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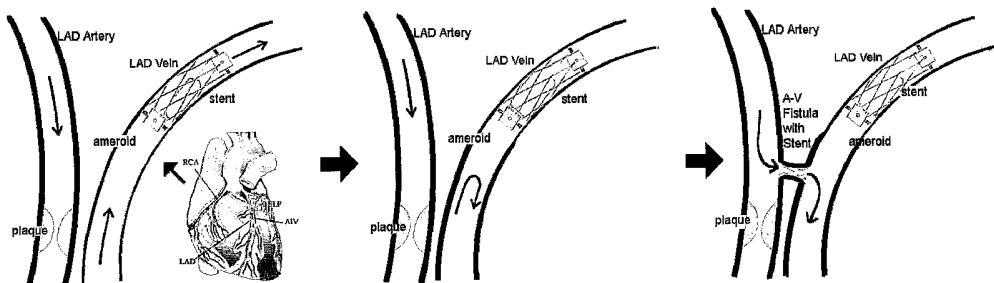
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(54) Title: DEVICES, SYSTEMS AND METHODS FOR ARTERIALIZATIONS OF VENOUS BLOOD VESSELS PRIOR TO RETROPERFUSION



(57) Abstract: The present invention discloses devices, systems and methods for arterIALIZATION of a blood vessel by introducing an anchor within that traps a particle capable of increasing in volume as it is exposed to blood flow. As the particle increases in volume, it serves to decrease the cross sectional area of the blood vessel, resulting in decreased blood flow and increased blood pressure. This invention may be used to arterIALIZATE blood vessels in the venous system to prepare them for an exposure to arterial pressures.

WO 2006/058290 A2

DEVICES, SYSTEMS AND METHODS FOR ARTERIALIZATIONS OF VENOUS BLOOD VESSELS PRIOR TO RETROPERFUSION

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 60/630,656, filed November 26, 2004, the content of which is hereby incorporated by reference in its entirety into this disclosure.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to arterialization of venous blood vessels prior to retroperfusion. More particularly, the present invention relates to devices, systems and methods for prevention of vessel rupture, hemorrhage or edema during venous retroperfusion to an ischemic region.

Background of the Invention

[0003] Coronary artery disease ("CAD") is one cause of blockage of blood flow to the working myocardium and is a major cause of mortality and morbidity. Coronary Artery Bypass Grafting ("CABG") is a common surgical procedure which reroutes blood flow around a blocked artery through a conduit. According to the American Heart Association, the number of CABG procedures in the U.S. was more than 600,000 (1.2 million worldwide) in the year 2000, twice that of 1986.

[0004] Despite the enormous surgical experience, a large number of bypass grafts fail postoperatively, due to various reasons, including acute thrombosis in the early post-operative period or due to intimal hyperplasia (IH) within

months or years. Approximately 10-20% of patients experience significant occlusion before the end of the first year (Braunwald, 1997) while 50% of all CABGs will occlude in 10 years; the rest will be more than 50% occluded (Canver 1995). Hence, millions of patients require multiple surgical procedures which increase medical costs and insurance premiums, as well as increased exposure to harm because of the need for repeated medical procedures. Worst yet, many are left with no other alternatives except heart transplantation, which has a very long waiting list.

[0005] CABG is one of the most prevalent surgical treatments for ischemic heart disease. In the last three decades, CABG evolved as one of the most common, best documented and most effective of all major surgical procedures since its inception in the 1960's. Despite its widespread use, however, the outcome is not completely satisfactory. Although CABG serves as a mechanical conduit to bridge the flow from a blood rich source to an ischemic myocardium, the implementation of the procedure often lacks a mechanical design or rationale. Indeed, there is no standard approach to the CABG procedure. The methods being used today are routine yet are not as effective as they should be, resulting in high incidences of the need for repeat care.

[0006] Furthermore, other known methods of treatment, such as introduction of an Arterial-Venous Fistula, have their own set of known drawbacks, including high incidences of venous breakdown, particularly because of the sudden and step-like exposure of vein to arterial pressure.

[0007] Thus, a need exists in the art for an alternative to the conventional methods of treating arterial occlusions that allows the redirection of blood past the occluded area but without the drawbacks of conventional methods, which include repeated care or operations or the inherent shock to the venous system by the sudden exposure to arterial pressure.

