



US 20020087127A1

(19) **United States**

(12) **Patent Application Publication**

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(10) **Pub. No.: US 2002/0087127 A1**

(43) **Pub. Date: Jul. 4, 2002**

(54) **SUBCUTANEOUSLY IMPLANTED CANNULA
AND METHOD FOR ARTERIAL ACCESS**

No. 5,807,356, which is a continuation-in-part of application No. 08/183,151, filed on Jan. 18, 1994, now Pat. No. 5,562,617.

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Publication Classification

(51) **Int. Cl.⁷** **A61M 25/00**
(52) **U.S. Cl.** **604/284**

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(21) Appl. No.: **10/059,850**

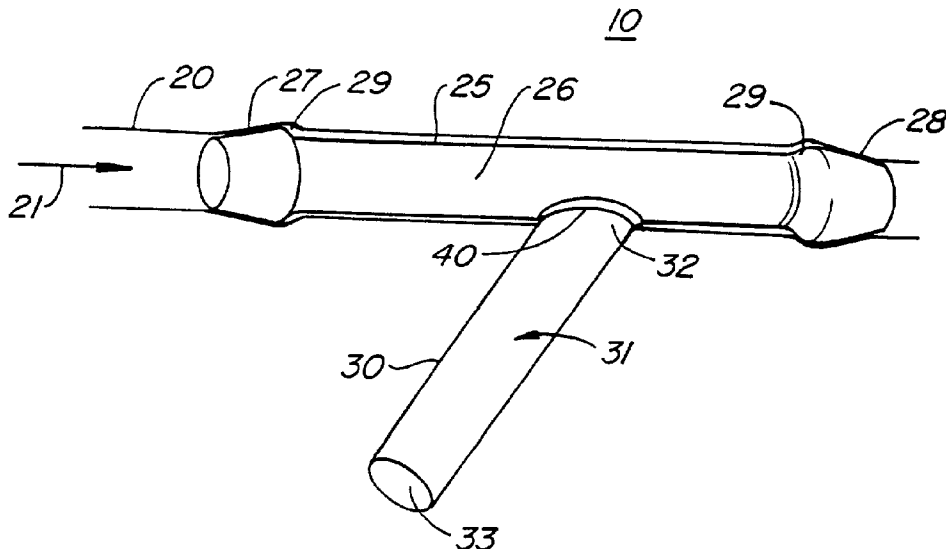
(22) Filed: **Jan. 28, 2002**

Related U.S. Application Data

(60) Division of application No. 09/472,593, filed on Dec. 27, 1999, which is a continuation of application No. 08/724,948, filed on Oct. 2, 1996, now Pat. No. 6,053,901, which is a continuation-in-part of application No. 08/539,105, filed on Oct. 4, 1995, now Pat.

(57) **ABSTRACT**

A catheter with valve for implantation in a vascular structure of a living being. The catheter is in the general shape of a "T" with the top of the "T" implanted within the lumen of a vascular structure, and the leg of the "T" extending out of the vascular structure through an incision in the vascular structure. The lumen of the implanted portion of the catheter completely occupies the lumen of the vascular structure, causing all blood flow through the vascular structure to be directed through the implanted portion of the catheter. A valve is placed in the wall of the implanted portion of the catheter which opens into the lumen of the leg of the "T" of the catheter upon application of sufficient differential pressure between the lumens of the two portions of the catheter. The leg of the "T" is connected to the side wall of the implant portion of the catheter at an angle, such that the axis of the lumen of the leg of the "T" intersects the axis of the lumen of the implanted portion of the catheter at approximately a 45 degree angle.



