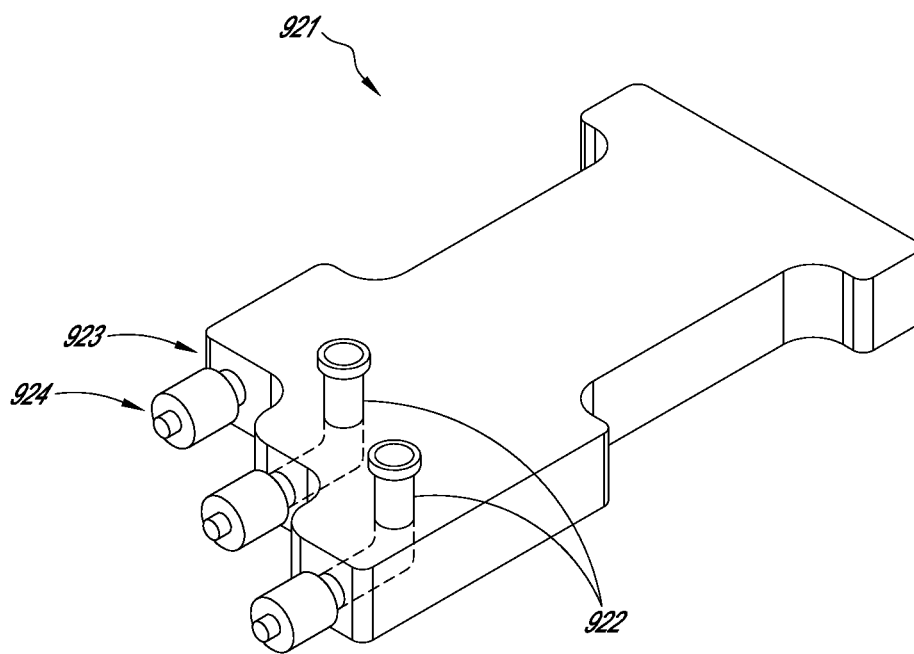


FIG. 7

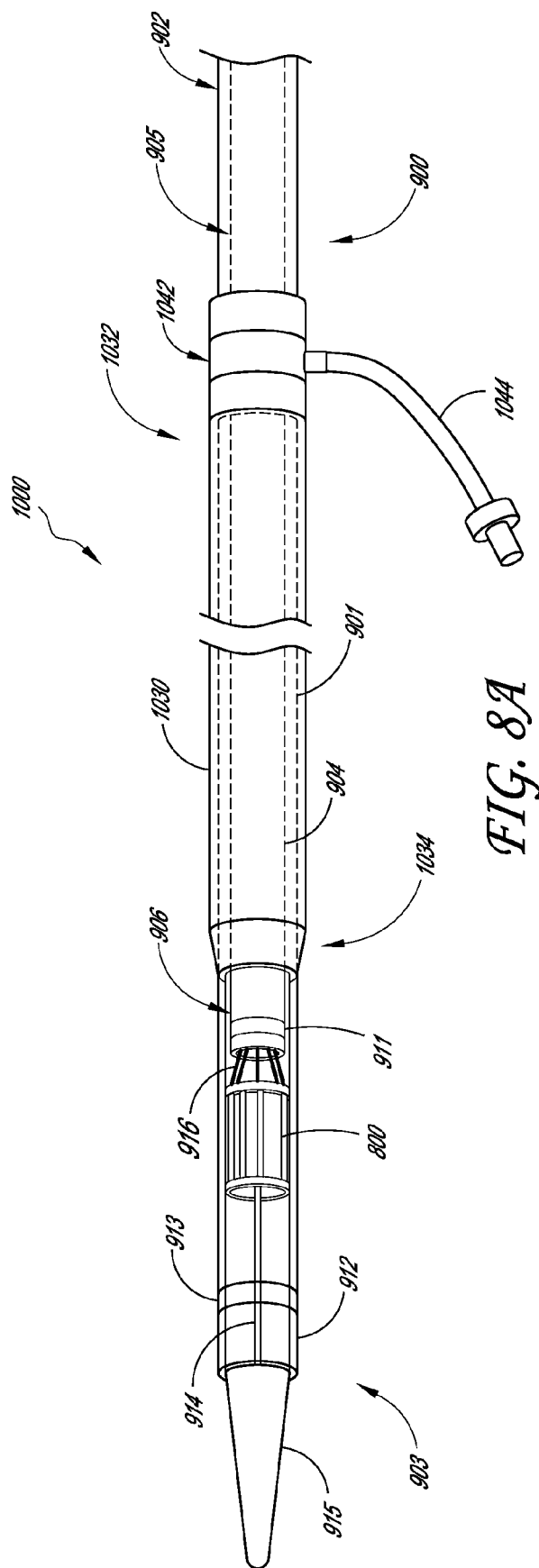
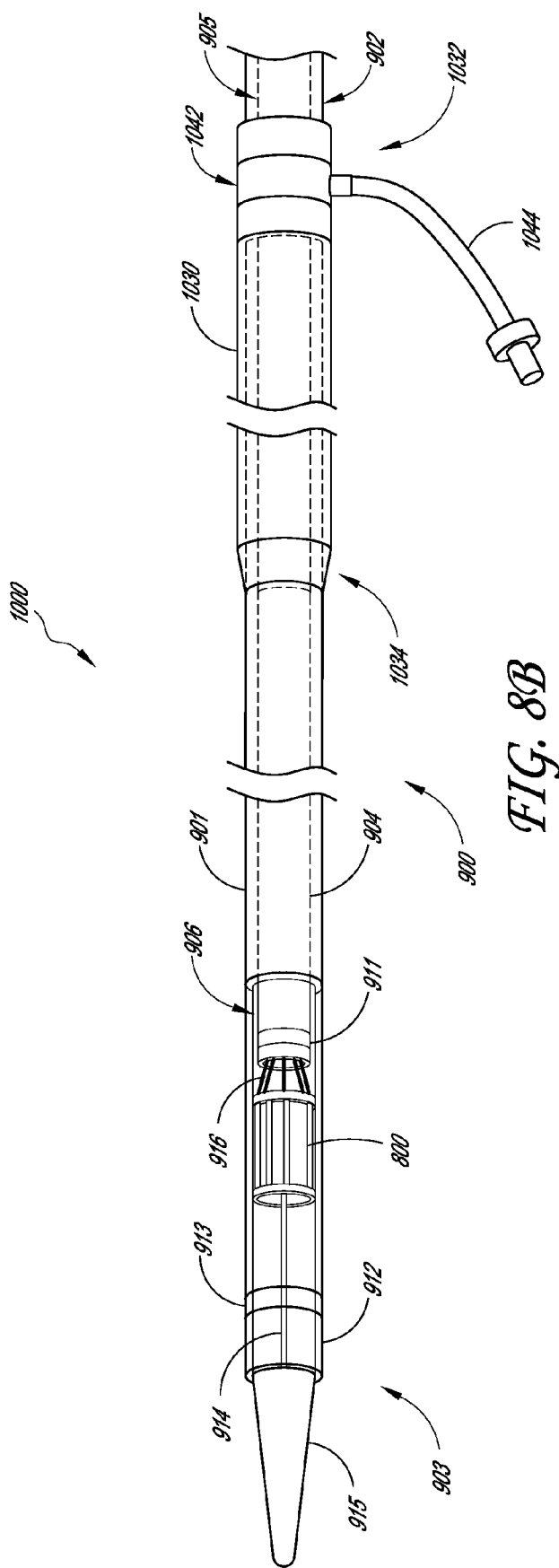


FIG. 8A



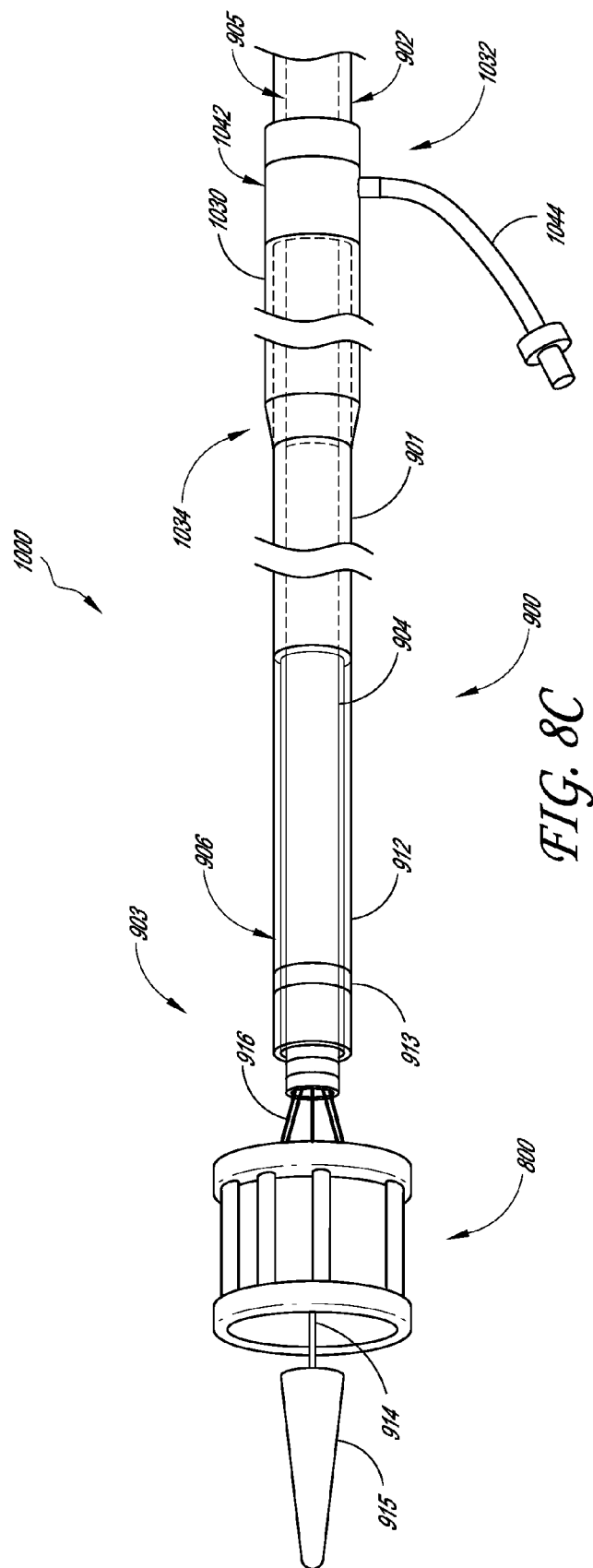
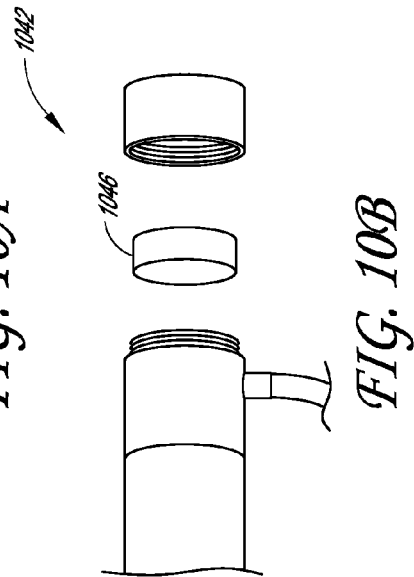
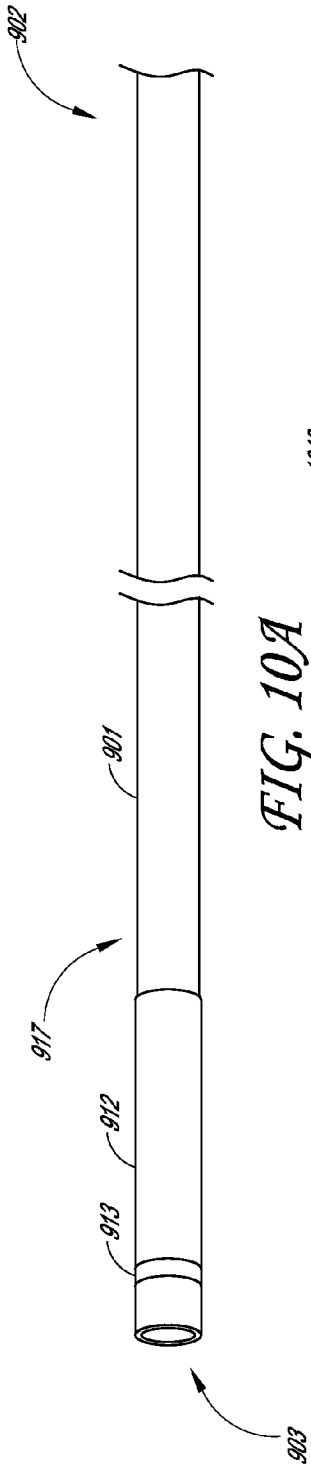
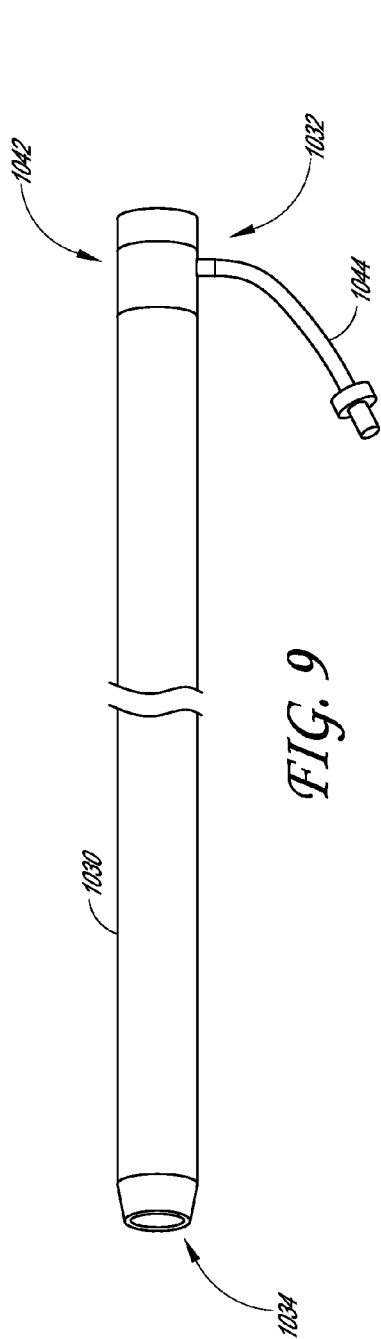