SUMMARY OF THE INVENTION

[0008] This present invention provides an alternative and enhancement to conventional treatments for coronary artery disease as well as other blood vessel conditions where an occlusion has caused a decrease in blood flow therethrough, resulting in immediate or inherent ischemic conditions. The present invention uses the findings that occluded blood vessels cause an increase in interior blood pressure, thereby allowing a thickening of the vessel wall, or "arterialization." Through use of unique devices, systems and methods, the present invention induces an arterialization of a desired section of the venous system through a gradual and minimally-shocking manner so that the venous system is conditioned to accept an increase in blood pressure, thereby making any eventual to increased blood pressure much less traumatic than conventional methods.

[0009] In exemplary embodiments, the present invention makes use of enclosures in blood vessels that enclose particles which increase in size, thereby resulting in an increased occlusion for the blood vessel, and resultant increase in pressure to the exposed blood vessels. This arterialization of the

blood vessels conditions them for eventual increases in blood pressure as through stents or other grafts.

[0010] In other exemplary embodiments, methods are disclosed to bypass an occluded region in a coronary artery without need to unnecessarily shock the coronary vein, thereby reducing the incidence of vessel rupture and hemorrhage and, hence, resulting in enhanced survival rates.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 shows an exemplary embodiment of the present invention as being introduced into a blood vessel through a conventional balloon catheter.

[0012] Figure 2 shows a method according to an exemplary embodiment of the present invention of conducting occlusion bypass surgery in the left anterior descending artery by introducing an enclosure within the left anterior descending vein and conditioning that vein to eventual exposure to arterial pressure.

[0013] Figure 3 shows an alternative embodiment to the operation of Figure 3 using an enclosure according to another exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0014] The present invention provides systems and methods for addressing some of the problems associated with conventional methods of bypassing arterial occlusions and venous retroperfusion. The problems that are common in such operations include the need for repeated operations, the

relatively high level of further medical conditions or mortality resulting from the shock of the venous system to arterial pressure, and other drawbacks known to one having ordinary skill in the art.

[0015] Studies have shown that blood vessels, particularly veins, have the ability to transform themselves into arterial-like vessels when an outside stimulus (for example, higher blood pressure) is imposed upon them. Using this finding, any attempt at transforming a vein into an arterial-like blood vessel through an increase in blood pressure brought about by vessel occlusion would necessarily require a stenosis that results in a blockage of the natural cross-sectional area of the normal blood vessel. Stated differently, a stenosis would have to result in a significant enough decrease in cross-sectional area with respect to the original cross-sectional area of the blood vessel in order to begin to produce an increase in blood pressure that would result in the physiological changes necessary to transform a vein into an arterial-like vessel.

[0016] Although a gradual increase in blood pressure to the exposed blood vessels is most ideal, studies have shown that even a single mid-range increase in blood pressure that results in total occlusion, as opposed to a full range blood pressure increase from venous to arterial levels, is sufficient to condition the venous system in a less harmful manner than conventionally methods. Such mid-range pressure value should likely be some value under 60 mmHg. For example, in pig models, such a total occlusion pressure has been shown to be 50 mmHg.

[0017] However, a rapid attempt at the transformation of a vein into an arterial-like vessel through immediate change of venous pressure to arterial pressure results in damage to the venous wall because of the shock of the step-like increase in blood pressure. In cases where a vein, with internal blood pressure in mmHg in the low teens to single digits is rapidly or in a step-like manner exposed to an arterial blood pressure, which is about an order of magnitude greater, the blood vessel attempts the process of physiological transformation to an arterial-like vessel quickly. However, the order of magnitude increase in pressure does not allow the architecture of the blood vessel to transform smoothly and in an orderly fashion, and deterioration of the blood vessel wall and other similar damage are not uncommon.

[0018] Part of the basis for the devices, systems and methods according to the present invention is to take advantage of the findings that blood vessels do have the ability to change from one form to another depending on the type of pressure to which they are exposed. However, the present invention also attempts to at least minimize if not eliminate the problems and drawbacks with conventional step- or rapid-exposure methods of exposing a vein to arterial pressure by creating a graded or gradual-increase in pressure to the vein.