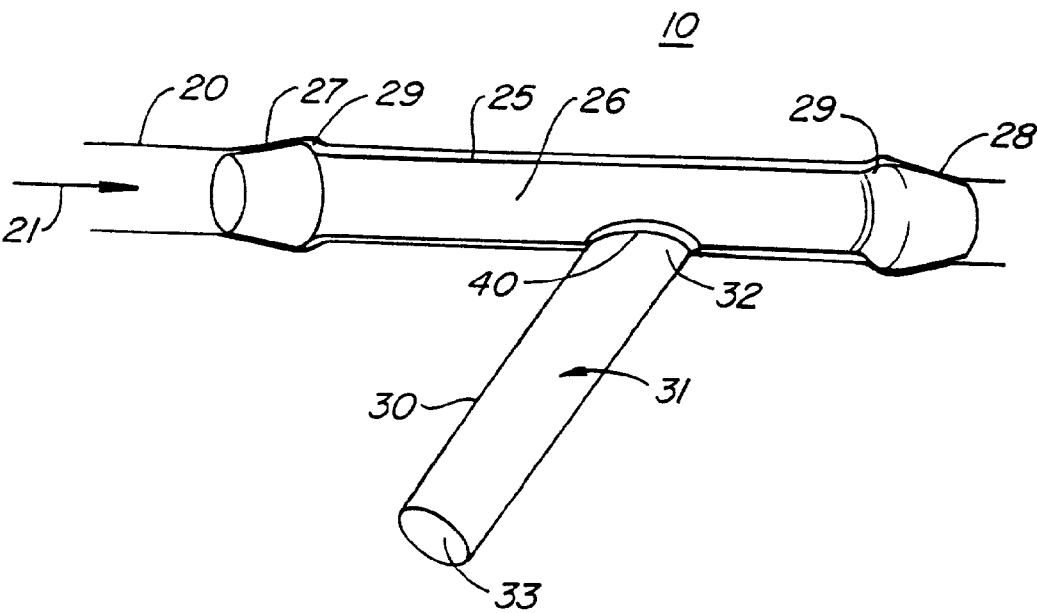


FIG. 1.

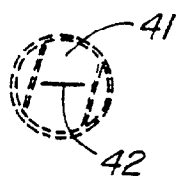


FIG. 3.

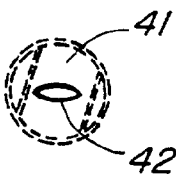


FIG. 4.