FIG. 8C



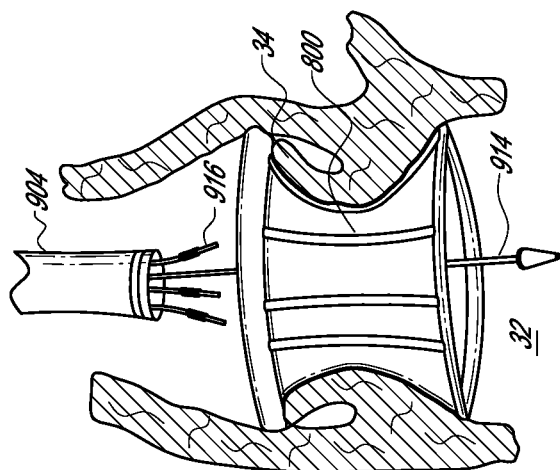


FIG. 11C

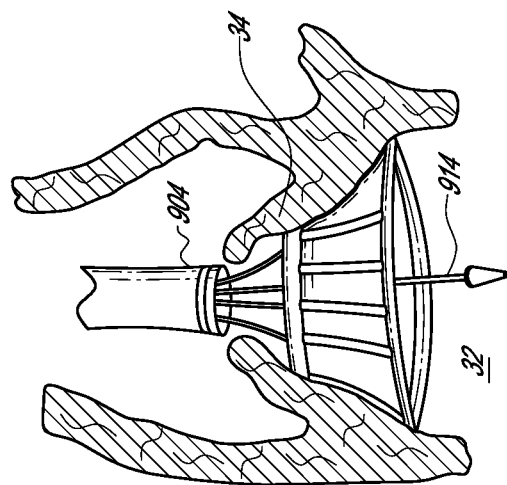


FIG. 11B

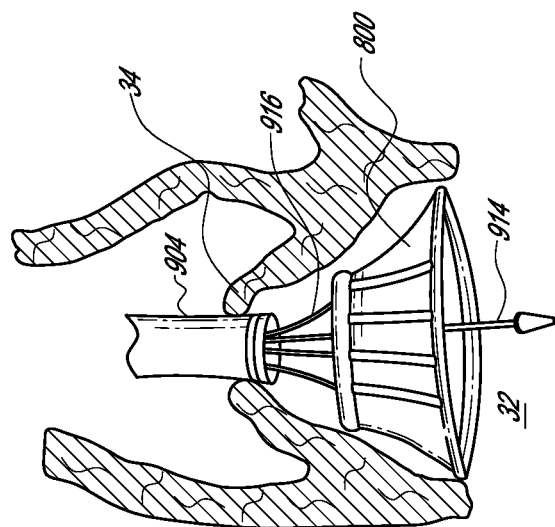


FIG. 11A

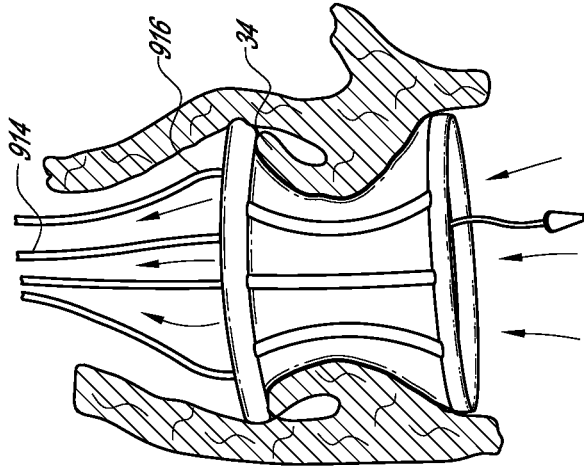


FIG. 12C

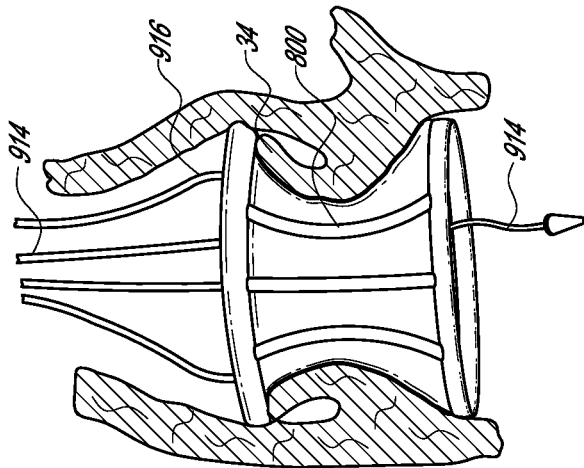


FIG. 12B

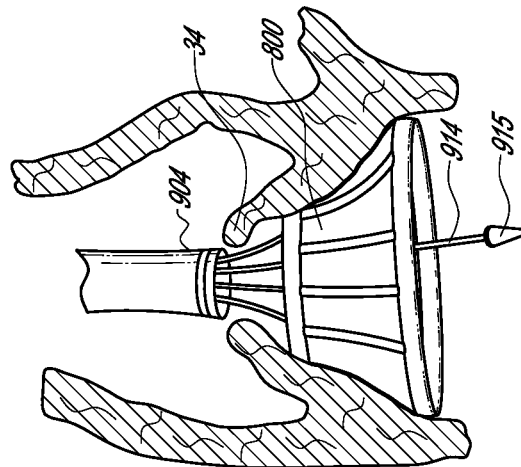


FIG. 12A

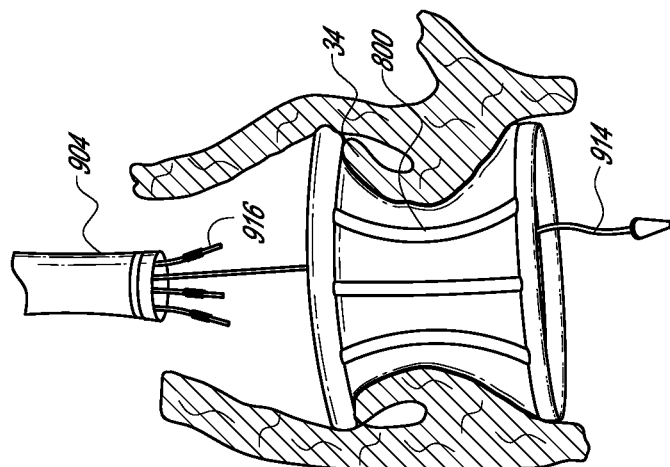


FIG. 12E

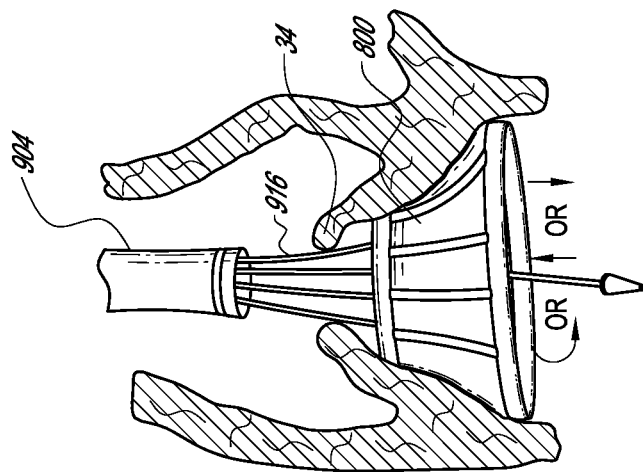


FIG. 12D

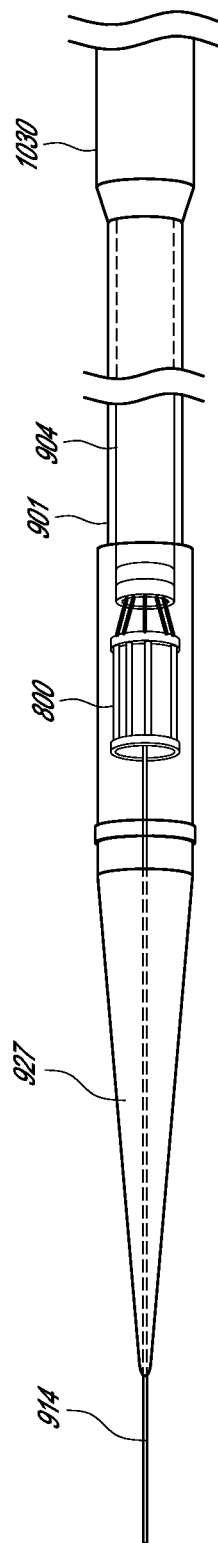


FIG. 13

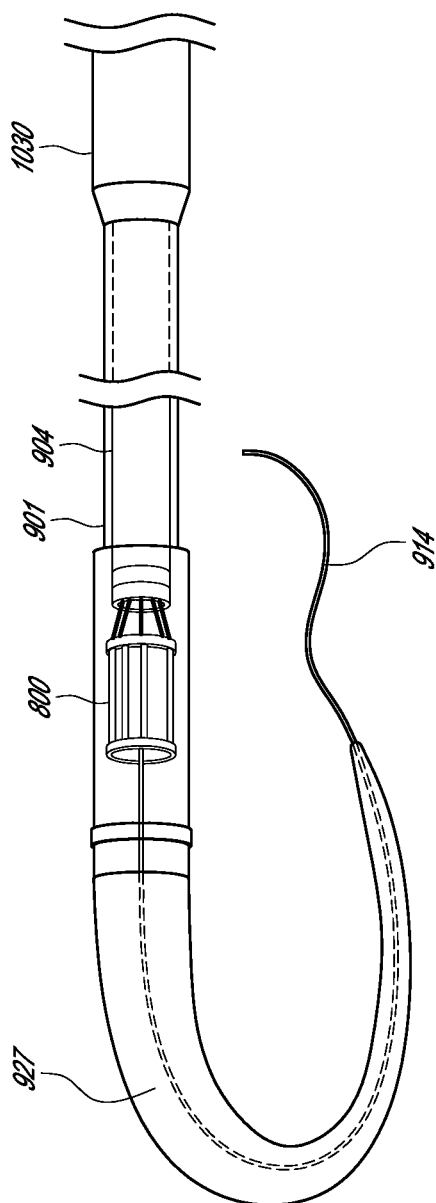


FIG. 14

1

PROSTHETIC IMPLANT DELIVERY DEVICE WITH INTRODUCER CATHETER

PRIORITY CLAIM TO RELATED PROVISIONAL APPLICATIONS

This present application claims priority benefit under 35 U.S.C. §119(e) from U.S. Provisional Application No. 61/640,862, filed May 1, 2012, entitled "Prosthetic Implant Delivery Device with Introducer Catheter," and U.S. Provisional Application No. 61/707,744, filed Sep. 28, 2012, entitled "Prosthetic Implant Delivery Device with Introducer Catheter," which is incorporated by reference herein.

BACKGROUND

1. Field

The present invention relates to medical methods and devices, and, more specifically, to methods and devices for percutaneously implanting a valve.

2. Description of the Related Art

The circulatory system is a closed loop bed of arterial and venous vessels supplying oxygen and nutrients to the body extremities through capillary beds. The driver of the system is the heart providing correct pressures to the circulatory system and regulating flow volumes as the body demands. Deoxygenated blood enters heart first through the right atrium and is allowed to the right ventricle through the tricuspid valve. Once in the right ventricle, the heart delivers this blood through the pulmonary valve and to the lungs for a gaseous exchange of oxygen. The circulatory pressures carry this blood back to the heart via the pulmonary veins and into the left atrium. Filling of the left atrium occurs as the mitral valve opens allowing blood to be drawn into the left ventricle for expulsion through the aortic valve and on to the body extremities. When the heart fails to continuously produce normal flow and pressures, a disease commonly referred to as heart failure occurs.

The four valves of the heart (i.e., the tricuspid, the pulmonary valve, the mitral valve and the aortic valve) function to ensure that blood flows in only one direction through the heart. The valves are made of thin flaps of tissue that open and close as the heart contracts. Valvular heart disease is any disease process involving one or more of the valves of the heart. For example, disease and age can cause the tissue of a heart valve to thicken and harden, which can cause the valve to fail to open properly and interfere with blood flow. This thickening process is often called stenosis. A heart valve can also become weakened or stretched such that it no longer closes properly, which can cause blood leak back through the valve. This leakage through the valve is often called regurgitation. Problems with a heart valve can increase the amount of work performed by the heart. The increase in work can cause the heart muscle to enlarge or thicken to make up for the extra workload.

The standard treatment for replacing an improperly working valve is to replace it. Traditionally, valve replacement has been accomplished via an open surgical procedure. More recently, transcatheter valve replacement has been attempted via percutaneous method such as a catheterization or delivery mechanism utilizing the vasculature pathways. Open surgical procedures often include the sewing of a new valve to the existing tissue structure for securement. Access to these sites generally include a thoracotomy or a sternotomy for the patient and include a great deal of recovery time. Such open-heart surgical procedures can include placing the patient on heart bypass to continue blood flow to vital organs

2

such as the brain during the surgery. Although open heart surgical valve repair and replacement can successfully treat many patients with valvular insufficiency, techniques currently in use are attended by significant morbidity and mortality due to the inherent invasiveness of open heart surgery.

According to recent estimates, more than 79,000 patients are diagnosed with aortic and mitral valve disease in U.S. hospitals each year. More than 49,000 mitral valve or aortic valve replacement procedures are performed annually in the U.S., along with a significant number of heart valve repair procedures. Since surgical techniques are highly invasive, the need for a less invasive method of heart valve replacement has long been recognized. As noted above, transcatheter heart valve systems have recently been developed in which heart valves are delivered through the heart by an intravascular catheter. Such transcatheter heart valves have the potential to reduce the anticipated mortality and morbidity rates associated with traditional surgical valve surgery particularly among patients of advanced age and/or with comorbidities. However, a need remains for improvements over the basic concept of transcatheter heart valve replacement. For example, current transcatheter valve replacement can sometimes result in vascular complications such as aortic dissection, access site or access related vascular and/or distal embolization from a vascular source. One method for reducing such complications is to reduce ratio of the diameter of the delivery device for the heart valve.

SUMMARY

One arrangement for delivering a cardiovascular prosthetic implant using a minimally invasive procedure comprises an introducer catheter having a proximal end and a distal end. A delivery catheter extends through the introducer catheter. The delivery catheter has a proximal end and a distal end extending beyond the distal end of the introducer catheter. A hemostasis seal assembly can be positioned at a proximal end of the introducer catheter. An outer diameter of the distal end of the delivery catheter is greater than an inner diameter of the distal end of the introducer catheter.

In the above mentioned arrangement, the delivery system can include a cardiovascular prosthetic implant at the distal end of the delivery catheter. The cardiovascular prosthetic implant can include an inflatable cuff and a tissue valve.

In any of the above mentioned arrangements, the delivery system can include at least one link between the catheter body and the cardiovascular prosthetic implant.

In any of the above mentioned arrangements, the inner diameter of the distal end of the introducer can be 16 F or less.

In any of the above mentioned arrangements, the introducer catheter can include an elongated tapered tip.

In any of the above mentioned arrangements, the introducer catheter can include a tapered tip that can transition from a first enlarged length configuration to a second shorter configuration.

In any of the above mentioned arrangements, the system can include a long tip in a first configuration and a short tip in a second configuration.

In any of the above mentioned arrangements, the system can include a tip that has a straight configuration and a bent configuration.

In another arrangement, a delivery system for delivering a cardiovascular prosthetic implant using a minimally invasive procedure includes an introducer catheter having a proximal end and a distal end and a lumen extending from

3

the proximal end to the distal end of the introducer catheter. The introducer catheter has an outer diameter defined by an outer surface of the introducer catheter and an inner diameter defining the through lumen. A delivery catheter extends through the introducer catheter. The delivery catheter comprises a tubular body having a proximal end and a distal end. The distal end includes a sheath jacket and stem portion extending proximally from the sheath jacket. The sheath jacket has an outer surface that defines an outer diameter of the sheath jacket. The outer diameter of the sheath jacket is greater than the inner diameter of the introduced catheter at the distal end of the introducer catheter. The stem portion has an outer surface that defines an outer diameter of the stem portion. The outer diameter of the stem portion is smaller than the inner diameter of the introducer catheter. A cardiovascular prosthetic implant is positioned at least partially within the sheath jacket.

In any of the above mentioned arrangements, the delivery system can include a seal assembly at a proximal end of the introducer catheter.

In any of the above mentioned arrangements, the delivery system can include a cardiovascular prosthetic implant having an inflatable cuff and a tissue valve.

In any of the above mentioned arrangements, the delivery system can include at least one inflation lumen extending between an inflatable cuff and the proximal end of the introducer catheter, the inflation lumen extending through the delivery catheter.

In any of the above mentioned arrangements, the delivery system can include at least one link between the catheter body and a cardiovascular prosthetic implant.

In any of the above mentioned arrangements, the inner diameter of the distal end of the introducer catheter is about 16 F.

In any of the above mentioned arrangements, the delivery system can include a tubing extending through the delivery catheter and a cardiovascular prosthetic implant.

In any of the above mentioned arrangements, the delivery system can include a distal tip coupled to a distal end of the tubing, the distal tip having a maximum outside diameter that is approximately the same as the outside diameter of a jacket sheath.

In any of the above mentioned arrangements, the delivery system can include a sheath jacket is coupled to a distal end of a stem portion.