[0019] Thus, systems and methods according to the present invention create an internal environment for the vein that results in a gradual increase and exposure to the levels of arterial blood pressure such that any risks of shock or disintegration of the blood vessel wall because of conventional exposure to a step-increase in blood pressure is minimized or avoided. Thus, various devices, systems and methods are introduced herein that have the ability to

create a gradual increase in blood pressure within pre-determined areas of blood vessels. Although certain exemplary embodiments of the invention are shown, the invention is not limited to these mere examples, and has a scope beyond the examples shown herein, to all devices, systems and methods that have the capability of producing a graded increase in blood pressure within the interior of a blood vessel, resulting in a gradual transformation of blood vessel wall thickness from that of vein or venule to a more arterial-like vessel.

[0020] In an exemplary embodiment of the present invention, as shown in Figure 1, a conventional balloon catheter is used to enter a blood vessel. Such procedures are conventionally performed to increase the cross-sectional area of an at least partially occluded blood vessel, such as an artery. As used here, the same conventional method of inserting a balloon catheter inside a blood vessel is used to initially introduce the balloon catheter into a predetermined section of a desired blood vessel. Once in place, the balloon is enlarged through conventional procedures. On the exterior of the balloon is a mesh-like enclosure that conforms to the contour of the balloon.

[0021] After the balloon is enlarged, the mesh-like enclosure is relatively anchored in place within the blood vessel by friction fit of its exterior points with the interior of the blood vessel wall. The balloon is typically then deflated and removed. However, the enclosure is then left in place, having been locked into place within the blood vessel.

[0022] Although such mesh-like enclosures may resemble conventional devices such as stents, the enclosure as described herein has a geometry that is distinguishable from conventional stents. As seen in the schematic

cross sectional view in Figure 1, the outer ends of the enclosure have an exterior wall that is used to create a cage-like environment within the interior space of the mesh-like enclosure. This cross-sectional view of the end walls is not drawn to scale but is enlarged to highlight its geometry. This architecture is unique and distinct from conventional stents, which typically attempt to maintain or enlarge the structural geometry of a portion of a blood vessel while, at the same time, not hindering blood flow therethrough by introducing anything that encroaches into the cross-sectional area of the blood vessel. In fact, the very purpose of many stents is to enlarge the blood vessel cross-sectional area, and not to impose upon it in any way.

[0023] As shown in Figure 1 and described herein, and in contrast with conventional stents, the cage-like enclosure that is created serves a purpose to act as a trap or guard to the movement of a particle, which is either trapped within the cage or is beyond the end walls of the cage or some combination thereof. Such geometry serves in the overall process of introducing a graded pressure increase environment, as described further herein.

[0024] Once the cage-like enclosure has been created, a particle may be introduced into its interior. This interior particle has a unique property of being expandable with increased exposure to the interior blood vessel environment. For example, it may be an object that retains fluids from the blood vessel when exposed thereto, or in response to a chemical introduced thereto.

[0025] In the exemplary embodiment shown in Figure 1, the interior particle is a pill, made primarily of ameroid, a dehydrated protein structure. However, the present invention is not limited to pill shapes or ameroids or any such

specific combination. Any material of any shape may be used that is introducible to the blood vessel environment, capable of enlargement in time and does not create physiological harm. Other shapes, such as masses (e.g., conventional children's play putty), or other materials, such as biocompatible polymers (e.g., hydrophilic polymers capable of attracting water) may also be used. One of ordinary skill in the art would be cognizant of other shapes and materials that may be used in the invention described herein, and all such other shapes and materials, although not described specifically herein for sake of brevity, are within the scope of the present invention.

[0026] As shown in the example of Figure 1, an ameroid pill is introduced into the enclosure by the lumen of the catheter. The ameroid pill is initially dry as it is inserted into the enclosure. Once in the enclosure, the pill is exposed to the surrounding environment of the blood vessel, thereby gaining moisture and enlarging in reaction therewith. This gradual attraction of fluid and enlargement of the ameroid pill contributes to the gradual increase in girth and overall size of the ameroid pill. As blood continually flows through the blood vessel, as shown in Figure 1, the ameroid pill enlarges within its confined area and continues to create a gradual decrease in cross-sectional area of the blood vessel.