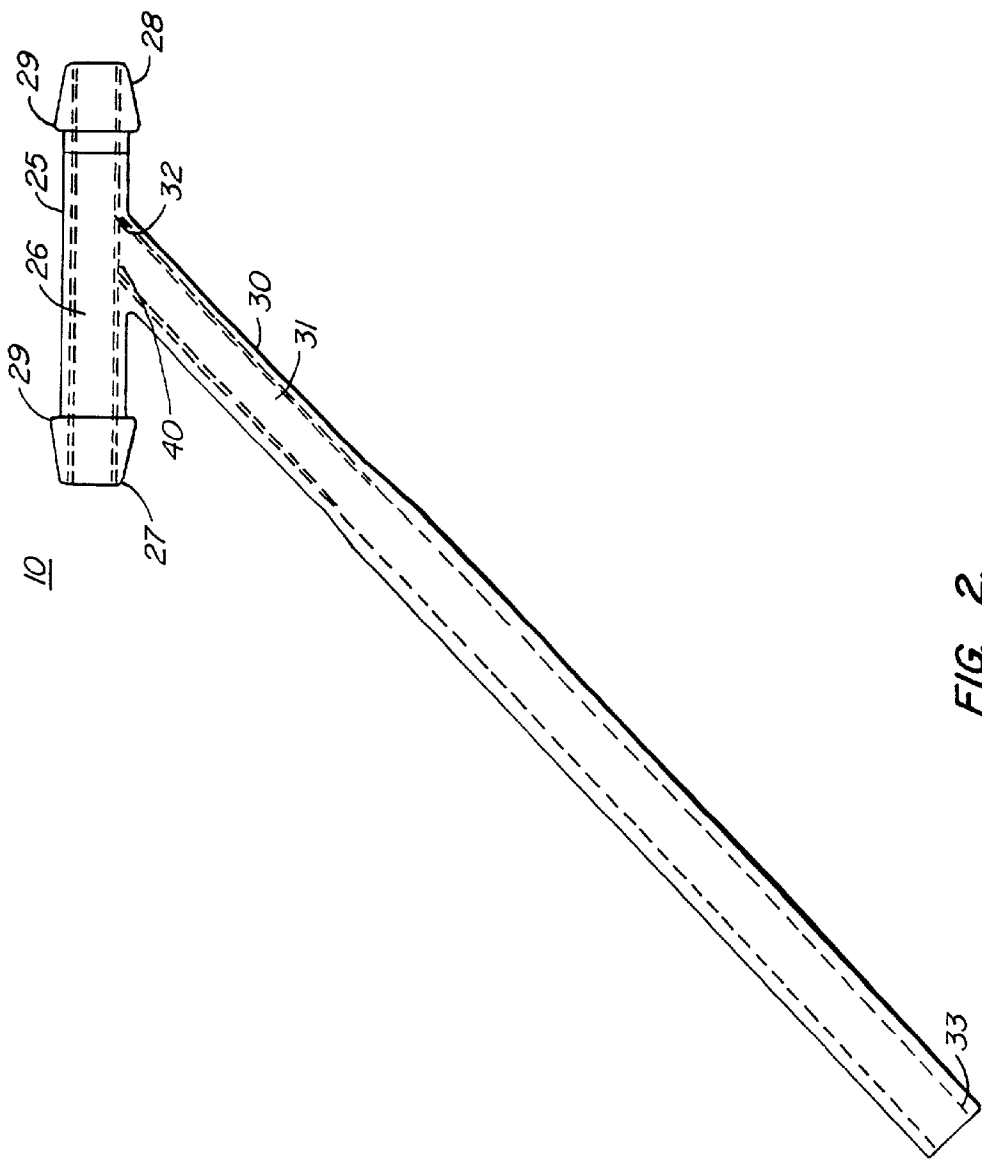


FIG. 2.

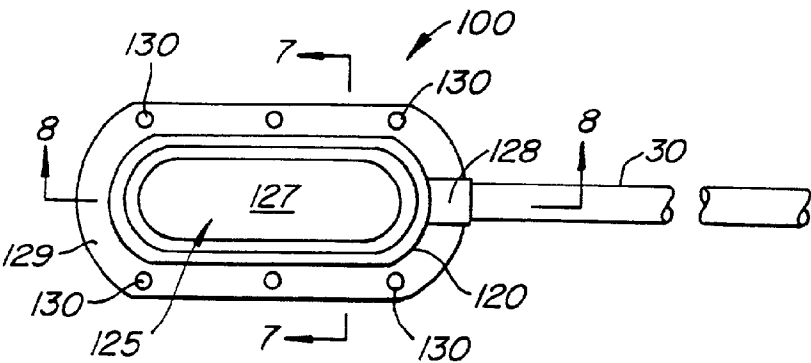


FIG. 5.

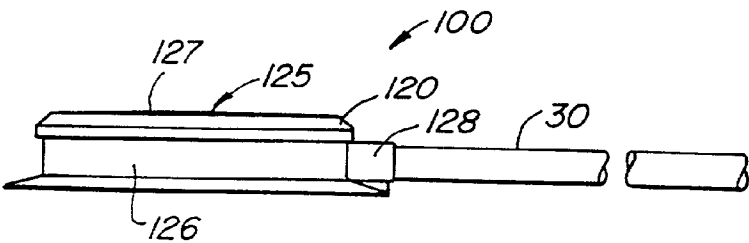


FIG. 6.

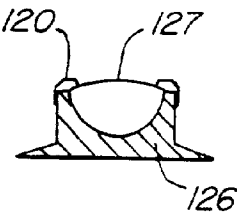


FIG. 7.

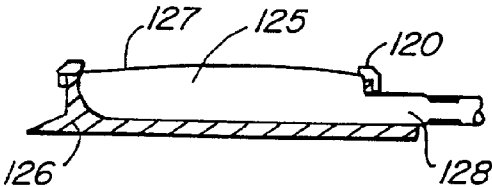


FIG. 8.