In another arrangement, a prosthetic implant is positioned within a heart. The method comprises advancing an introducer catheter positioned over a delivery catheter comprising a prosthetic valve into a patient's vascular system, translumenally advancing the prosthetic valve to a position proximate a native valve of the heart; and deploying the prosthetic valve.

In the above mentioned method, the method can include advancing the introducer catheter and delivery catheter over a guidewire.

In any of the above mentioned methods, the method can include inserting the introducer catheter into the femoral artery.

In any of the above mentioned methods, the method can include advancing the prosthetic valve through the aorta.

In any of the above mentioned methods, the method can include inflating a portion of the prosthetic valve.

In any of the above mentioned methods, the method can include inserting a distal end of the delivery catheter directly into an access vessel.

4

In any of the above mentioned methods, the method can include removing the delivery catheter and introducer catheter together from the patient.

Further features and advantages of the present invention will become apparent from the detailed description of preferred embodiments which follows, when considered together with the attached drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional schematic view of a heart and its major blood vessels.

FIG. 2A is a partial cut-away view a left ventricle and aortic with an prosthetic aortic valve implant according to one embodiment.

FIG. 2B is a side view of the implant of FIG. 2A positioned across a native aortic valve.

FIG. 3A is a front perspective view of the implant of FIG. 2B.

FIG. 3B is a front perspective view of an inflatable support structure of the implant of FIG. 3A.

FIG. 3C is a cross-sectional side view of the implant of FIG. 3A.

FIG. 3D is an enlarged cross-sectional view of an upper portion of FIG. 3C.

FIG. 4 is a cross-sectional view of the connection port and the inflation valve in the implant of FIG. 3B.

FIG. 5A is a side perspective view of a deployment catheter with retracted implant.

FIG. 5B is a side perspective view of the deployment catheter of FIG. 5A with the implant outside of the outer sheath jacket.

FIG. 5C is a side perspective view of the position-and-fill lumen (PFL), which is a component of the deployment catheter of FIGS. 5A and 5B.

FIG. 6 is a cross-sectional view taken through line A-A of FIG. 5B.

FIG. 7 is a side perspective view of a loading tool base.

FIG. 8A is a side perspective view of an introduced catheter deployment catheter with retracted implant.

FIG. 8B is a side perspective view of the introducer catheter and deployment catheter of FIG. 8A with the implant outside of the outer sheath jacket.

FIG. 8C is a side perspective view of the position-and-fill lumen (PFL), which is a component of the deployment catheter of FIGS. 8A and 8B.

FIG. 9 is a side view of the introducer catheter of FIGS. 8A-8C.

FIG. 10A is a side view of the deployment catheter of FIGS. 8A-8C.

FIG. 10B is an exploded view of a seal assembly.

FIG. 11A illustrates a step of partially deploying and positioning an artificial valve implant.

FIG. 11B illustrates a second step of partially deploying and positioning an artificial valve implant.

FIG. 11C illustrates a third step of partially deploying and positioning an artificial valve implant.

FIG. 12A illustrates a step deploying, testing and repositioning an artificial valve implant.

FIG. 12B illustrates a step deploying, testing and repositioning an artificial valve implant.

FIG. 12C illustrates a step deploying, testing and repositioning an artificial valve implant.

FIG. 12D illustrates a step deploying, testing and repositioning an artificial valve implant.

FIG. 12E illustrates a step deploying, testing and repositioning an artificial valve implant.

5

FIG. 13 illustrates a side view of another embodiment of a deployment system.

FIG. 14 illustrates a side view of another embodiment of a deployment system.

DETAILED DESCRIPTION

FIG. 1 is a schematic cross-sectional illustration of the anatomical structure and major blood vessels of a heart 10. Deoxygenated blood is delivered to the right atrium 12 of the heart 10 by the superior and inferior vena cava 14, 16. Blood in the right atrium 12 is allowed into the right ventricle 18 through the tricuspid valve 20. Once in the right ventricle 18, the heart 10 delivers this blood through the pulmonary valve 22 to the pulmonary arteries 24 and to the lungs for a gaseous exchange of oxygen. The circulatory pressures carry this blood back to the heart via the pulmonary veins 26 and into the left atrium 28. Filling of the left atrium 28 occurs as the mitral valve 30 opens allowing blood to be drawn into the left ventricle 32 for expulsion through the aortic valve 34 and on to the body extremities through the aorta 36. When the heart 10 fails to continuously produce normal flow and pressures, a disease commonly referred to as heart failure occurs.

One cause of heart failure is failure or malfunction of one or more of the valves of the heart 10. For example, the aortic valve 34 can malfunction for several reasons. For example, the aortic valve 34 may be abnormal from birth (e.g., bicuspid, calcification, congenital aortic valve disease), or it could become diseased with age (e.g., acquired aortic valve disease). In such situations, it can be desirable to replace the abnormal or diseased valve 34.

FIG. 2 is a schematic illustration of the left ventricle 32, which delivers blood to the aorta 36 through the aortic valve 34. The aorta 36 comprises (i) the ascending aorta 38, which arises from the left ventricle 32 of the heart 10, (ii) the aortic arch 40, which arches from the ascending aorta 38 and (iii) the descending aorta 42 which descends from the aortic arch 40 towards the abdominal aorta (not shown). Also shown are the principal branches of the aorta 14, which include the innominate artery 44 that immediately divides into the right carotid artery (not shown) and the right subclavian artery (not shown), the left carotid 46 and the subclavian artery 48. Inflatable Prosthetic Aortic Valve Implant

With continued reference to FIG. 2A, a cardiovascular prosthetic implant 800 in accordance with one embodiment is shown spanning the native abnormal or diseased aortic valve 34. The implant 800 and various modified embodiments thereof will be described in detail below. As will be explained in more detail below, the implant 800 can be delivered minimally invasively using an intravascular delivery catheter 900 or trans apical approach with a trocar. Further details, additional embodiments of and/or modifications of the implant or delivery system can be found in U.S. Pat. Nos. 7,641,686, 8,012,201 and U.S. Publication Nos. 2007/0005133; 2009/0088836 and 2012/0016468, the entirety of these patents and publications are hereby incorporated by reference herein in their entirety.

The description below will be primarily in the context of replacing or repairing an abnormal or diseased aortic valve 34. However, various features and aspects of methods and structures disclosed herein are applicable to replacing or repairing the mitral valve 30, pulmonary valve 22 and/or tricuspid valve 20 of the heart 10 as those of skill in the art will appreciate in light of the disclosure herein. In addition, those of skill in the art will also recognize that various features and aspects of the methods and structures disclosed herein can

6

be used in other parts of the body that include valves or can benefit from the addition of a valve, such as, for example, the esophagus, stomach, ureter and/or vesicle, biliary ducts, the lymphatic system and in the intestines.

In addition, various components of the implant and its delivery system will be described with reference to coordinate system comprising “distal” and “proximal” directions. In this application, distal and proximal directions refer to the deployment system 900, which is used to deliver the implant 800 and advanced through the aorta 36 in a direction opposite to the normal direction of blood through the aorta 36. Thus, in general, distal means closer to the heart while proximal means further from the heart with respect to the circulatory system.

In some embodiments, the implant 800 can be a prosthetic aortic valve implant. With reference to FIG. 2B in the illustrated embodiment, the implant 800 can have a shape that can be viewed as a tubular member or hyperboloid shape where a waist 805 excludes the native valve 34 or vessel and proximally the proximal end 803 forms a hoop or ring to seal blood flow from re-entering the left ventricle 32. Distally, the distal end 804 can also form a hoop or ring to seal blood from forward flow through the outflow track. Between the two ends 803 and 804, a valve 104 can be mounted to the cuff or body 802 such that when inflated the implant 800 excludes the native valve 34 or extends over the former location of the native valve 34 and replaces its function. The distal end 804 can have an appropriate size and shape so that it does not interfere with the proper function of the mitral valve, but still secures the valve adequately. For example, there can be a notch, recess or cut out in the distal end 804 of the device to prevent mitral valve interference. The proximal end 803 can be designed to sit in the aortic root. In one arrangement, the proximal end 803 can be shaped in such a way that it maintains good apposition with the wall of the aortic root. This can prevent the device from migrating back into the ventricle 32. In some embodiments, the implant 800 can be configured such that it does not extend so high that it interferes with the coronary arteries.

Any number of additional inflatable rings or struts can be disposed between the proximal end 803 and distal end 804. The distal end 804 of the implant 800 can be positioned within the left ventricle 34 and can utilize the aortic root for axial stabilization as it may have a larger diameter than the aortic lumen. This arrangement may lessen the need for hooks, barbs or an interference fit to the vessel wall. Since the implant 800 can be placed without the aid of a dilatation balloon for radial expansion, the aortic valve 34 and vessel may not have any duration of obstruction and would provide the patient with more comfort and the physician more time to properly place the device accurately. Since in the illustrated arrangement, the implant 800 is not utilizing a support member with a single placement option as a plastically deformable or shaped memory metal stent does, the implant 800 can be movable and or removable if desired. This could be performed multiple times until the implant 800 is permanently disconnected from the delivery catheter 900 as will be explained in more detail below. In addition, as will be described below, the implant 800 can include features, which allow the implant 800 to be tested for proper function, sealing and sizing, before the catheter 900 is disconnected.

With reference to FIG. 3A, the implant 800 of the illustrated embodiment generally comprises the inflatable cuff or body 802, which is configured to support the valve 104 (see FIG. 2A) that is coupled to the cuff 802. In some embodiments, the valve 104 is a tissue valve. In some embodiments, the tissue valve has a thickness equal to or

greater than about 0.011 inches. In another embodiment, the tissue valve has a thickness equal to or greater than about 0.018 inches. As will be explained in more detail below, the valve **104** can be configured to move in response to the hemodynamic movement of the blood pumped by the heart **10** between an “open” configuration where blood can flow through the implant **800** in a first direction and a “closed” configuration whereby blood is prevented from back flowing through the valve **104** in a second direction.

In the illustrated embodiment, the cuff **802** can comprise a thin flexible tubular material such as a flexible fabric or thin membrane with little dimensional integrity. As will be explained in more detail below, the cuff **802** can be changed preferably, in situ, to a support structure to which other components (e.g., the valve **104**) of the implant **800** can be secured and where tissue ingrowth can occur. Uninflated, the cuff **802** can be incapable of providing support. In one embodiment, the cuff **802** comprises Dacron, PTFE, ePTFE, TFE or polyester fabric as seen in conventional devices such as surgical stented or stent less valves and annuloplasty rings. The fabric thickness can range from about 0.002 inches to about 0.020 inches depending upon material selection and weave. Weave density may also be adjusted from a very tight weave to prevent blood from penetrating through the fabric to a looser weave to allow tissue to grow and surround the fabric completely. In certain embodiments, the fabric may have a linear mass density about 20 denier or lower.

With reference to FIGS. 3B-3D, in the illustrated embodiment, the implant **800** can include an inflatable structure **813** that is formed by one or more inflation channels **808**. The inflatable channels **808** can be formed by a pair of distinct balloon rings or toroids (**807a** and **807b**) and struts **806**. In the illustrated embodiment, the implant **800** can include a proximal toroid **807a** at the proximal end **803** of the cuff **802** and a distal toroid **807b** at the distal end **804** of the cuff **802**. The toroids **807** can be secured to the cuff **802** in any of a variety of manners. With reference to FIGS. 3C and 3D, in the illustrated embodiment, the toroids **807** can be secured within folds **801** formed at the proximal end **803** and the distal end **804** of the cuff **802**. The folds **801**, in turn, can be secured by sutures or stitches **812**. When inflated, the implant **800** can be supported in part by series of struts **806** surrounding the cuff **802**. In some embodiments, the struts **806** are configured so that the portions on the cuff run substantially perpendicular to the toroids. The struts can be sewn onto the cuff **802** or can be enclosed in lumens made from the cuff material and sewn onto the cuff **802**. The toroids **807** and the struts **806** together can form one or more inflatable channels **808** that can be inflated by air, liquid or inflation media.

With reference to FIG. 3B, the inflation channels can be configured so that the cross-sectional profile of the implant **800** is reduced when it is compressed or in the retracted state. For example, the inflation channels **808** can be arranged in a step-function pattern. The inflation channels **808** can have three connection ports **809** for coupling to the delivery catheter **900** via position and fill lumen tubing (PFL) tubing **916** (see FIGS. 5A-5C). In some embodiments, at least two of the connection ports **809** also function as inflation ports, and inflation media, air or liquid can be introduced into the inflation channel **808** through these ports. The PFL tubing **916** can be connected to the connection ports **809** via suitable connection mechanisms. In one embodiment, the connection between the PFL tubing **916** and the connection port **809** is a screw connection. In some embodiments, an inflation valve **810** is present in the con-

nection port **809** and can stop the inflation media, air or liquid from escaping the inflation channels **808** after the PFL tubing is disconnected. In some embodiments, the distal toroid **807b** and the proximal toroid **807a** can be inflated independently. In some embodiments, the distal toroid **807b** can be inflated separately from the struts **806** and the proximal toroid **807a**. The separate inflation can be useful during the positioning of the implant at the implantation site. With reference to FIGS. 3C and 3D, the portion of struts **806** can run parallel to the toroids **807** and can be encapsulated within the folds **801** of the implant **800**. This arrangement may also aid in reducing the cross-sectional profile when the implant is compressed or folded.

As mentioned above, the inflatable rings or toroids **807** and struts **806** can form the inflatable structure **813**, which, in turn, defines the inflation channels **808**. The inflation channels **808** can receive inflation media to generally inflate the inflatable structure **813**. When inflated, the inflatable rings **807** and struts **806** can provide structural support to the inflatable implant **800** and/or help to secure the implant **800** to the heart **10**. Uninflated, the implant **800** is a generally thin, flexible shapeless assembly that is preferably incapable of support and is advantageously able to take a small, reduced profile form in which it can be percutaneously inserted into the body. As will be explained in more detail below, in modified embodiments, the inflatable structure **813** can comprise any of a variety of configurations of inflation channels **808** that can be formed from other inflatable members in addition to or in the alternative to the inflatable rings **807** and struts **806** shown in FIGS. 3A and 3B. In one embodiment, the valve has an expanded diameter that is greater than or equal to 22 millimeters and a maximum compressed diameter that is less than or equal to 6 millimeters (18 F).

With particular reference to FIG. 3B, in the illustrated embodiment, the distal ring **807b** and struts **806** can be joined such that the inflation channel **808** of the distal ring **807b** is in fluid communication with the inflation channel **808** of some of the struts **806**. The inflation channel **808** of the proximal ring **807a** can also be in communication with the inflation channels **808** of the proximal ring **807a** and a few of the struts **806**. In this manner, the inflation channels of the (i) proximal ring **807a** and a few struts **806** can be inflated independently from the (ii) distal ring **807b** and some struts. In some embodiments, the inflation channel of the proximal ring **807a** can be in communication with the inflation channel of the struts **806**, while the inflation channel of the distal ring **807b** is not in communication with the inflation channel of the struts. As will be explained in more detail below, the two groups of inflation channels **808** can be connected to independent PFL tubing **916** to facilitate the independent inflation. It should be appreciated that in modified embodiments the inflatable structure can include less (i.e., one common inflation channel) or more independent inflation channels. For example, in one embodiment, the inflation channels of the proximal ring **807a**, struts **806** and distal ring **807b** can all be in fluid communication with each other such that they can be inflated from a single inflation device. In another embodiment, the inflation channels of the proximal ring **807a**, struts **806** and distal ring **807b** can all be separated and therefore utilize three inflation devices.