[0027] Use of the concept exemplified in Figure 2 results in gradual conditioning of a blood vessel to increases levels of pressure such that its physiological changes in geometry are gradual, and not shockingly rapid. This will serve to decrease or prevent any of the conventional drawbacks of conventional methods where certain blood vessels, such as veins, are

exposed to arterial blood pressures in a shocking step-like manner, resulting in high rates of eventual failure or vessel structure breakdowns.

[0028] In use, the concept shown in Figure 1 may be used to assist in the long-term recovery and health of patients who undergo bypass surgeries. In the non-limiting example shown in Figure 2, a highly occluded left anterior descending artery ("LAD") has severely limited the flow of blood therethrough. Conventional methods of addressing such an occlusion include balloon catheter enlargement of the occluded area, bypass surgery to detour the blood through an alternative second route past the occluded region or creating a LAD artery to LAD vein fistula (which typically results in high pressure shock to the LAD vein) in a procedure known as "coronary venous retroperfusion". The present invention allows a minimally invasive alternative to the conventional methods that also decreases the level of shock exposed to downstream blood vessels as a result of exposure to the re-directed blood.

[0029] As shown in the three exemplary steps of Figure 2, a device according to the present invention is introduced into the interior of the LAD vein through conventional methods, such as the catheter method described with respect to Figure 1. Once in place, the enclosure device allows exposure of the ameroid pill contained therein to the flow of blood traversing through the blood vessel. With time, the ameroid pill retains moisture from the flowing blood and increases in girth and size. As the ameroid pill increases in size, its overall volume serves to decrease the cross-sectional size of the blood vessel in which the enclosure is positioned. Thus, as the ameroid pill increases in

size, the part of the LAD vein that is upstream of the enclosure increases in size as it arterializes in response to the increase in pressure.

[0030] At some point in time, the ameroid pill is enlarged to a point that it serves to essentially block the blood flow through the LAD vein, as shown in the second diagram of Figure 2. For example, in a pig model, about two weeks is sufficient to achieve about 95% occlusion. Although such blockage would create tissue hypoxia and eventual death if occurring on the arterial side, the highly vascular nature of the venous system allows for redundant flows to account for any such induced or natural vessel blockage. Furthermore, the time required to create such blockage is determinable by a health care professional as a function of the size of the blood vessel area being blocked as well as the size of the ameroid pill and the absorbency qualities of such a pill. Such factors would be known to one having ordinary skill in the art without the need for undue experimentation.

[0031] Once the enclosure has succeeded in blocking off downstream flow in the LAD vein, as shown in the second diagram of Figure 2, a surgeon is able to determine how much additional time, if any, is needed to allow the upstream side of the blood vessel to be exposed to such increased pressure. This time period of exposure should take into account the time needed for the vein to arterialize in order to be able to withstand any increase in pressure in a more conforming and less damaging manner.

[0032] When it has been determined that the time of exposure of the LAD vein to a no-flow condition has been sufficient to arterialize the blood vessel in a healthy manner, a surgeon can then introduce an A-V fistula with a stent, as

shown in the third diagram of Figure 2. This fistula is typically placed upstream of the occluded region of the LAD artery so that the majority of blood flow will be redirected through the stent into the LAD vein. Once the LAD vein is exposed to the flow of blood directly from the LAD artery through the A-V fistula, the LAD vein continues to arterialize to account for the increase in pressure. However, such increase in pressure is much less in magnitude than that experienced in conventional operations because of the prior introduction and use of the enclosure and its resultant increase in LAD vein blood pressure. In the pig model, it has been determined that a two week period is sufficient to significantly arterialize the venous vessels.

[0033] Thus, at the least, the LAD vein and its branches would be exposed to one much smaller step increase in pressure using the teachings of the present invention, as opposed to one very large increase in blood pressure exposure. Even if there is no gradual increase in pressure, there is still a smaller step in between pressure increase. In essence, blood vessels that have undergone the methods taught by the present invention are exposed to a gradual increase in pressure to a given high point for the LAD vein, at which time, they are then introduced to a higher pressure level (when A-V fistula created), which higher pressure level is not as high a step increase as it would be using conventional surgical methods.