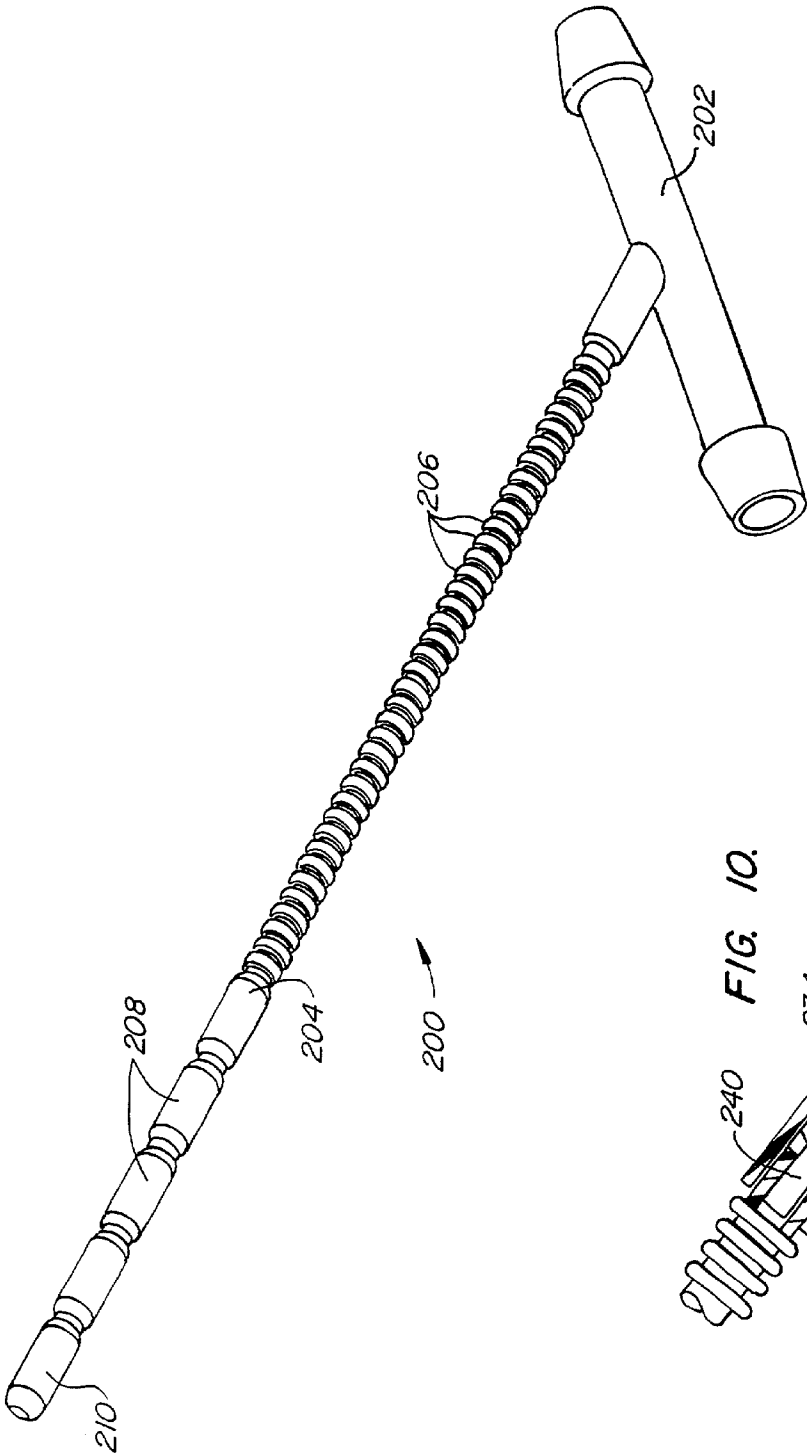


FIG. 9.

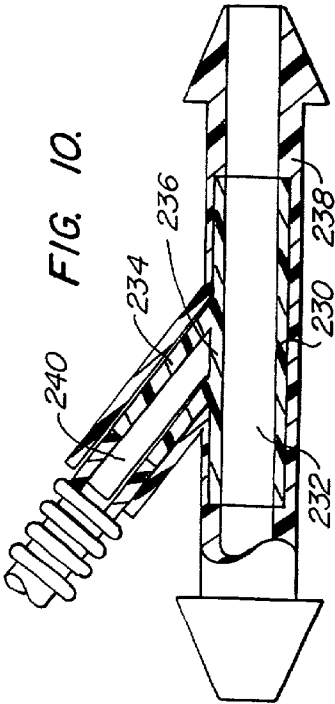


FIG. 10.