With reference to FIG. 3B, in the illustrated embodiment, each of the proximal ring **807a** and the distal ring **807b** can have a cross-sectional diameter of about 0.090 inches. The struts can have a cross-sectional diameter of about 0.060 inches. In some embodiments, within the inflation channels **808** are also housed valve systems that allow for pressur-

ization without leakage or passage of fluid in a single direction. In the illustrated embodiment shown in FIG. 3B, two end valves or inflation valves **810** can reside at each end section of the inflation channels **808** adjacent to the connection ports **809**. These end valves **810** are utilized to fill and exchange fluids such as saline, contrast agent and inflation media. The length of this inflation channel **808** can vary depending upon the size of the implant **800** and the complexity of the geometry. The inflation channel material can be blown using heat and pressure from materials such as nylon, polyethylene, Pebax, polypropylene or other common materials that will maintain pressurization. The fluids that are introduced are used to create the support structure, where without them, the implant **800** can be an undefined fabric and tissue assembly. In one embodiment the inflation channels **808** are first filled with saline and contrast agent for radiopaque visualization under fluoroscopy. This can make positioning the implant **800** at the implantation site easier. This fluid is introduced from the proximal end of the catheter **900** with the aid of an inflation device such as an endoflator or other devices to pressurize fluid in a controlled manner. This fluid can be transferred from the proximal end of the catheter **900** through the PFL tubes **916** which are connected to the implant **800** at the end of each inflation channel **808** at the connection port **809**.

With reference to FIG. 3B, in the illustrated embodiment, the inflation channel **808** can have an end valve **810** (i.e., inflation valve) at each end whereby they can be separated from the PFL tubes **916** thus disconnecting the catheter from the implant. This connection can be a screw or threaded connection, a colletting system, an interference fit or other devices and methods of reliable securement between the two components (i.e., the end valve **810** and the PFL tubes **916**). In between the ends of the inflation channel **808** can be an additional directional valve **811** to allow fluid to pass in a single direction. This allows for the filling of each end of the inflation channel **808** and displacement of fluid in a single direction. Once the implant **808** is placed at the desired position while inflated with saline and contrast agent, this fluid can be displaced by an inflation media that can solidify or harden. As the inflation media can be introduced from the proximal end of the catheter **900**, the fluid containing saline and contrast agent is pushed out from one end of the inflation channel **808**. Once the inflation media completely displaces the first fluid, the PFL tubes can then be disconnected from the implant **800** while the implant **800** remains inflated and pressurized. The pressure can be maintained in the implant **800** by the integral valve (i.e., end valve **810**) at each end of the inflation channel **808**. In the illustrated embodiment, this end valve **810** can have a ball **303** and seat to allow for fluid to pass when connected and seal when disconnected. In some case the implant **800** has three or more connection ports **809**, but only two have inflation valves **810** attached. The connection port without the end valve **810** can use the same attachment device such as a screw or threaded element. Since, the illustrated embodiment, this connection port is not used for communication with the support structure **813** and its filling, no inflation valve **810** is necessary. In other embodiments, all three connection ports **809** can have inflation valves **810** for introducing fluids or inflation media.

With reference to FIG. 4, the end valve system **810** can comprise a tubular section **312** with a soft seal **304** and spherical ball **303** to create a sealing mechanism **313**. The tubular section **312** in one embodiment is about 0.5 cm to about 2 cm in length and has an outer diameter of about 0.010 inches to about 0.090 inches with a wall thickness of about 0.005 inches to about 0.040 inches. The material can

include a host of polymers such as nylon, polyethylene, Pebax, polypropylene or other common materials such as stainless steel, Nitinol or other metallic materials used in medical devices. The soft seal material can be introduced as a liquid silicone or other material where a curing occurs thus allowing for a through hole to be constructed by coring or blanking a central lumen through the seal material. The soft seal **304** can be adhered to the inner diameter of the wall of the tubular member **312** with a through hole for fluid flow. The spherical ball **303** can move within the inner diameter of the tubular member **312** where it seats at one end sealing pressure within the inflation channels and is moved the other direction with the introduction of the PFL tube **916** but not allowed to migrate too far as a stop ring or ball stopper **305** retains the spherical ball **303** from moving into the inflation channel **808**. As the PFL tube **916** is screwed into the connection port **809**, the spherical ball **303** is moved into an open position to allow for fluid communication between the inflation channel **808** and the PFL tube **916**. When disconnected, the ball **303** can move against the soft seal **304** and halt any fluid communication external to the inflation channel **808** leaving the implant **800** pressurized. Additional embodiments can utilize a spring mechanism to return the ball to a sealed position and other shapes of sealing devices may be used rather than a spherical ball. A duck-bill style sealing mechanism or flap valve can also be used to halt fluid leakage and provide a closed system to the implant. Additional end valve systems have been described in U.S. Patent Publication No. 2009/0088836 to Bishop et al., which is thereby incorporated by reference herein.

The implant **800** of the illustrated embodiment can allow delivery a prosthetic valve via catheterization in a lower profile and a safer manner than currently available. When the implant **800** is delivered to the site via a delivery catheter **900**, the implant **800** is a thin, generally shapeless assembly in need of structure and definition. At the implantation site, the inflation media (e.g., a fluid or gas) can be added via PFL tubes of the delivery catheter **900** to the inflation channels **808** providing structure and definition to the implant **800**. The inflation media therefore can comprise part of the support structure for implant **800** after it is inflated. The inflation media that is inserted into the inflation channels **808** can be pressurized and/or can solidify in situ to provide structure to the implant **800**. Additional details and embodiments of the implant **800**, can be found in U.S. Pat. No. 5,554,185 to Block and U.S. Patent Publication No. 2006/0088836 to Bishop et al., the disclosures of which are expressly incorporated by reference in their entirety herein.

The cuff **802** can be made from many different materials such as Dacron, TFE, PTFE, ePTFE, woven metal fabrics, braided structures, or other generally accepted implantable materials. These materials may also be cast, extruded, or seamed together using heat, direct or indirect, sintering techniques, laser energy sources, ultrasound techniques, molding or thermoforming technologies. Since the inflation channels **808** generally surrounds the cuff **802**, and the inflation channels **808** can be formed by separate members (e.g., balloons and struts), the attachment or encapsulation of these inflation channels **808** can be in intimate contact with the cuff material. In some embodiments, the inflation channels **808** are encapsulated in the folds **801** or lumens made from the cuff material sewn to the cuff **802**. These inflation channels **808** can also be formed by sealing the cuff material to create an integral lumen from the cuff **802** itself. For example, by adding a material such as a silicone layer to a porous material such as Dacron, the fabric can resist fluid

11

penetration or hold pressures if sealed. Materials can also be added to the sheet or cylinder material to create a fluid-tight barrier.

Various shapes of the cuff **802** can be manufactured to best fit anatomical variations from person to person. As described above, these may include a simple cylinder, a hyperboloid, a device with a larger diameter in its mid portion and a smaller diameter at one or both ends, a funnel type configuration or other conforming shape to native anatomies. The shape of the implant **800** is preferably contoured to engage a feature of the native anatomy in such a way as to prevent the migration of the device in a proximal or distal direction. In one embodiment the feature that the device engages is the aortic root or aortic bulb **34** (see e.g., FIG. 2A), or the sinuses of the coronary arteries. In another embodiment the feature that the device engages is the native valve annulus, the native valve or a portion of the native valve. In certain embodiments, the feature that the implant **800** engages to prevent migration has a diameter difference between 1% and 10%. In another embodiment, the feature that the implant **800** engages to prevent migration the diameter difference is between 5% and 40%. In certain embodiments the diameter difference is defined by the free shape of the implant **800**. In another embodiment the diameter difference prevents migration in only one direction. In another embodiment, the diameter difference prevents migration in two directions, for example proximal and distal or retrograde and antigrade. Similar to surgical valves, the implant **800** will vary in diameter ranging from about 14 mm to about 30 mm and have a height ranging from about 10 mm to about 30 mm in the portion of the implant **800** where the leaflets of the valve **104** are mounted. Portions of the implant **800** intended for placement in the aortic root can have larger diameters preferably ranging from about 20 mm to about 45 mm. In some embodiment, the implant **800** can have an outside diameter greater than about 22 mm when fully inflated.

In certain embodiments, the cuffs, inflated structure can conform (at least partially) to the anatomy of the patient as the implant **800** is inflated. Such an arrangement may provide a better seal between the patient's anatomy and the implant **800**.

Different diameters of prosthetic valves may be needed to replace native valves of various sizes. For different locations in the anatomy, different lengths of prosthetic valves or anchoring devices will also be required. For example a valve designed to replace the native aortic valve needs to have a relatively short length because of the location of the coronary artery ostium (left and right arteries). A valve designed to replace or supplement a pulmonary valve could have significantly greater length because the anatomy of the pulmonary artery allows for additional length. Different anchoring mechanisms that may be useful for anchoring the implant **800** have been described in U.S. Patent Publication No. 2009/0088836 to Bishop et al.

In the embodiments described herein, the inflation channels **808** can be configured such that they are of round, oval, square, rectangular or parabolic shape in cross section. Round cross sections may vary from about 0.020-about 0.100 inches in diameter with wall thicknesses ranging from about 0.0005-about 0.010 inches. Oval cross sections may have an aspect ratio of two or three to one depending upon the desired cuff thickness and strength desired. In embodiments in which the inflation channels **808** are formed by balloons, these channels **808** can be constructed from con-

12

ventional balloon materials such as nylon, polyethylene, PEEK, silicone or other generally accepted medical device material

In some embodiments, portions of the cuff or body **802** can be radio-opaque to aid in visualizing the position and orientation of the implant **800**. Markers made from platinum gold or tantalum or other appropriate materials may be used. These may be used to identify critical areas of the valve that must be positioned appropriately, for example the valve commissures may need to be positioned appropriately relative to the coronary arteries for an aortic valve. Additionally during the procedure it may be advantageous to catheterize the coronary arteries using radio-opaque tipped guide catheters so that the ostium can be visualized. Special catheters could be developed with increased radio-opacity or larger than standard perfusion holes. The catheters could also have a reduced diameter in their proximal section allowing them to be introduced with the valve deployment catheter.

As mentioned above, during delivery, the body **802** can be limp and flexible providing a compact shape to fit inside a delivery sheath. The body **802** is therefore preferably made form a thin, flexible material that is biocompatible and may aid in tissue growth at the interface with the native tissue. A few examples of material may be Dacron, ePTFE, PTFE, TFE, woven material such as stainless steel, platinum, MP35N, polyester or other implantable metal or polymer. As mentioned above with reference to FIG. 2A, the body **802** may have a tubular or hyperboloid shape to allow for the native valve to be excluded beneath the wall of the cuff **802**. Within this cuff **802** the inflation channels **808** can be connected to a catheter lumen for the delivery of an inflation media to define and add structure to the implant **800**. The valve **104**, which is configured such that a fluid, such as blood, may be allowed to flow in a single direction or limit flow in one or both directions, is positioned within the cuff **802**. The attachment method of the valve **104** to the cuff **802** can be by conventional sewing, gluing, welding, interference or other devices and methods generally accepted by industry.

In one embodiment, the cuff **802** would have a diameter of between about 15 mm and about 30 mm and a length of between about 6 mm and about 70 mm. The wall thickness would have an ideal range from about 0.01 mm to about 2 mm. As described above, the cuff **802** may gain longitudinal support in situ from members formed by inflation channels or formed by polymer or solid structural elements providing axial separation. The inner diameter of the cuff **802** may have a fixed dimension providing a constant size for valve attachment and a predictable valve open and closure function. Portions of the outer surface of the cuff **802** may optionally be compliant and allow the implant **800** to achieve interference fit with the native anatomy.

The implant **800** can have various overall shapes (e.g., an hourglass shape to hold the device in position around the valve annulus, or the device may have a different shape to hold the device in position in another portion of the native anatomy, such as the aortic root). Regardless of the overall shape of the implant **800**, the inflatable channels **808** can be located near the proximal and distal ends **803**, **804** of the implant **800**, preferably forming a configuration that approximates a ring or toroid **807**. These channels may be connected by intermediate channels designed to serve any combination of three functions: (i) provide support to the tissue excluded by the implant **800**, (ii) provide axial and radial strength and stiffness to the **800**, and/or (iii) to provide support for the valve **104**. The specific design characteristics or orientation of the inflatable structure **813** can be opti-

13

mized to better serve each function. For example if an inflatable channel **808** were designed to add axial strength to the relevant section of the device, the channels **808** would ideally be oriented in a substantially axial direction.

The cuff **802** and inflation channels **808** of the implant **800** can be manufactured in a variety of ways. In one embodiment the cuff **802** is manufactured from a fabric, similar to those fabrics typically used in endovascular grafts or for the cuffs of surgically implanted prosthetic heart valves. The fabric is preferably woven into a tubular shape for some portions of the cuff **802**. The fabric may also be woven into sheets. In one embodiment, the yarn used to manufacture the fabric is preferably a twisted yarn, but monofilament or braided yarns may also be used. The useful range of yarn diameters is from approximately 0.0005 of an inch in diameter to approximately 0.005 of an inch in diameter. Depending on how tight the weave is made. Preferably, the fabric is woven with between about 50 and about 500 yarns per inch. In one embodiment, a fabric tube is woven with a 18 mm diameter with 200 yarns per inch or picks per inch. Each yarn is made of 20 filaments of a PET material. The final thickness of this woven fabric tube is 0.005 inches for the single wall of the tube. Depending on the desired profile of the implant **800** and the desired permeability of the fabric to blood or other fluids different weaves may be used. Any biocompatible material may be used to make the yarn, some embodiments include nylon and PET. Other materials or other combinations of materials are possible, including Teflon, fluoropolymers, polyimide, metals such as stainless steel, titanium, Nitinol, other shape memory alloys, alloys comprised primarily of a combinations of cobalt, chromium, nickel, and molybdenum. Fibers may be added to the yarn to increase strength or radiopacity, or to deliver a pharmaceutical agent. The fabric tube may also be manufactured by a braiding process.

The fabric can be stitched, sutured, sealed, melted, glued or bonded together to form the desired shape of the implant **800**. The preferred method for attaching portions of the fabric together is stitching. The preferred embodiment uses a polypropylene monofilament suture material, with a diameter of approximately 0.005 of an inch. The suture material may range from about 0.001 to about 0.010 inches in diameter. Larger suture materials may be used at higher stress locations such as where the valve commissures attach to the cuff. The suture material may be of any acceptable implant grade material. Preferably a biocompatible suture material is used such as polypropylene. Nylon and polyethylene are also commonly used suture materials. Other materials or other combinations of materials are possible, including Teflon, fluoropolymers, polyimides, metals such as stainless steel, titanium, Kevlar, Nitinol, other shape memory alloys, alloys comprised primarily of a combinations of cobalt, chromium, nickel, and molybdenum such as MP35N. Preferably the sutures are a monofilament design. Multi strand braided or twisted suture materials also may be used. Many suture and stitching patterns are possible and have been described in various texts. The preferred stitching method is using some type of lock stitch, of a design such that if the suture breaks in a portion of its length the entire running length of the suture will resist unraveling. And the suture will still generally perform its function of holding the layers of fabric together.

In some embodiments, the implant **800** is not provided with separate balloons, instead the fabric of the cuff **802** itself can form the inflation channels **808**. For example, in one embodiment two fabric tubes of a diameter similar to the desired final diameter of the implant **800** are placed coaxial to

14

each other. The two fabric tubes are stitched, fused, glued or otherwise coupled together in a pattern of channels **808** that is suitable for creating the geometry of the inflatable structure **813**. In some embodiments, the fabric tubes are sewn together in a pattern so that the proximal and distal ends of the fabric tubes form an annular ring or toroid **807**. In some embodiments, the middle section of the implant **800** contains one or more inflation channels shaped in a step-function pattern. In some embodiments, the fabric tubes are sewn together at the middle section of the implant to form inflation channels **808** that are perpendicular to the toroids **807** at the end sections of the implant **800**. Methods for fabricating the implant **800** have been described in U.S. Patent Publication No. 2006/0088836 to Bishop et al.