[0034] Although the examples above have shown the ameroid pill being located inside of the cage-like enclosure, the present invention is not limited to such an architecture, nor are other alternatives not possible. For example, as shown in the alternative embodiment of the present invention in Figure 3, the

ameroid pill may be positioned outside of the cage-like enclosure such that the increased size and girth of the pill serves to block the flow of blood past the enclosure. The same method and process is essentially used to introduce the cage-like enclosure and ameroid pill to the LAD vessel as that described with respect to Figure 2. In fact, the same materials may also be used to introduce a situation where the ameroid pill is positioned outside of the enclosure, as shown in Figure 3, as opposed to inside of the enclosure, as shown in Figure 2. The only difference could be that when the ameroid pill is introduced into the blood vessel, as shown with respect to Figure 1, the pill may be placed within the enclosure, as shown in Figures 1 and 2, as opposed to being pushed outside of the outer end wall of the enclosure, as shown in Figure 3. The exact position and location of the ameroid pill, or any other particle being used, is dependent on various factors, including the geometry of the blood vessel, the nature of the particle, the skill and preference of the surgeon, as well as other relevant physiological and spatial factors known to one having ordinary skill in the art.

[0035] The foregoing disclosure of the preferred embodiments of the present invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many variations and modifications of the embodiments described herein will be apparent to one of ordinary skill in the art in light of the above disclosure. For example, the principles described above may be applied to other venous systems other than those of the heart, such as the eye, brain and other systems or organs as long as such other systems or organs do not

have single venous outlet. Single venous outlet systems or organs may not work as effectively with the present invention because occlusion of the venous outlet would result in a dramatic increase in venous pressure. Thus, organs and systems with multiple venous outlets are preferred and the heart, as described herein, is a non-limiting example of where the invention may be applied. The scope of the invention is to be defined only by the claims appended hereto, and by their equivalents.

[0036] Further, in describing representative embodiments of the present invention, the specification may have presented the method and/or process of the present invention as a particular sequence of steps. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the specification should not be construed as limitations on the claims. In addition, the claims directed to the method and/or process of the present invention should not be limited to the performance of their steps in the order written, and one skilled in the art can readily appreciate that the sequences may be varied and still remain within the spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. A device for arterialization of blood vessels, the device comprising:
an anchor that locks into and spans across a cross-sectional area of a lumen of a blood vessel; and
a particle that is prevented by the anchor from flowing away in a direction of blood flow in the lumen of the blood vessel;
wherein the particle enlarges gradually with exposure to blood, thereby decreasing the cross-sectional area of the lumen that is exposed to blood, resulting in arterialization of the blood vessels.
2. The device of claim 1, wherein the particle is an ameroid pill.
3. The device of claim 1, wherein the particle is trapped within the anchor.
4. The device of claim 1, wherein the particle is outside of any confines of the anchor.
5. A system for arterialization of blood vessels, the system comprising:
an elongated catheter;

an enclosure at one end of the catheter that locks into and spans across a cross-sectional area of a lumen of a blood vessel; and

a particle that is prevented by the anchor from flowing away in a direction of blood flow in the lumen of the blood vessel;

wherein the particle enlarges gradually with exposure to blood, thereby decreasing the cross-sectional area of the lumen that is exposed to blood, resulting in arterialization of blood vessels.

6. The system of claim 5, wherein the particle is an ameroid pill.

7. The system of claim 5, wherein the particle is trapped within the enclosure.

8. The system of claim 5, wherein the particle is outside of any confines of the enclosure.

9. A method for arterialization of a blood vessel, the method comprising:

introducing an anchor into a lumen of a blood vessel; and

introducing a particle in communication with the anchor, wherein the particle increases in volume with increased exposure to fluid in the lumen of the blood vessel;

wherein the particle decreases a cross-sectional area of the lumen as it grows in volume, resulting in arterialization of the blood vessel.

10. The method of claim 9, wherein the particle is an ameroid pill.
11. The method of claim 9, wherein the particle is trapped within the anchor.
12. The method of claim 9, wherein the particle is outside of any confines of the anchor.