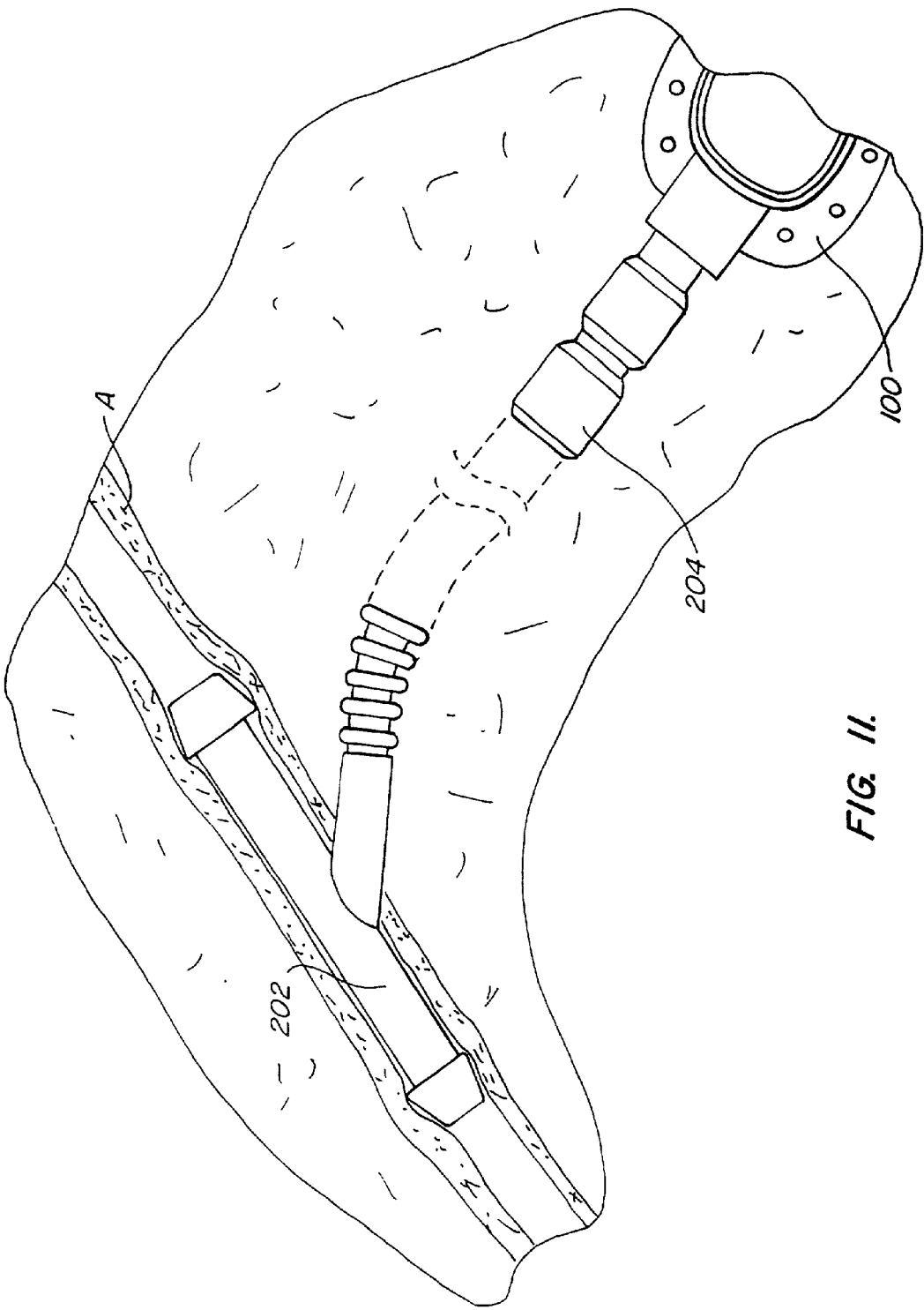


FIG. 11.

SUBCUTANEOUSLY IMPLANTED CANNULA AND METHOD FOR ARTERIAL ACCESS

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] The present application is a division from co-pending application Ser. No. 09/472,593 (Attorney Docket No. 017742-000430) filed Dec. 27, 1999, which was a continuation of application Ser. No. 08/724,948 (Attorney Docket No. 017742-000410) filed Oct. 2, 1996, now U.S. Pat. No. 5,807,356, which is a continuation-in-part of application Ser. No. 08/539,105 (Attorney Docket No. 017742-000400), filed on Oct. 4, 1995, which was a continuation-in-part of application Ser. No. 08/183,151 (Attorney Docket No. 017742-000200), filed on Jan. 18, 1994, now U.S. Pat. No. 5,562,617, the full disclosures of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. The Field of Invention.

[0003] The present invention relates to subcutaneously implanted cannulas used to access the body's circulation. More particularly, this invention provides a cannula and method for establishing intermittent vascular access using an implanted cannula in the general shape of a "T".

[0004] The advent of hemodialysis for the treatment of end-stage renal disease has prompted the development of many vascular access devices for the purpose of acquiring and returning large quantities of blood for passage through an extracorporeal circuit during hemodialysis procedure. Available devices have generally relied on the use of either indwelling venous catheters or flow through shunt devices which create an artificial fistula between an artery and vein.

[0005] Venous catheters are limited by relatively poor draw flows and by their tendency to be irritative resulting in vessel stenosis, thrombosis, and occasionally vessel perforation. They frequently fail because of infection, weakness in the vessel wall, poor catheter position, and/or thrombus formation in the catheter lumen. Shunt devices which create a fistulous blood flow between an artery and a vein have been the mainstay of modern vascular access for dialysis but are similarly problematic. Installation of these "shunts" is an extensive surgical procedure resulting in significant tissue trauma and pain. Once in place, the shunts result in additional cardiac output needs with as much as one-fifth of the cardiac output (approximately 1000 ml per minute) required for adequate function. In addition, the transfer of the arterial pressure wave results in damage to the vein at the point of anastomosis with the shunt and can result in intimal hyperplasia and subsequent thrombosis and shunt occlusion. When such occlusion occurs, another vein segment must be used for shunt revision, and exhaustion of available sites is distressingly common and can be fatal. Repeated punctures of the wall of the shunt often result in eventual failure and require additional surgery to repair or replace the shunt. The expense in terms of both health care dollars and human misery is enormous.