In the illustrated embodiment of FIGS. 3A and 3B, the struts **806** are arranged such that there is no radial overlap with the distal and proximal rings **807a**, **807b**. That is, in the illustrated embodiment, the struts **808** do not increase the radial thickness of the inflation structure because there is no radial overlap between the distal and proximal rings and the channels so that the channels lie within the radial thickness envelop defined by the distal and proximal rings **807a**, **807b**. In another embodiment, the struts **808** can be wider in the radial direction than the distal and proximal rings **807a**, **807b** such that the distal and proximal rings **807a**, **807b** lie within a radial thickness envelop defined by the struts **806**.

In one embodiment, the valve **800** can be delivered through a deployment catheter with an 18 F or smaller outer diameter and when fully inflated has an effective orifice area of at least about 1.0 square cm; and in another embodiment at least about 1.3 square cm and in another embodiment about 1.5 square cm. In one embodiment, the valve **800** has a minimum cross-sectional flow area of at least about 1.75 square cm.

35 Leaflet Subassembly

With reference back to the embodiments of FIG. 2A, the valve **104** preferably is a tissue-type heart valve that includes a dimensionally stable, pre-aligned tissue leaflet subassembly. Pursuant to this construction, an exemplary tissue valve **104** can include a plurality of tissue leaflets that are templated and attached together at their tips to form a dimensionally stable and dimensionally consistent coapting leaflet subassembly. Then, in what can be a single process, each of the leaflets of the subassembly can be aligned with and individually sewn to the cuff **802**, from the tip of one commissure uniformly, around the leaflet cusp perimeter, to the tip of an adjacent commissure. As a result, the sewed sutures act like similarly aligned staples, all of which equally take the loading force acting along the entire cusp of each of the pre-aligned, coapting leaflets. Once inflated, the cuff **802** can support the commissures with the inflation media and its respective pressure which will solidify and create a system similar to a stent structure. The resulting implant **800** thereby formed can reduce stress and potential fatigue at the leaflet suture interface by distributing stress evenly over the entire leaflet cusp from commissure to commissure. In some embodiments, the tissue valve is coupled to the inflatable cuff **802** by attaching to the fabric of the cuff only.

In one embodiment, the tissue leaflets are not coupled to each other but are instead individually attached to the cuff **802**.

A number of additional advantages can result from the use of the implant **800** and the cuff **802** construction utilized therein. For example, for each key area of the cuff **802**, the flexibility can be optimized or customized. If desired, the coapting tissue leaflet commissures can be made more or less flexible to allow for more or less deflection to relieve

15

stresses on the tissue at closing or to fine tune the operation of the valve. Similarly, the base radial stiffness of the overall implant structure can be increased or decreased by pressure or inflation media to preserve the roundness and shape of the implant **800**.

Attachment of the valve **104** to the cuff **802** can be completed in any number of conventional methods including sewing, ring or sleeve attachments, gluing, welding, interference fits, bonding through mechanical devices and methods such as pinching between members. An example of these methods are described in Published Applications from Huynh et al (Ser. No. 06/102944) or Lafrance et al (2003/0027332) or U.S. Pat. No. 6,409,759 to Peredo, which are hereby incorporated by reference herein. These methods are generally known and accepted in the valve device industry. The valve, whether it is tissue, engineered tissue, mechanical or polymer, may be attached before packaging or in the hospital just before implantation. Some tissue valves are native valves such as pig, horse, cow or native human valves. Most of which are suspended in a fixing solution such as Glutaraldehyde.

In some embodiments, heart valve prostheses can be constructed with flexible tissue leaflets or polymer leaflets. Prosthetic tissue heart valves can be derived from, for example, porcine heart valves or manufactured from other biological material, such as bovine or equine pericardium. Biological materials in prosthetic heart valves generally have profile and surface characteristics that provide laminar, nonturbulent blood flow. Therefore, intravascular clotting is less likely to occur than with mechanical heart valve prostheses.

Natural tissue valves can be derived from an animal species, typically mammalian, such as human, bovine, porcine canine, seal or kangaroo. These tissues can be obtained from, for example, heart valves, aortic roots, aortic walls, aortic leaflets, pericardial tissue such as pericardial patches, bypass grafts, blood vessels, human umbilical tissue and the like. These natural tissues are typically soft tissues, and generally include collagen containing material. The tissue can be living tissue, decellularized tissue or recellularized tissue. Tissue can be fixed by crosslinking. Fixation provides mechanical stabilization, for example by preventing enzymatic degradation of the tissue. Glutaraldehyde or formaldehyde is typically used for fixation, but other fixatives can be used, such as other difunctional aldehydes, epoxides, genipin and derivatives thereof. Tissue can be used in either crosslinked or uncrosslinked form, depending on the type of tissue, use and other factors. Generally, if xenograft tissue is used, the tissue is crosslinked and/or decellularized. Additional description of tissue valves can be found in U.S. Patent Publication No. 2009/008836 to Bishop et al.

Inflation Media

The inflatable structure **813** can be inflated using any of a variety of inflation media, depending upon the desired performance. In general, the inflation media can include a liquid such as water or an aqueous based solution, a gas such as CO₂, or a hardenable media which may be introduced into the inflation channels **808** at a first, relatively low viscosity and converted to a second, relatively high viscosity. Viscosity enhancement may be accomplished through any of a variety of known UV initiated or catalyst initiated polymerization reactions, or other chemical systems known in the art. The end point of the viscosity enhancing process may result in a hardness anywhere from a gel to a rigid structure, depending upon the desired performance and durability.

Useful inflation media generally include those formed by the mixing of multiple components and that have a cure time

16

ranging from a tens of minutes to about one hour, preferably from about twenty minutes to about one hour. Such a material may be biocompatible, exhibit long-term stability (preferably on the order of at least ten years in vivo), pose as little an embolic risk as possible, and exhibit adequate mechanical properties, both pre and post-cure, suitable for service in the cuff in vivo. For instance, such a material should have a relatively low viscosity before solidification or curing to facilitate the cuff and channel fill process. A desirable post-cure elastic modulus of such an inflation medium is from about 50 to about 400 psi—balancing the need for the filled body to form an adequate seal in vivo while maintaining clinically relevant kink resistance of the cuff. The inflation media ideally should be radiopaque, both acute and chronic, although this is not absolutely necessary.

One preferred family of hardenable inflation media are two part epoxies. The first part is an epoxy resin blend comprising a first aromatic diepoxy compound and a second aliphatic diepoxy compound. The first aromatic diepoxy compound provides good mechanical and chemical stability in an aqueous environment while being soluble in aqueous solution when combined with suitable aliphatic epoxies. In some embodiments, the first aromatic diepoxy compound comprises at least one N,N-diglycidylaniline group or segment. In some embodiments, the first aromatic diepoxy compound are optionally substituted N,N-diglycidylaniline. The substituent may be glycidyloxy or N,N-diglycidylaniliny-methyl. Non-limiting examples of the first aromatic diepoxy compound are N,N-diglycidylaniline, N,N-dicycidyl-4-glycidyloxyaniline (DGO) and 4,4'-methylene-bis (N,N-diglycidylaniline) (MBD), etc.

The second aliphatic diepoxy compound provides low viscosity and good solubility in an aqueous solution. In some embodiments, the second aliphatic diepoxy compound may be 1,3-butadiene diepoxide, glycidyl ether or C₁₋₅ alkane diols of glycidyl ether. Non-limiting examples of the second aliphatic diepoxy compounds are 1,3-butadiene diepoxide, butanediol diglycidyl ether (BDGE), 1,2-ethanediol diglycidyl ether, glycidyl ether, etc.

In some embodiments, additional third compound may be added to the first part epoxy resin blend for improving mechanical properties and chemical resistance. In some embodiments, the additional third compound may be an aromatic epoxy other than the one containing N,N-diglycidylaniline. However, the solubility of the epoxy resin blend can also decrease and the viscosity can increase as the concentration of the additional aromatic epoxies increases. The preferred third compound may be tris(4-hydroxyphenyl)methane triglycidyl ether (THTGE), bisphenol A diglycidyl ether (BADGE), bisphenol F diglycidyl ether (BFDGE), or resorcinol diglycidyl ether (RDGE).

In some embodiments, the additional third compound may be a cycloaliphatic epoxy compound, preferably more soluble than the first aromatic diepoxy compound. It can increase the mechanical properties and chemical resistance to a lesser extent than the aromatic epoxy described above, but it will not decrease the solubility as much. Non-limiting examples of such cycloaliphatic epoxy are 1,4-cyclohexanedimethanol diclycidyl ether and cyclohexene oxide diglycidyl 1,2-cyclohexanedicarboxylate. Similarly, in some embodiments, aliphatic epoxy with 3 or more glycidyl ether groups, such as polyglycidyl ether, may be added as the additional third compound for the same reason. Polyglycidyl ether may increase cross linking and thus enhance the mechanical properties.

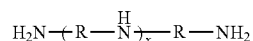
In general, the solubility of the epoxy resin blend decreases and the viscosity increases as the concentration of

17

the first aromatic diepoxy compound increases. In addition, the mechanical properties and chemical resistance may be reduced as the concentration of the aliphatic diepoxy compound goes up in the epoxy resin blend. By adjusting the ratio of the first aromatic diepoxy compound and the second aliphatic diepoxy compound, a person skilled in the art can control the desired properties of the epoxy resin blend and the hardened media. Adding the third compound in some embodiments may allow further tailoring of the epoxy resin properties.

The second part of the hardenable inflation media comprises a hardener comprising at least one cycloaliphatic amine. It provides good combination of reactivity, mechanical properties and chemical resistance. The cycloaliphatic amine may include, but not limited to, isophorone diamine (IPDA), 1,3-bisaminocyclohexane (1,3-BAC), diamino cyclohexane (DACH), n-aminoethylpiperazine (AEP) or n-aminopropylpiperazine (APP).

In some embodiments, an aliphatic amine may be added into the second part to increase reaction rate, but may decrease mechanical properties and chemical resistance. The preferred aliphatic amine has the structural formula (I):



wherein each R is independently selected from branched or linear chains of C₂₋₅ alkyl, preferably C₂ alkyl. The term "alkyl" as used herein refers to a radical of a fully saturated hydrocarbon, including, but not limited to, methyl, ethyl, n-propyl, isopropyl (or i-propyl), n-butyl, isobutyl, tert-butyl (or t-butyl), n-hexyl, and the like. For example, the term "alkyl" as used herein includes radicals of fully saturated hydrocarbons defined by the following general formula C_nH_{2n+2}. In some embodiments, the aliphatic amine may include, but not limited to, tetraethylenepentamine (TEPA), diethylene triamine and triethylene tetraamine. In some embodiments, the hardener may further comprise at least one radio-opaque compound, such as iodo benzoic acids.

Additional details of hardenable inflation media are described in co-pending application titled "Inflation Media Formulation" Application Ser. No. 13/110,780, filed May 18, 2011, the entirety of which is hereby incorporated herein by reference. Other suitable inflation media are also described in U.S. patent application Ser. No. 09/496,231 to Hubbell et al., filed Feb. 1, 2000, entitled "Biomaterials Formed by Nucleophilic Addition Reaction to Conjugated Unsaturated Groups" and U.S. Pat. No. 6,958,212 to Hubbell et al. The entireties of each of these patents are hereby incorporated herein by reference.

Below is listed one particular two-component medium. This medium comprises:

First Part—Epoxy Resin Blend

(1) N,N-Diglycidyl-4-glycidylxyaniline (DGO), present in a proportion ranging from about 10 to about 70 weight percent; specifically in a proportion of about 50 weight percent,

(2) Butanediol diglycidyl ether (BDGE) present in a proportion ranging from about 30 to about 75 weight percent; specifically in a proportion of about 50 weight percent, and optionally

(3) 1,4-Cyclohexanedimethanol diglycidyl ether, present in a proportion ranging from about 0 to about 50 weight percent.

18

Second Part—Amine Hardener

(1) Isophorone diamine (IPDA), present in a proportion ranging from about 75 to about 100 weight percent, and optionally

(2) Diethylene triamine (DETA), present in a proportion ranging from about 0 to about 25 weight percent.

The mixed uncured inflation media preferably has a viscosity less than 2000 cps. In one embodiment the epoxy based inflation media has a viscosity of 100-200 cps. In another embodiment the inflation media has a viscosity less than 1000 cps. In some embodiments, the epoxy mixture has an initial viscosity of less than about 50 cps, or less than about 30 cps after mixing. In some embodiments, the average viscosity during the first 10 minutes following mixing the two components of the inflation media is about 50 cps to about 60 cps. The low viscosity ensures that the inflation media can be delivered through the inflation lumen of a deployment catheter with small diameter, such as an 18 French catheter

In some embodiments, the balloon or inflation channel may be connected to the catheter on both ends. This allows the balloon to be pre-inflated with a non-solidifying material such as a gas or liquid. If a gas is chosen, CO₂ or helium are the likely choices; these gasses are used to inflate intra-aortic balloon pumps. Preferably the pre-inflation media is radio-opaque so that the balloon position can be determined by angiography. Contrast media typically used in interventional cardiology could be used to add sufficient radio-opacity to most liquid pre-inflation media. When it is desired to make the implant permanent and exchange the pre-inflation media for the permanent inflation media, the permanent inflation media is injected into the inflation channel through a first catheter connection. In some embodiments, the permanent inflation media is capable of solidifying into a semi-solid, gel or solid state. As the permanent inflation media is introduced into the inflatable structure, the pre-inflation media is expelled out from a second catheter connection. The catheter connections are positioned in such a way that substantially all of the pre-inflation media is expelled as the permanent inflation media is introduced. In one embodiment an intermediate inflation media is used to prevent entrapment of pre-inflation media in the permanent inflation media. In one embodiment the intermediate inflation media is a gas and the pre-inflation media is a liquid. In another embodiment the intermediate inflation media or pre-inflation media functions as a primer to aid the permanent inflation media to bond to the inner surface of the inflation channel. In another embodiment the pre-inflation media or the intermediate inflation media serves as a release agent to prevent the permanent inflation media from bonding to the inner surface of the inflation channel.

The permanent inflation media may have a different radiopacity than the pre-inflation media. A device that is excessively radiopaque tends to obscure other nearby features under angiography. During the pre-inflation step it may be desirable to visualize the inflation channel clearly, so a very radiopaque inflation media may be chosen. After the device is inflated with the permanent inflation media a less radiopaque inflation media may be preferred. The feature of lesser radiopacity is beneficial for visualization of proper valve function as contrast media is injected into the ventricle or the aorta.

Low Crossing Profile Delivery System

FIGS. 5A-5B illustrate an embodiment of a low crossing profile delivery catheter 900 that can be used to deliver the implant 800. In general, the delivery system comprises a delivery catheter 900, and the delivery catheter 900 can

19

comprise an elongate, flexible catheter body having a proximal end and a distal end. In some embodiments, the catheter body has a maximum outer diameter of about 18 French or less particularly at the distal portion of the catheter body (i.e. the deployment portion). In some embodiments, the delivery catheter also comprises a cardiovascular prosthetic implant **800** (e.g., configured as described above) at the distal end of the catheter body. While using a cardiovascular prosthetic implant **800** as described above has certain advantages, in modified embodiments, certain features of the delivery catheter and delivery system described herein can also be used with a prosthetic implant that utilizes a stent or other support structure and/or does not utilize an inflation media.

As described herein, certain features of the implant **800** and delivery catheter **900** are particularly advantageous for facilitating delivering of cardiovascular prosthetic implant **800** within a catheter body having outer diameter of about 18 French or less while still maintaining a tissue valve thickness equal to or greater than about 0.011 inches and/or having an effective orifice area equal to or greater than about 1 cm squared, or in another embodiment, 1.3 cm squared or in another embodiment 1.5 cm squared. In such embodiments, the implant **800** can also have an expanded maximum diameter that is greater than or equal to about 22 mm. In some embodiments, at least one link exists between the catheter body and the implant **800**. In some embodiments, the at least one link is the PFL tubing. In one embodiment, the delivery system is compatible with 0.035" or 0.038" guidewire.