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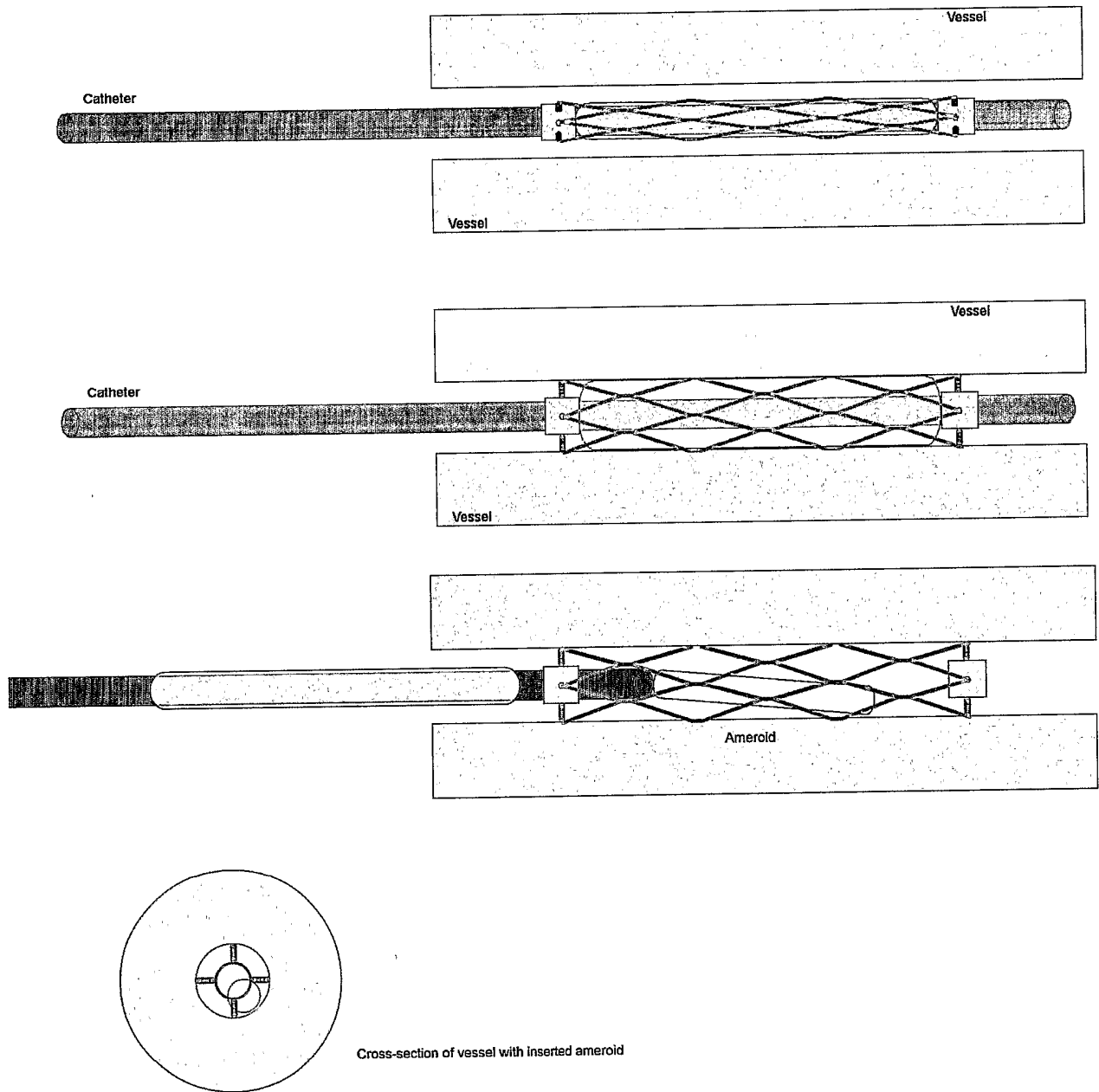