[0006] Each of the available access technologies mentioned thus far are also complicated by the possibility of recirculation of blood already passed through the extracorporeal circuit resulting in the loss of treatment efficiency.

The harm done to patients by the "recirculation syndrome" is insidious and at times undetected until great harm has been done.

[0007] Indwelling catheters which occupy only a portion of the vessel lumen are subject to movement within the vessel, which can cause irritation or even vessel perforation. Further, catheters which occupy only a portion of the vessel lumen, and which are inserted or threaded through the lumen for substantial distances tend to disrupt the normal flow of blood through the vascular structure, altering the hemodynamics of the blood flow in a manner which can damage the vessel, the components of the blood, and which can encourage thrombosis. Such catheters are generally unsuitable for long term implantation in arteries.

[0008] What is needed is a cannula that can be implanted within an artery and that will cause minimal disruption of blood flow through the lumen of the artery during use and nonuse of the cannula, which does not cause vessel stenosis, thrombosis, or vessel perforation, which is capable of handling large quantities of blood, and which will retain its usefulness for a long period of time after implantation.

[0009] 2. Description of the Background Art.

[0010] Vascular access employing indwelling catheters is described in a number of patents and publications including U.S. Pat. Nos. 3,888,249; 4,543,088; 4,634,422; 4,673,394; 4,685,905; 4,692,146; 4,695,273; 4,704,103; 4,705,501; 4,772,270; 4,846,806; 5,053,613; 5,057,084; 5,100,392; 5,167,638; 5,108,365; 5,226,879; 5,263,930; 5,281,199; 5,306,255; 5,318,545; 5,324,518; 5,336,194; 5,350,360; 5,360,407; 5,399,168; 5,417,656; 5,476,451; 5,503,630; 5,520,643; 5,527,277; and 5,527,278; and EP 228 532; and Wigness et al. (1982) paper entitled "Biodirectional Implantable Vascular Access Modality" presented at the Meeting of the American Society for Artificial Internal Organs, Apr. 14-16, 1982, Chicago, Ill.

[0011] Catheters having distal valves are described in a number of patents including U.S. Pat. Nos. 274,447; 3,331,371; 3,888,249; 4,549,879; 4,657,536; 4,671,796; 4,701,166; 4,705,501; 4,759,752; 4,846,806; 4,973,319; 5,030,710; 5,112,301; 5,156,600; and 5,224,978.

[0012] Implantable dialysis connection parts are described in a number of patents including U.S. Pat. Nos. 4,692,146; 4,892,518; 5,041,098; 5,180,365; and 5,350,360.

BRIEF SUMMARY OF THE INVENTION

[0013] The present invention provides improved implantable vascular cannulas which are particularly useful for providing long-term access to the arterial vasculature, including both native arteries and artificial arterial lumens (such as an arteriovenous (AV) shunt or an arterial graft). The cannulas of the present invention comprise a tubular body which is implantable within an arterial lumen and an access leg having one end attached to a side wall of the tubular body. Both the tubular body and the access leg have lumens therethrough, with the lumen of the tubular body being configured to receive the entire blood flow of the arterial lumen in which it is implanted. The access leg, which is attached to the tubular body in a generally T-shaped configuration, thus provides for access into the lumen of the tubular body for either withdrawing blood (e.g. for hemo-

dialysis or other extra- corporeal treatment) or for introducing drugs or other media into the arterial blood flow.

[0014] The arterial access cannula may be implanted either subcutaneously or transcutaneously. By transcutaneous, it is meant that a portion of the access leg will pass outwardly through the patient's skin to permit direct arterial access using external drug pumps, syringes, or other equipment. It will be appreciated, of course, that a hemostasis valve must be provided on the access leg to prevent uncontrolled blood loss. Usually, any transcutaneous use of the cannula of the present invention will be only for a short time.

[0015] More usually, the cannula of the present invention will be intended for subcutaneous use. In that case, an access port is connected to the open end of the access leg and is also subcutaneously implanted beneath the patient's skin. The access port will be suitable for attachment to needles, tubes, catheters, and other devices which may be percutaneously introduced into the access port to provide a desired external connection. An example of an access port comprises a chamber having a penetrable membrane on one side thereof. Temporary access to the chamber is formed by penetrating the needle, tube, or catheter through the penetrable membrane.