In general, the delivery catheter **900** can be constructed with extruded tubing using well known techniques in the industry. In some embodiments, the catheter **900** can incorporate braided or coiled wires and or ribbons into the tubing for providing stiffness and rotational torqueability. Stiffening wires may number between 1 and 64. In some embodiments, a braided configuration is used that comprises between 8 and 32 wires or ribbon. If wires are used in other embodiments, the diameter can range from about 0.0005 inches to about 0.0070 inches. If a ribbon is used, the thickness is preferably less than the width, and ribbon thicknesses may range from about 0.0005 inches to about 0.0070 inches while the widths may range from about 0.0010 inches to about 0.0100 inches. In another embodiment, a coil is used as a stiffening member. The coil can comprise between 1 and 8 wires or ribbons that are wrapped around the circumference of the tube and embedded into the tube. The wires may be wound so that they are parallel to one another and in the curved plane of the surface of the tube, or multiple wires may be wrapped in opposing directions in separate layers. The dimensions of the wires or ribbons used for a coil can be similar to the dimensions used for a braid.

With reference to FIGS. 5A and 5B, the catheter **900** can comprise an outer tubular member **901** having a proximal end **902** and a distal end **903**, and an inner tubular member **904** also having a proximal end **905** and a distal end **906**. The inner tubular member **904** can extend generally through the outer tubular member **901**, such that the proximal and distal ends **902**, **903** of the inner tubular member **904** extend generally past the proximal end **902** and distal end **903** of the outer tubular member **901**. The distal end **903** of the outer tubular member **901** can comprise a sheath jacket **912** and a stem region **917** that extends proximally from the sheath jacket **912**. In some embodiments, the sheath jacket **912** may comprise KYNAR tubing. The sheath jacket **912** can house the implant **800** in a retracted state for delivery to the implantation site. In some embodiments, the sheath jacket

20

912 is capable of transmitting at least a portion of light in the visible spectrum. This allows the orientation of the implant **800** to be visualized within the catheter **900**. In some embodiments, an outer sheath marking band **913** may be located at the distal end **903** of the outer tubular member **901**.

In one embodiment, the sheath jacket **912** can have a larger outside diameter than the adjacent or proximate region of the stem region **917** of the tubular member **901**. In such embodiments, the sheath jacket **917** and the stem region **917** can comprise separate tubular components that are attached or otherwise coupled to each other. In other embodiments, the tubular member **901** can be expanded to form the larger diameter sheath jacket **912** such that the stem region **917** and sheath jacket **912** are formed from a common tubular member. In another embodiment or in combination with the previous embodiments, the diameter of the stem region **917** can be reduced.

The proximal end **905** of the inner tubular member **904** can be connected to a handle **907** for grasping and moving the inner tubular member **904** with respect to the outer tubular member **901**. The proximal end **902** of the outer tubular member **901** can be connected to an outer sheath handle **908** for grasping and holding the outer tubular member **901** stationary with respect to the inner tubular member **904**. A hemostasis seal **909** can be preferably provided between the inner and outer tubular members **901**, **904**, and the hemostasis seal **909** can be disposed in outer sheath handle **908**. In some embodiments, the outer sheath handle **908** comprises a side port valve **921**, and the fluid can be passed into the outer tubular member through it.

In general, the inner tubular member **904** comprises a multi-lumen hypotube (see FIG. 6). In some embodiments, a neck section **910** is located at the proximal end **905** of the inner tubular member **904**. The neck section **910** may be made from stainless steel, Nitinol or another suitable material which can serve to provide additional strength for moving the inner tubular member **904** within the outer tubular member **901**. In some embodiments, a marker band **911** is present at the distal end **906** of the inner tubular member **904**. The multi-lumen hypotube can have a wall thickness between about 0.004 in and about 0.006 in. In one embodiment, the wall thickness is about 0.0055 in, which provides sufficient column strength and increases the bending load required to kink the hypotube. With reference to FIG. 6, the inner tubular member **904** (i.e., multi-lumen hypotube in the illustrated embodiment) can comprise at least four lumens. One of the lumens can accommodate the guidewire tubing **914**, and each of the other lumens can accommodate a positioning-and-fill lumen (PFL) tubing **916**. The guidewire tubing **914** can be configured to receive a guidewire. The PFL tubing **916** can be configured to function both as a control wire for positioning the implant **800** at the implantation cite, and as an inflation tube for delivering a liquid, gas or inflation media to the implant **800**. In particular, the tubing **916** can allow angular adjustment of the implant **800**. That is, the plane of the valve (defined generally perpendicular to the longitudinal axis of the implant **800**) can be adjusted with the tubing **916**.

With reference to FIGS. 5A and 5B, in general, the guidewire tubing **914** can be longer than and can extend throughout the length of the delivery catheter **900**. The proximal end of the guidewire tubing **914** can pass through the inner sheath handle **907** for operator's control; the distal end of the guidewire tubing **914** can extend past the distal end **903** of the outer tubular member **901**, and can be coupled to a guidewire tip **915**. The guidewire tip **915** can

21

close the distal end **903** of the outer tubular member **901** (or the receptacle) and protect the retracted implant **800**, for example, during the advancement of the delivery catheter. The guidewire tip **915** can be distanced from the outer tubular member **901** by proximally retracting the outer tubular member **901** while holding the guidewire tubing **914** stationary. Alternatively, the guidewire tubing **914** can be advanced while holding the outer tubular member **901** stationary. The guidewire tubing **914** can have an inner diameter of about 0.035 inches to about 0.042 inches, so the catheter system is compatible with common 0.035" or 0.038" guidewires. In some embodiments, the guidewire tubing **914** may have an inner diameter of about 0.014 inches to about 0.017 inches, so the catheter system is compatible with a 0.014" diameter guidewire. The guidewire tubing **914** can be made from a lubricious material such as Teflon, polypropylene or a polymer impregnated with Teflon. It can also be coated with a lubricous or hydrophilic coating.

The guidewire tip **915** may be cone shaped, bullet shaped or hemispherical on the front end. The largest diameter of the guidewire tip **915** is preferably approximately the same as the distal portion **903** of the outer tubular member **901**. The guidewire tip **915** preferably steps down to a diameter slightly smaller than the inside diameter of the outer sheath jacket **912**, so that the tip can engage the outer sheath jacket **912** and provide a smooth transition. In the illustrated embodiment, the guidewire tip **915** is connected to the guidewire tube **914**, and the guidewire lumen passes through a portion of the guidewire tip **915**. The proximal side of the guidewire tip **915** also has a cone, bullet or hemispherical shape, so that the guidewire tip **915** can easily be retracted back across the deployed implant **800**, and into the deployment catheter **900**. The guidewire tip **915** can be manufactured from a rigid polymer such as polycarbonate, or from a lower durometer material that allows flexibility, such as silicone. Alternatively, the guidewire tip **915** may be made from multiple materials with different durometers. For example, the portion of the guidewire tip **915** that engages the distal portion **903** of the outer tubular member **901** can be manufactured from a rigid material, while the distal and or proximal ends of the guidewire tip **915** are manufactured from a lower durometer material.

As will be explained in detail below, in one embodiment, the guidewire tip **915** is configured (e.g., has a tapered shape) to for direct insertion into an access vessel over a guidewire. In this manner, the guidewire tip **915** and the jacket **912** can be used to directly dilate the access vessel to accommodate an introducer catheter positioned over the delivery catheter.

Each PFL tubing **916** can extend throughout the length of the delivery catheter **900**. The proximal end of the PFL tubing **916** passes through the handle **907**, and has a luer lock **917** for connecting to fluid, gas or inflation media source. The distal end of the PFL tubing **916** extends past the distal end **906** of the inner tubular member **904** through the hypotube lumen. With reference to FIG. 5C, in some embodiments, the PFL tubing **916** comprises a strain relief section **918** at the proximal end where the tubing **916** is connected to the luer lock **917**, and the strain relief section **918** serves to relieve the strain on the PFL tubing **916** while being maneuvered by the operator. The distal end of the PFL tubing **916** comprises a tip or needle **919** for connecting to the implant **800**. In some embodiments, the tip **919** may have a threaded section toward the end of the needle **919** (see FIG. 5C). In some embodiments, the PFL tubing **916** may have

22

PFL marker(s) **920** at the distal end and/or proximal end of the tubing **916** for identification.

The PFL tubing **916** can be designed to accommodate for the ease of rotation in a tortuous anatomy. The tubing **916** may be constructed using polyimide braided tube, Nitinol hypotube, or stainless steel hypotube. In a preferred embodiment, the PFL tubing **916** is made from braided polyimide, which is made of polyimide liner braided with flat wires, encapsulated by another polyimide layer and jacketed with prebax and nylon outer layer. In some embodiments, a Nitinol sleeve can be added to the proximal end of the PFL tubing **916** to improve torque transmission, kinks resistance and pushability. In some embodiments, the outside surface of the PFL tubing **916** and/or the inside surface of the lumens in the multi-lumen hypotube can also be coated with a lubricious silicone coating to reduce friction. In some embodiments, an inner lining material such as Teflon can be used on the inside surface of the lumens in the multi-lumen hypotube to reduce friction and improve performance in tortuous curves. Additionally, slippery coatings such as DOW 360, MDX silicone or a hydrophilic coating from BSI Corporation may be added to provide another form of friction reducing elements. This can provide a precision control of the PFL tubings **916** during positioning of the implant **800**. In some embodiments, the outside surface of the PFL tubing **916** can be jacketed and reflowed with an additional nylon 12 or Relsan AESNO layer to ensure a smooth finished surface. In some embodiments, anti-thrombus coating can also be put on the outside surface of the PFL tubing **916** to reduce the risk of thrombus formation on the tubing.

In some embodiments, the outer diameter of the catheter **900** can measure between about 0.030 inches to about 0.200 inches with a wall thickness of the outer tubular member **901** being about 0.005 inches to about 0.060 inches. In certain embodiments, the outer diameter of the outer tubular member **901** can be between about 0.215 and about 0.219 inches. In this embodiment, the wall thickness of the outer tubular member **901** is between about 0.005 inches and about 0.030 inches. The overall length of the catheter **900** can range from about 80 centimeters to about 320 centimeters. In certain embodiments, the working length of the outer tubular member **901** (from the distal end of the sheath jacket **912** to the location where the tubular member **901** is connected to the outer sheath handle **908**) can be about 100 cm to about 120 cm. In some embodiments, the inner diameter of the sheath jacket **912** can be greater than or equal to about 0.218 inches, and the outer diameter of the sheath jacket **912** is less than or equal to about 0.241 inches. In a preferred embodiment, the outer diameter of the sheath jacket portion **912** can be less than or equal to about 0.236 inches or 18 French. In some embodiments, the outer diameter of the PFL tubing **916** can be less than or equal to about 0.0435 inches, and the length is about 140 cm to about 160 cm.

In the embodiments that employ a low crossing profile outer tubular member, a low profile inflatable implant in a retracted state is preferable for fitting into the sheath jacket **912**. The sheath jacket **912** can have an outer diameter of 18 French or less. In some embodiments, the implant **800** comprises a tissue valve **104** with an expanded outer diameter greater than or equal to about 22 mm and a tissue thickness of greater than or equal to about 0.011 inches. The compressed diameter of the implant **800** may be less than or equal to about 6 mm or 18 French. The retracted implant **800** is generally loaded between the distal portion **903** of the outer tubular member **901** and the distal portion **906** of the inner tubular member **904**. The distal portion **903** of the

23

outer tubular member **901** therefore can form a receptacle for the implant **800**. The implant **800** can be exposed or pushed out of the receptacle by holding the implant **800** stationary as the outer tubular member **901** is retracted. Alternatively, the outer tubular member **901** can be held

stationary while the inner tubular member **904** is advanced and thereby pushing the implant **800** out of the receptacle. The delivery system can include a loading tool base **925** that can connect to the PFL tubing **916**. In some embodiments, the PFL tubing **916** can connect to the loading tool base **921** via a luer connection. With reference to FIG. 7, one end of the loading tool base **921** can be configured to have step edge **923s**. In some embodiments, the distal end of the loading tool base has three step edges **923**, each step edge **923** has a luer connector **924** for connecting the PFL tubing **916**. In some embodiments, the loading tool base **921** can also comprise at least two additional connectors **922** (e.g. additional luer connectors), each in fluid communication with one of the luer connector **924** on the stepped edges **923**, which would allow the introduction of fluid, gas or air into the implant **800** for testing purposes. For example, in the exemplified embodiment, once the PFL tubings **916** are connected to the loading tool base **921**, a liquid or air source can be connected to the loading tool base **921** via the additional connectors **922**. The liquid or air can then be introduced into the implant **800** through the loading tool base **921** and the PFL tubings **916**.

The step edges **923** on the loading tool base **921** can allow the implant **800** to be collapsed or folded up tightly so it can be loaded into the sheath jacket **912** at the distal end of the outer tubular member **901**. When the proximal end of the PFL tubings **916** are connected to the loading tool base **921** and the distal end connected to the connection ports **809** of the implant **800**, the step edge connections can pull the PFL tubings **916** in a way that creates an offset of the inflation valves **810** and/or the connection ports **809** in the inflation channels **808** when the implant **800** is folded or collapsed. By staggering the connection ports/inflation valves, the collapsed implant **800** can have a reduced cross-sectional profile. In some embodiments, the check valve **814** in the inflation channel is also staggered with the connection ports/inflation valves in the collapsed state. Accordingly, in one embodiment, the inflation valves **810** and/or the connection ports **809** are axially aligned when the valve is positioned within the deployment catheter in a collapsed configuration. That is, the inflation valves **810** and/or the connection ports **809** and/or check valve **814** are positioned such that they do not overlap with each other but are instead aligned generally with respect to the longitudinal axis of the deployment catheter. In this manner, the implant **800** can be collapsed into a smaller diameter as opposed to a configuration in which with the inflation valves **810** and/or the connection ports **809** and/or check valve **814** overlap each other in a radial direction, which can increase the diameter of the compressed implant **800**. In a similar manner, the channels **806** can be arranged positioned such that they also do not overlap with each other. The loading tool base **925** can be used to pull one end of the distal and proximal rings **807a**, **807b** in a proximal direction so as to align the inflation valves **810** and/or the connection ports **809** and/or check valve **814** axially as described above and/or align the channels so as to reduce the overlap between multiple channels **806**.

Combined Delivery System with Delivery Catheter and Introducer Catheter

FIG. 8A illustrates an exemplary embodiment of a combined delivery system **1000** that can be used to deliver an

24

implant **800**, such as the implant embodiments described above. The combined delivery system **1000** can include an introducer catheter **1030** and that is positioned at least partially over the delivery catheter **900** described above. As will be explained in more detail below, in certain arrangements, it is advantageous to use the combined delivery system **1000** because the introducer catheter **1030** can have a smaller diameter than would be possible if the introducer catheter **1030** and the delivery catheter **900** are separately introduced into the patient. For example, in the illustrated embodiment, the sheath jacket **912** of the delivery catheter **900** can have an outer diameter that is too large to be inserted through the introducer catheter **1030** (i.e., the outer diameter of the sheath jacket **912** can be larger than the inner diameter of the introducer catheter **1030** and in some embodiments the outer diameter of the sheath jacket **912** can be the same or substantially the same as the outer diameter of the introducer catheter). Accordingly, by preassembling or building the introducer catheter **1030** over a proximal portion of the delivery catheter **900**, a reduced diameter combined delivery system **1000** can be created. In one embodiment, the introducer catheter **1030** is a 16 French introducer catheter capable of receiving a 16 French catheter. The outer diameter the sheath jacket **912** of the delivery catheter **900** and a distal end of the introducer catheter **1030** can be about 18 French or smaller. It is believed that such a combined delivery system **1000** has a smaller outer diameter than any known approved delivery system and introducer systems for transcatheter heart valves. The smaller delivery system size can reduce vascular complications such as aortic dissection, access site or access related vascular and/or distal embolization from a vascular source particularly in situations in which the patient's femoral artery has a smaller diameter.