Figure 1

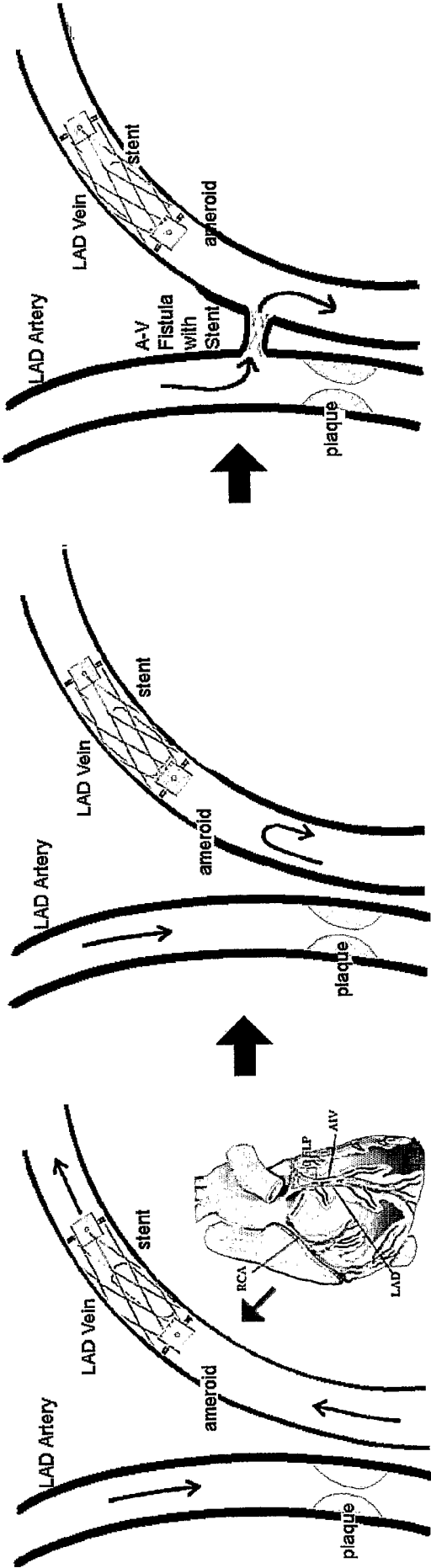


Figure 2

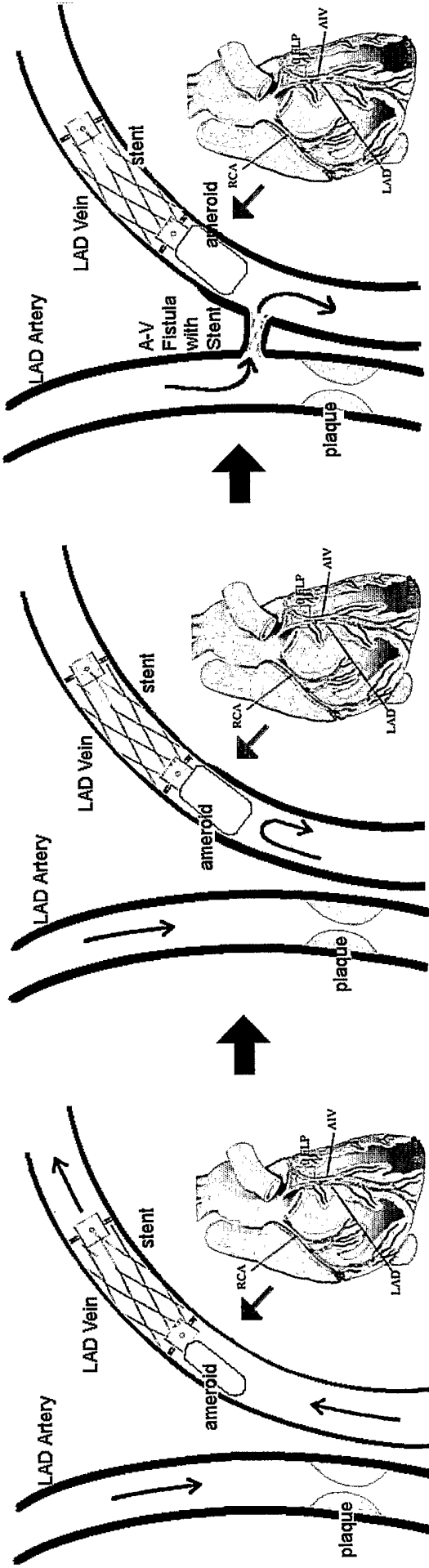


Figure 3