[0016] In all cases, the T-configured arterial cannula of the present invention is an improvement over prior indwelling catheters in a number of respects. The tubular body is firmly anchored within the artery and not subject to being moved or dislodged by blood flow. Thus, trauma to the arterial wall from movement of the cannula is significantly lessened. Moreover, by assuring that the lumen of the tubular body has a cross-sectional shape and dimensions which closely match those of the arterial lumen, smooth blood flow through the cannula can be enhanced while the risk of thrombus formation is substantially reduced.

[0017] In a preferred construction, the arterial cannula will include an isolation valve, at or near the junction between the access leg and the tubular body. The isolation valve can be any type of valve that closes or inhibits flow between the tubular body lumen and the access leg lumen in the absence of a pressure drop therebetween. Thus, when blood is not being withdrawn and/or when drugs or other media are not being introduced, the isolation valve will close and isolate the lumen of the access leg from arterial blood flow. Such isolation is a significant advantage since it reduces the risk of thrombus formation within the access leg and thrombus release into the arterial lumen. Often, it will be desirable to flush the lumen of the access leg with an anti-coagulant fluid after each use. The removal of static blood and the placement of the anti-coagulant fluid further decreases the risk of thrombus formation and release. The isolation valve may be in a variety of forms, including slit valves, flap valves, ball valves, and may further be configured to provide for one-way or bi-direction flow. For example, in the case of arterial cannulas used for withdrawing blood, it will often be advantageous to have a one-way isolation valve which permits blood flow from the tubular body into the access leg, but inhibits reverse flow of any materials from the access leg into the lumen. In the case of drug and other infusions into the artery, it may be desirable to provide a one-way isolation valve which permits such introduction, but prevents reflux of blood into the access leg. A particularly preferred valve is a slit valve formed into the wall of the tubular body, as

illustrated in detail hereinafter. When such a slit valve is closed, the inner profile of the tubular body lumen will be substantially smooth and free from discontinuities caused by the valve.

[0018] The arterial cannula may be formed from any one or a combination of a variety of biocompatible materials. By biocompatible, it is meant that the material(s) will be suitable for a long term implantation within patient vasculature and tissue and will be free from immunogenicity and inflammatory response. Usually, the cannula will be formed in whole or in part from an organic polymer, such as silicone rubber, polyethylenes, polyurethanes, polyvinylchloride, polytetrafluoroethylene (PTFE), polysulfone, or the like. Portions of the cannula may be reinforced, for example the access leg may include circumferential reinforcement to enhance its hoop strength without significantly diminishing flexibility. Such reinforcement may take the form of a helical wire or ribbon, axially spaced-apart hoops, or the like. Preferably, the reinforcement may be achieved by molding the access leg to incorporate circumferential corrugation, i.e. a plurality of axially spaced-apart circumferential ribs along all or a portion of its lengths. In all cases, it is desirable that the internal lumen of the access leg and the tubular body remain as smooth as possible to avoid disturbances to blood flow.

[0019] The tubular body of the arterial cannula will have dimensions compatible with implantation within a variety of arteries, including both native (natural) arteries and implanted synthetic arteries. The most common native arteries in which the cannulas may be implanted include the proximal ulnar, proximal radial, brachial artery, axillary artery, and subclavian artery. Implanted synthetic arteries include bypasses, shunts (e.g. AV shunts), arterial grafts, and the like. Both native arteries and implanted synthetic arteries have lumens, and reference to "arterial lumens" herein is intended to refer to both such lumens.

[0020] Generally, the length of the tubular body will be in the range from 10 mm to 50 mm and the outer diameter will be in the range from 3 mm to 10 mm. The diameter of the lumen of the tubular body will generally be in the range from 1 mm to 8 mm. The access leg will usually have a length in the range from 25 mm to 700 mm and an outer diameter in the range from 3 mm to 10 mm. The lumen diameter of the access leg will generally be in the range from 2 mm to 8 mm.

[0021] In a preferred aspect of the present invention, at least a portion of the access leg of the arterial cannula will be sufficiently compliant so that substantially no forces are transmitted from the access leg back into the tubular body. For proper functioning of the arterial cannula, it is important that the tubular body remain properly aligned within the arterial lumen. This can be achieved by fabricating at least a portion of the access leg adjacent to the tubular body to have a low bending stiffness. The hoop strength of the access tube, in contrast, should remain relatively high, being at least sufficient to maintain patency of its lumen at internal pressures below -250 mmHg, preferably below -400 mmHg. Use of the helical reinforcement designs described above helps assure that the access leg can be sufficiently flexible while retaining sufficient strength.