FIG. 9 illustrates the introducer catheter **1030** of the illustrated embodiment in more detail. In general, the introducer catheter **1030** can comprise an elongate catheter having a proximal end **1032** and a distal end **1034**. In some embodiments, the distal end **1034** of the introducer catheter **1030** can be tapered. The introducer catheter **1030** can comprise a seal assembly **1042** positioned at the proximal end **1032** of the introducer catheter **1030**.

An inner diameter of the introducer catheter **1030** can be smaller than an outer diameter of a distal portion of the delivery catheter **900**. In some embodiments, the inner diameter of the introducer catheter **1030** is about 16 French or less. In some embodiments, the introducer catheter **1030** can comprise a commercially available introducer catheter having an appropriate diameter. For example, in some embodiments, the introducer catheter **1030** is a 16 F introducer catheter commercially available from Cook Medical®.

The seal assembly **1042** (see FIG. 10B) can threadably engage the proximal end **1032** of the introducer catheter **1030**. The seal assembly **1042** can include a seal member **1046** configured to form a seal around the delivery catheter **900**. The seal assembly **1042** can be adjusted to maintain the position of the introducer catheter **1030** relative to the delivery catheter **900** during the procedure. In some embodiments, the seal assembly **1042** comprises a hemostasis seal/valve configured to minimize blood loss during percutaneous procedures. In some embodiments, the seal assembly **1042** comprises a flush port **1044**.

As discussed above, in general, the combined delivery system **1000** comprises the delivery catheter **900**, which extends through the introducer catheter **1030**. In the illustrated embodiment, the components of the delivery catheter **900** can be the same, similar, or identical to the correspond-

25

ing components of the low crossing profile delivery catheter **900** discussed above accordingly. Accordingly, for the sake of brevity only certain components of the delivery catheter **900** will be described below.

As noted above, the delivery catheter **900** can include outer tubular member **901** having a proximal end **902** and a distal end **903**, and an inner tubular member **904** also having a proximal end **905** and a distal end **906**. The inner tubular member **904** extends generally through the outer tubular member **901**, such that the proximal and distal ends **902**, **903** of the inner tubular member **904** extend generally past the proximal end **902** and distal end **903** of the outer tubular member **901**. In some embodiments, the delivery catheter **900** extends generally through the introducer catheter **1030**, such that the proximal end **902** and the distal end **903** of the delivery catheter **900** extend generally past the proximal end **1032** and the distal end **1034** of the introducer catheter **1030**.

In several embodiments, the outer diameter of the distal portion of the delivery catheter **900** and in particular, the sheath jacket **912**, is larger than an inner diameter at the distal end of the introducer catheter **1030**. In some embodiments, the outer diameter of the delivery catheter **900** is about 18 French or less, particularly at the distal portion of the delivery catheter **900**. In some embodiments, the outer diameter at the proximal portion of the delivery catheter **900** is about 16 French or less. In FIGS. **8A** and **8B**, the outer diameter of the sheath jacket **912**, the proximal portion of the guidewire tip **915** and the introducer catheter **1030** are illustrated as having different outer diameters. However, in certain arrangements, the outer diameters of these components **912**, **915** and **1030** can be the same or substantially the same and the outer tubular member **901** can have a smaller outer diameter than these components. In certain arrangements, the sheath jacket **912** and the proximal portion of the guidewire tip **915** can have the same outer diameter or substantially same outer diameter as the proximal portions of the introducer catheter **1030**.

FIG. **10** illustrates a closer view of the outer tubular member **901**. The distal end **903** of the outer tubular member **901** can form the sheath jacket **912**. As noted above, the sheath jacket **912** can house the implant **800** in a retracted state for delivery to the implantation site. In some embodiments, an outer diameter of the sheath jacket **912** is larger than an outer diameter of stem portion **917** of the outer tubular member **901**. In the illustrated embodiment, the outer diameter of the sheath jacket **912** is larger than the inner diameter of at the distal end of the introducer catheter **1030** while the stem portion **912** has an outer diameter that is smaller than the inner diameter of the introducer catheter **1030**. In some embodiments, the outer diameter of the sheath jacket **912** is about 18 F or less. In some embodiments, the outer diameter of the stem portion **917** of the outer tubular member **901** is 16 F or less. As described above, in some embodiments, the sheath jacket **912** is a separate component connected to the step portion **917** of the outer tubular member **901**, while in other embodiments, the sheath jacket **912** is integrally formed with the proximal of the outer tubular member **901**.

As explained above, in some arrangements, it can be advantageous to use the combined delivery system **1000** to reduce the diameter of the introducer catheter **1030** used to deliver the delivery catheter **900** to a treatment site. If the introducer catheter **1030** and delivery catheter **900** are separately introduced, the inner diameter of the introducer catheter **1030** has to be greater than the outer diameter of the largest portion of the delivery catheter **900** to be introduced into the patient. In contrast, in several embodiments of the

26

combined delivery system **1000**, the outer diameter of the distal portion of the delivery catheter **900** is greater than the inner diameter of the introducer catheter **1030**. For example, in some embodiments, the outer diameter of the distal portion of the delivery catheter **900** is about 18 French, and the outer diameter of the proximal portion of the delivery catheter **900** is about 16 French. In some embodiments, the inner diameter of the introducer catheter **1030** is about 16 French. In some embodiments, the introducer catheter **1030** can be pre-installed over the proximal portion of the delivery catheter **900**.

Method of Deployment Using the Combined Delivery System

In several embodiments, an implant **800** may be deployed in an aortic position using the combined delivery system **1000** described above and a minimally invasive procedure. In some embodiments, the method generally comprises gaining access to the aorta, most often through the femoral artery. The vascular access site can be prepared according to standard practice, and the guidewire can be inserted into the left ventricle through the vascular access.

As shown in FIG. **8A** and as described above, the introducer catheter **1030** can be pre-installed over the delivery catheter **900** prior to performing the minimally invasive procedure. For example, the manufacturer can pre-install the introducer catheter **1030** over the delivery catheter **900**. In some embodiments, the manufacturer extends the delivery catheter **900** through the introducer catheter **1030** prior to completing assembly of the combined delivery system **1000**. For example, in some arrangements, it can be desirable to extend the delivery catheter **900** through the introducer catheter **1030** prior to attaching a handle to the proximal end **902** of outer tubular member **901**. In other arrangements, it can be desirable to extend the delivery catheter **900** through the introducer catheter prior to attaching the sheath jacket **912** or implant **800** to the distal end **940** of the delivery catheter **900**.

In other embodiments, the operator (e.g., a nurse, physician, or other individual) extends the delivery catheter **900** through the introducer catheter **1030** prior to inserting the introducer catheter **1030** or delivery catheter **900** into the patient. In some embodiments, the handle of the outer tubular member **901** can be removable, thus allowing the user to remove the handle and extend the delivery catheter **900** through the introducer catheter **1030** prior to inserting the introducer catheter **1030** or delivery catheter **900** into the patient.

In some embodiments, after the manufacturer or operator extends the delivery catheter **900** through the introducer catheter **1030**, a distal portion of the delivery catheter **900** extends distally from the distal end **1034** of the introducer catheter **1030**. In some embodiments, the distal sheath jacket **912** or implant **800** extends distally from the distal end **1034** of the introducer catheter **1030**.

After the combined delivery system **1000** is assembled, as shown in FIG. **10**, the combined delivery system **1000** carrying the cardiovascular prosthetic implant **800** can be transluminally advanced. In some embodiments, the combined delivery system **1000** is inserted over the guidewire. In such embodiments, the guidewire tip **915** can be inserted directly into the access vessel over the guidewire such that the guidewire tip dilates the access vessel for the introducer catheter **1030**. In some embodiments, the combined delivery system **1000** is advanced until the seal assembly **1042** reaches the patient. In other embodiments, the introducer catheter **1030** is held in place while the delivery catheter **900** is further advanced as shown in FIG. **8B**. The delivery

27

catheter **900** can be advanced to a position proximate a native valve. In other embodiments, the entire combined delivery system **1000**, including both the introducer catheter **1030** and the delivery catheter **900** can be advanced to a position proximate a native valve.

After the delivery catheter **900** is advanced over the aortic arch and past the aortic valve, the position of the outer tubular member **901** relative to the introducer catheter **1030** can be maintained by adjusting the seal assembly **1042** to form a seal around the outer tubular member **901**.

As shown in FIG. 8C, in some embodiments, the implant **800** can be revealed or exposed by retracting the outer tubular member **901** partially or completely while holding the inner tubular member **904** stationary and allowing proper placement at or beneath the native valve. In some embodiments, the implant can also be revealed by pushing the inner tubular member **904** distally while holding the outer tubular member **901** stationary. Once the implant **800** is unsheathed, it may be moved proximally or distally, and the fluid or inflation media may be introduced to the cuff **802** providing shape and structural integrity. In some embodiments, the distal toroid of the inflatable cuff or inflatable structure is inflated first with a first liquid, and the implant **800** is positioned at the implantation site using the links between the implant **800** and the combined delivery system **1000**. In some embodiments, no more than three links are present. In some embodiments, the links are PFL tubes **916**, which can be used to both control the implant **800** and to fill the inflatable cuff. The implant **800** may be otherwise inflated or controlled using any of the other methods disclosed above.

In some embodiments, the links are PFL tubes **916**, which can be used to both control the implant **800** and to fill the inflatable cuff.

The deployment of the implant **800** can be controlled by the PFL tubes **916** that are detachably coupled to the implant **800**. The PFL tubes **916** are attached to the cuff **802** of the implant **800** so that the implant **800** can be controlled and positioned after it is removed from the sheath or delivery catheter **900**. Preferably, three PFL tubes **916** are used, which can provide precise control of the implant **800** PFL tubes **916** during deployment and positioning. The PFL tubes **916** can be used to move the implant **800** proximally and distally, or to tilt the implant **800** and change its angle relative to the native anatomy.

In some embodiments, the implant **800** contains multiple inflation valves **810** to allow the operator to inflate specific areas of the implant **800** with different amounts of a first fluid or a first gas. With reference to FIGS. 11A-C, in some embodiments, the implant **800** is initially deployed partially in the ventricle **32** (FIG. 11A). The inflation channel **808** is filled partially, allowing the distal portion of the implant **800** to open to approximately its full diameter. The implant is then pulled back into position at or near the native valve **34** annulus (FIG. 11B). In some embodiments, the distal toroid **807b** is at least partially inflated first, and the cardiovascular prosthetic implant **800** is then retracted proximally for positioning the cuff across the native valve **34**. The distal ring **807b** seats on the ventricular side of the aortic annulus, and the implant **800** itself is placed just above the native valve **34** annulus in the aortic root. At this time, the PFL tubes **916** may act to help separate fused commissures by the same mechanism a cutting balloon can crack fibrous or calcified lesions. Additional inflation fluid or gas may be added to inflate the implant **800** fully, such that the implant **800** extends across the native valve annulus extending slightly to either side (See FIG. 11C). The PFL tubes **916** provide a mechanism for force transmission between the

28

handle of the deployment catheter **900** and the implant **800**. By moving all of the PFL tubes **916** together or the inner tubular member **904**, the implant **800** can be advanced or retracted in a proximal or distal direction. By advancing only a portion of the PFL tubes **916** relative to the other PFL tubes **916**, the angle or orientation of the implant **800** can be adjusted relative to the native anatomy. Radiopaque markers on the implant **800** or on the PFL tubes **916**, or the radio-opacity of the PFL tubes **916** themselves, can help to indicate the orientation of the implant **800** as the operator positions and orients the implant **800**.

In some embodiments, the implant **800** has two inflation valves **810** at each end of the inflation channel **808** and a check valve **811** in the inflation channel **808**. The check valve **811** is positioned so the fluid or gas can flow in the direction from the proximal toroid **807a** to the distal toroid **807b**. In some embodiments, the implant **800** is fully inflated by pressurizing the endoflator attached to the first PFL tube **916** that is in communication with the first inflation valve **810** that leads to the proximal toroid **807a**, while the endoflator attached to the second inflation valve **810** that is in communication with the distal toroid **807b** is closed. The fluid or gas can flow into the distal toroid **807b** through the one-way check valve. The proximal toroid **807a** is then deflated by de-pressurizing the endoflator attached to the second inflation valve. The distal toroid **807b** will remain inflated because the fluid or gas cannot escape through the check valve **811**. The implant **800** can then be positioned across the native annulus. Once in the satisfactory placement, the proximal toroid **807a** can then be inflated again.

In some embodiments, the implant **800** may only have one inflation valve. When the inflation channel **808** is inflated with the first fluid or gas, the proximal portion of the implant **800** may be slightly restricted by the spacing among the PFL tubes **916** while the distal portion expands more fully. In general, the amount that the PFL tubes **916** restricts the diameter of the proximal end of the implant **800** depends on the length of the PFL tubes **916** extend past the outer tubular member **901**, which can be adjusted by the operator. In other embodiments, burst discs or flow restrictors are used to control the inflation of the proximal portion of the implant **800**.

The implant **800** can also be deflated or partially deflated for further adjustment after the initial deployment. As shown in FIG. 12A, the implant **800** can be partially deployed and the PFL tubes **916** used to seat the implant **800** against the native aortic valve **34**. The implant **800** can then be fully deployed as in shown in FIG. 12B and then tested as shown in FIG. 13C. If justified by the test, the implant **800** can be deflated and moved as shown in FIG. 12D to a more optimum position. The implant **800** can then be fully deployed and released from the control wires as shown in FIG. 12E.

As discussed above, in some embodiments, the first inflation fluid or gas can be displaced by an inflation media that can harden to form a more permanent support structure in vivo. Once the operator is satisfied with the position of the implant **800**, the PFL tubes **916** are then disconnected, and the catheter is withdrawn leaving the implant **800** behind (see FIG. 12C), along with the hardenable inflation media. The inflation media is allowed to solidify within the inflatable cuff. The disconnection method may included cutting the attachments, rotating screws, withdrawing or shearing pins, mechanically decoupling interlocked components, electrically separating a fuse joint, removing a trapped cylinder from a tube, fracturing an engineered zone, removing a collecting mechanism to expose a mechanical joint or many

other techniques known in the industry. In modified embodiments, these steps may be reversed or their order modified if desired.

In some arrangements, it may be desirable to deliver a cardiovascular prosthetic implant **800** using a combined delivery system **1000** to reduce the number of components and steps necessary to position the cardiovascular prosthetic implant **800**. For example, if the introducer catheter is inserted separately from the delivery catheter, the operator uses a dilator to facilitate delivery of the introducer catheter. In some scenarios, the dilator includes a flexible, elongate catheter body and a generally cone-shaped tip. The dilator is often a separate component that extends through the introducer catheter and must be removed after the introducer catheter is delivered to the appropriate position. After the dilator is removed, the operator inserts the delivery catheter through the introducer catheter. It can be advantageous to eliminate the use of the dilator or eliminate the catheter exchange step by delivering the cardiovascular prosthetic implant **800** using a combined delivery system **1000**. Instead of relying on the separate dilator component, the combined delivery system **1000** can use the guidewire tip **915** to function as the dilator. As described above, in some embodiments, the guidewire tip **915** can be cone-shaped, bullet-shaped, or hemispherical-shaped to facilitate dilation. Further, the diameter of the guidewire tip **915** can be configured to form a smooth transition from the distal end of the sheath jacket **912** to the guidewire tip **915**. The smooth transition can help prevent the distal end of the introducer catheter **1030** from damaging a vessel wall.

In certain arrangements, it is advantageous to deliver a cardiovascular prosthetic implant **800** using a combined delivery system **1000** to reduce the number steps necessary to remove the combined delivery system **1000** after the implant **800** is delivered to the appropriate location. For example, if the introducer catheter is inserted separately from the delivery catheter, the delivery catheter can be completely removed from the patient before the introducer catheter is removed from the patient. In some scenarios, it can be desirable to remove both the introducer catheter and delivery catheter simultaneously using the combined delivery system **1000**. After the implant **800** is delivered to the appropriate location, the PFL tubing **916** can be retracted proximally into the inner tubular member **904**. In some embodiments, the delivery catheter **900** is retracted proximally until a proximal end of the sheath jacket **912** abuts the distal end **1034** of the introducer catheter **1030**. The guidewire tubing **914** can be retracted proximally until the guidewire tip **915** closes the distal end of the outer tubular member **901** and forms a smooth transition from the distal end **1034** of the introducer catheter **1030** to the guidewire tip **915**. The smooth transition can help prevent the distal end **1034** of the introducer catheter **1030** from damaging the blood vessel as the introducer catheter is removed from the patient. The introducer catheter **1030** and the delivery catheter **900** can then be removed from the patient simultaneously.

With the integral introducer, it is desirable to have a relatively long tapered tip to facilitate introduction through tortuous arteries and tensioning of the sutures for arterial closure upon device removal, but for safe deployment in the relatively small ventricle it is desirable to have a tip that does not take up too much space. Several embodiments addressing this issue are described. These embodiments can be used in combination with the various embodiments described above.

In a first embodiment shown in FIG. **13**, the distal portion of the catheter tip **927** can be about 2 to 8 cm, similar to a dilator introducer for a similarly sized introducer, but is extremely flexible, so that it can follow the curve of the guidewire **914** inside the ventricle (see e.g., FIG. **14**). In one embodiment the tip is manufactured from a material such as silicone or urethane with a durometer of less than about 25 A. In another embodiment the outer surface of the tip **927** is substantially continuous but material from the internal volume of the tip is omitted allowing the tip to flex. Preferably the tip **927** is capable of bending to a radius of less than 3 cm with less than 1 lb force. More preferably the tip **927** is capable of bending to a radius of less than 3 cm with less than 0.5 lb force. In another embodiment the tip **927** has a preset curve with a radius of approximately 2 to 8 cm or more preferably about 3 to 5 cm. Preferably the curved tip **927** is substantially straightened when placed over the stiff section of a very stiff 0.035 guidewire **914**, and returns to a curved shape over the flexible or curved distal section of the guidewire **914**. Preferably the tip **927** is radiopaque. This can be accomplished by filling the tip **927** with a radiopaque material such as barium sulfate, tungsten or tantalum.

In another embodiment the device has a long tip in one configuration and a short tip in a second configuration, where the long tip is greater than about 3 cm and the short tip is less than about 3 cm. In a similar embodiment the long tip is greater than about 2 cm and the short tip is less than about 2 cm. The device is advanced through the iliac arteries in the long tip configuration and advanced near the treatment location into the ventricle in the short tip configuration. In one embodiment a long tip fits over a short tip and is held in place by at least one tension member which extends to a proximal portion of the device. After the device has passed through the challenging access site the tension members are loosened allowing the long tip to move away from the short tip, but containing it for later removal.

In another embodiment the tip has a straight configuration and a bent configuration and can be oriented from one configuration to the other by devices of a mechanism such as a pullwire.

In another embodiment the tip is inflatable, achieving a long configuration when pressurized and a short configuration when deflated, or when a vacuum is applied.

When treating a patient with the integral introducer sheath it is typically to introduce the device with the guidewire already in position across the aortic valve. In some cases this can present a challenge or risk to keep the guidewire in proper position during device insertion. The embodiments describe herein include several methods to facilitate crossing the native valve with the guidewire after the device is inserted.

In one embodiment the guidewire exits the distal tip of the guidewire at an angle at least 5 degrees from the axis of the delivery system, and preferably between 10 and 40 degrees. This allows the delivery catheter to be rotated to point the guidewire directly at the aortic valve to allow easy crossing of the valve with the guidewire. In one embodiment the shape of the tip is similar to the shape of a coronary guide catheter commonly used to cross the aortic valve.

In another embodiment the tip is deflectable and the bend of the tip can be selected by the operator. In one embodiment this is accomplished by use of a pull wire.

One embodiment includes a steerable guidewire as an accessory. Steerable guidewires are commonly known in the art.

In another embodiment a lumen is provided with a bend near the distal end and an outside diameter of approximately

31

0.035 or configured so that it passes through the guidewire lumen. The inside diameter of the lumen is configured so that a 0.032, 0.018 or 0.014 or 0.009 guidewire can pass through it. This additional lumen can be used to control the guidewire and facilitate crossing the aortic valve with the guidewire.

When treating a patient with the integral introducer sheath it is typically necessary to introduce the device with the guidewire already in position across the aortic valve. In some cases this can present a challenge or risk to keep the guidewire in proper position during device insertion. The embodiments described herein include several methods to minimize the difficulty and risk of the sheath exchange.

In one embodiment the guidewire lumen exits the catheter at least 5, 10 20 or 50 cm distal to the proximal end of the catheter. This allows a single operator to control the guidewire position during the removal of the smaller sheath and the insertion of the device.

In one embodiment the guidewire passes through a lumen in the tip, where one end of the lumen is at approximately the distal end of the tip and the second end of the lumen is near a side of the tip distal to where the tip is in contact with the sheath portion of the delivery catheter. This provides the benefits of single operator guidewire control while additionally allowing the connection to the tip to be of smaller cross sectional area, allowing for further profile reduction.

When treating a patient with the integral introducer sheath it may be desirable to have a larger diameter sheath for certain manipulations that are not used in all procedures, such as retrieval of the implant. In some embodiments the introducer can expand in these situations but maintains the low profile of the device during normal use. The expandable introducer may be of a design similar to the e-sheath marketed by Edwards Lifesciences or of a design similar to one marketed by onset medical. In another embodiment the introducer sheath can be made from a polymer in a tubular cross section that expands during retrieval through elastic and plastic deformation. The expanded configuration is preferably at least 10 percent larger than the non expanded configuration. The ID of the expanded configuration is preferably similar to the OD of the non expanded configuration. The ID of the expanded configuration is preferably larger than the OD of the non expanded configuration.

For the withdrawal of the device with the integral sheath, especially when used with percutaneous closure techniques utilizing device such as prostar or proglide marketed by Abbot laboratories, it is preferable to be able to tighten the sutures on the tapered tip of the device as the device is being removed from the patient. To facilitate easy removal the preferred embodiments have a mechanism to lock the tip to the catheter body and or the catheter body to the introducer sheath, so that by pulling back on a single component while cinching the sutures is a simple procedure requiring a minimum of coordination between multiple operators.

In one embodiment the tip and the largest diameter portion of the outer sheath are collapsible to facilitate their removal through an integral introducer that is not substantially expandable. In one embodiment the components are mechanically collapsible such that by providing axial force to pull the components into the introducer sheath they collapse. In one embodiment the tip is made from nylon 12 with a hollow cross section and a wall thickness of between 0.005 and 0.050 in.

In one embodiment the lock mechanism is a cam located in the proximal handle that locks the guidewire lumen to the catheter body, substantially preventing relative motion between the catheter body and the tip. In another embodi-

32

ment a lock mechanism is a toughy-borst type valve located on the proximal end of the integral introducer sheath that can be tightened to prevent relative motion between the integral introducer sheath and the catheter body.

For the withdrawal of the device with the integral sheath, especially when used with percutaneous closure techniques utilizing device such as prostar or proglide marketed by Abbot laboratories, it is important to know the relative location of the tip, the distal and proximal ends of the large diameter portion of the delivery device and the distal portion of the integral introducer sheath.

One embodiment of the device includes radiopaque markers at the locations described above. In another embodiment a visible mark on the outer portion of the delivery device that when aligned with a visible mark or edge of the bub of the integral introducer, indicates that the proximal end of the large diameter portion of the delivery device is aligned with the distal end of the delivery catheter.

One embodiment includes an accessory device for accessing difficult iliac anatomies. An inverted tip balloon is inserted though the contralateral side, and advanced through the aortic bifurcation back into the access vessel. The inverted tip allows the guidewire to be advanced through the device, and then through the guidewire lumen of the inverted tip balloon. The balloon can be advanced close to the device so that the tip of the device is inside the inverted tip of the balloon. the device can be advanced through severe calcification and tortuosity by inflating the balloon and advancing the system with the balloon. The inverted tip balloon has an OD similar to the OD of the delivery system, preferably between 3 mm and 8 mm. The balloon has a rated burst pressure between 2 and 20 atmospheres and preferably a guidewire lumen of approximately 0.036 in diameter. The balloon preferably has low compliance to maintain the inverted tip shape at pressure and allow dilation of the vessel to the size needed for device delivery without causing unnecessary trauma.

The above-describe methods generally describes an embodiment for the replacement of the aortic valve. However, similar or modified methods could be used to replace the pulmonary valve or the mitral or tricuspid valves. For example, the pulmonary valve could be accessed through the venous system, either through the femoral vein or the jugular vein. The mitral valve could be accessed through the venous system as described above and then trans-septally accessing the left atrium from the right atrium. Alternatively, the mitral valve could be accessed through the arterial system as described for the aortic valve, additionally the catheter can be used to pass through the aortic valve and then back up to the mitral valve. Additional description of mitral valve and pulmonary valve replacement can be found in U.S. Patent Publication No. 2009/0088836 to Bishop et al.

The various methods and techniques described above provide a number of ways to carry out the embodiments described herein. Of course, it is to be understood that not necessarily all objectives or advantages described may be achieved in accordance with any particular embodiment described herein. Thus, for example, those skilled in the art will recognize that the methods may be performed in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objectives or advantages as may be taught or suggested herein.

Furthermore, the skilled artisan will recognize the interchangeability of various features from different embodiments disclosed herein. Similarly, the various features and steps discussed above, as well as other known equivalents

33

for each such feature or step, can be mixed and matched by one of ordinary skill in this art to perform methods in accordance with principles described herein. Additionally, the methods which is described and illustrated herein is not limited to the exact sequence of acts described, nor is it necessarily limited to the practice of all of the acts set forth. Other sequences of events or acts, or less than all of the events, or simultaneous occurrence of the events, may be utilized in practicing the embodiments of the invention.

Although the invention has been disclosed in the context of certain embodiments and examples, it will be understood by those skilled in the art that the invention extends beyond the specifically disclosed embodiments to other alternative embodiments and/or uses and obvious modifications and equivalents thereof. Accordingly, the invention is not intended to be limited by the specific disclosures of preferred embodiments herein

What is claimed is:

1. A method of positioning a prosthetic implant within a heart, the method comprising:

advancing together a delivery catheter and an introducer catheter that is preassembled over the delivery catheter into a patient's vascular system, the delivery catheter comprising a prosthetic valve and a distal tip that can be inserted directly into the access vessel such that the distal tip dilates the access vessel for the introducer catheter;

wherein during advancement, an outer diameter of a distal end of the delivery catheter being greater than an inner diameter of a distal end of the introducer catheter, the introducer catheter comprising a hemostasis valve assembly at a proximal end of the introducer catheter; translumenally advancing the prosthetic valve to a position proximate a native valve of the heart, the prosthetic valve being at least partially disposed within the distal end of the delivery catheter during advancement of the introducer catheter; and

deploying the prosthetic valve.

2. The method of claim 1, wherein the step of advancing the introducer catheter preassembled over the delivery catheter comprising the prosthetic valve into the patient's vascular system comprises advancing the introducer catheter and delivery catheter over a guidewire.

3. The method of claim 1, wherein the step of advancing the introducer catheter preassembled over the delivery catheter comprising the prosthetic valve into the patient's vascular system comprises inserting the introducer catheter into a femoral artery.

4. The method of claim 1, wherein the step of translumenally advancing the prosthetic valve to a position proximate the native valve of the heart comprises advancing the prosthetic valve through an aorta.

5. The method of claim 1, wherein deploying the prosthetic valve comprises inflating a portion of the prosthetic valve.

6. The method of claim 1, wherein the distal end of the delivery catheter is inserted directly into an access vessel.

7. The method of claim 1, further comprising removing the delivery catheter and introducer catheter together from the patient.

34

8. The method of claim 1, wherein deploying the prosthetic valve comprises retracting the delivery catheter to expose the prosthetic valve.

9. The method of claim 8, wherein deploying the prosthetic valve comprises holding the prosthetic valve stationary as the delivery catheter is retracted.

10. The method of claim 1, wherein the delivery catheter comprises an outer tubular member and an inner tubular member extending through the outer tubular member.

11. The method of claim 10, wherein deploying the prosthetic valve comprises advancing the inner tubular member to push the prosthetic valve out of the outer tubular member.

12. The method of claim 11, wherein deploying the prosthetic valve comprises holding the outer tubular member stationary as the inner tubular member is advanced.

13. The method of claim 1 further comprising adjusting an angular position of the prosthetic valve using control wires.

14. The method of claim 13, further comprising releasing the prosthetic valve from the control wires.

15. The method of claim 13, further comprising delivering fluid through the control wires to inflate the prosthetic valve.

16. The method of claim 1, wherein deploying the prosthetic valve comprises:

partially deploying the prosthetic valve;
adjusting an angular position of the prosthetic valve; and
fully deploying the prosthetic valve.

17. The method of claim 1, further comprising simultaneously removing the introducer catheter and the delivery catheter.

18. The method of claim 1, wherein the distal end of the delivery catheter comprises a sheath jacket, the sheath jacket having an outer surface that defines an outer diameter of the sheath jacket, the outer diameter of the sheath jacket being greater than the inner diameter of the introducer catheter at the distal end of the introducer catheter.

19. The method of claim 18, further comprising, after deploying the prosthetic valve, retracting the delivery catheter until a proximal end of the sheath jacket abuts the distal end of the introducer catheter.

20. The method of claim 1, wherein the delivery catheter comprises an outer tubular member and a guidewire tubing extending through the outer tubular member, the guidewire tubing being coupled to the distal tip of the delivery catheter, wherein during advancement, the distal tip closes a distal end of the outer tubular member.

21. The method of claim 20, further comprising distancing the distal tip from the outer tubular member.

22. The method of claim 21, wherein distancing the distal tip comprising retracting the outer tubular member while holding the guidewire tubing stationary.

23. The method of claim 21, wherein distancing the distal tip comprising advancing the guidewire tubing while holding the outer tubular member stationary.

24. The method of claim 20, further comprising, after deploying the prosthetic valve, retracting the guidewire tubing until the distal tip closes the distal end of the outer tubular member.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,445,897 B2
APPLICATION NO. : 13/777745
DATED : September 20, 2016
INVENTOR(S) : Gordon B. Bishop et al.

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

In Column 1 at Line 47, Change “case” to --cause--.

In Column 6 at Line 55, Change “and or” to --and/or--.

In Column 11 at Line 29 (approx.), Change “antigrade.” to --antegrade.--.

In Column 12 at Line 3, After “material” insert --,--.

In Column 16 at Line 27, Change “substitutent” to --substituent--.

In Column 16 at Lines 29-30, Change “-diclycidyl” to -- -diglycidyl--.

In Column 16 at Lines 44-45, Change “-diglycidylanaline.” to -- -diglycidylaniline.--.

In Column 16 at Line 59, Change “diclycidyl” to --diglycidyl--.

In Column 17 at Line 39, Change “tetraehtylenepentamine” to --tetraethylenepentamine--.

In Column 18 at Line 19, After “catheter” insert --,--.

In Column 19 at Line 33, Change “and or” to --and/or--.

In Column 21 at Lines 42-43, Change “and or” to --and/or--.

In Column 30 at Line 35, Change “form” to --from--.

In Column 30 at Line 51, After “inserted” insert --,--.

Signed and Sealed this
Thirtieth Day of May, 2017



Michelle K. Lee
Director of the United States Patent and Trademark Office

CERTIFICATE OF CORRECTION (continued)

Page 2 of 2

U.S. Pat. No. 9,445,897 B2

In Column 31 at Line 51, Change “and or” to --and/or--.

In Column 32 at Line 1, Change “toughy-” to --touhy- --.

In Column 33 at Line 17, After “herein” insert --,--.

In the Claims

In Column 33 at Line 41, Change “patients” to --patient’s--.