[0022] In a first specific aspect of the present invention, a system for performing extracorporeal blood treatment comprises an arterial cannula as described above in combination

with a venous cannula which is implantable within a venous lumen. The venous cannula will also comprise an access leg, but will usually be in the form of a conventional in-dwelling catheter or a distal portion of the cannula as within the venous lumen in a generally free or unrestricted manner. The use of conventional in-dwelling cannula in the venous vasculature is not problematic. Usually, both the arterial cannula and the venous cannula of the systems of the present invention will further include access ports intended to be connected to catheters for completing an extracorporeal circuit. Such access ports may be of generally conventional construction and may be connected to extracorporeal treatment circuits in a general conventional manner.

[0023] In another aspect, the present invention comprises a method for implanting an arterial access cannula within the lumen of an artery. The method comprises surgically exposing the artery and making an incision in its wall. The tubular body of the access channel is introduced through the incision and into the lumen of the artery. The lumen of the tubular body will be evenly circumferentially aligned with the arterial lumen, and the incision then closed. In some instances, the tubular body will have flared portions at either end, and the flared portions can optionally be tied within the artery to further anchor the cannula therein. The method may further comprise an initial step of determining a cross-sectional dimension of the artery and selecting a tubular body having a cross-section dimension substantially equal to that of the arterial lumen. The method may still further comprise subcutaneously introducing an arterial port, where the arterial port is connected or connectable to the access leg of the arterial access cannula. The arterial port may be introduced through the same incision as the arterial cannula. Alternatively, the arterial port may be introduced through a second incision formed remotely from the first incision, and the port thereafter connected to the access leg by forming a subcutaneous path between the two.

[0024] The method may still further comprise introducing a venous cannula by surgically exposing a vein, and introducing the venous cannula therethrough. The venous port may then be introduced, either through the same or a different surgical incision, in order to form a desired subcutaneous access assembly. By having introduced both an arterial cannula and a venous cannula, the patient is ready for access to hemodialysis or a variety of other extracorporeal treatment modalities.

[0025] In still further aspects of the present invention, methods are provided for performing extracorporeal blood treatment by percutaneously attaching a first catheter to an access leg of a subcutaneously implanted arterial cannula having a tubular body disposed within an arterial lumen. A second catheter is then percutaneously attached to a subcutaneously implanted venous access catheter, and blood may be circulated from the first catheter through an extracorporeal circuit to the second catheter. The first and/or second catheters are typically percutaneously penetrated to connect to the access leg, e.g. by penetrating a needle or needle-introduced catheter through a membrane of a conventional access port. The extracorporeal circuit may be hemodialysis, and the method may further comprise stopping blood circulation and filling at least the access leg of the arterial cannula with an anti-coagulant fluid.

[0026] In still a further aspect of the present invention, a method for administering a fluid medium into an artery

comprises percutaneously attaching a needle or needle-introduced catheter to an access leg of a subcutaneously implanted arterial cannula having a tubular body implanted within the arterial lumen. The fluid medium is then infused through the needle or catheter into the access leg and from there into the lumen of the tubular body. The fluid medium will usually be a medication, but could also be a diagnostic or other conventional agent introduced to arterial blood flow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] FIG. 1 shows a perspective view of the preferred embodiment of the present invention implanted within a vascular structure.

[0028] FIG. 2 shows a cross-sectional view of the preferred embodiment of the present invention.

[0029] FIG. 3 shows a cross-sectional view of the valve of the preferred embodiment of the present invention in the closed position.

[0030] FIG. 4 shows a cross-sectional view of the valve of the preferred embodiment of the present invention in the open position.

[0031] FIGS. 5 and 6 are top and side elevational views, respectively, of a percutaneous access port which may be utilized with either the arterial cannula or venous cannula of the present invention.

[0032] FIG. 7 is a cross-sectional view taken along line 7-7 of FIG. 5.

[0033] FIG. 8 is a cross-sectional view taken along line 8-8 of FIG. 5.

[0034] FIG. 9 is an isometric view of a second embodiment of an arterial cannula constructed in accordance with the principles of the present invention.

[0035] FIG. 10 is a detailed view of the tubular body of the cannula of FIG. 9 shown in partial cross-section.

[0036] FIG. 11 illustrates subcutaneous implantation of the arterial cannula of FIG. 9 in tissue.

DETAILED DESCRIPTION OF THE INVENTION

[0037] Referring to FIG. 1 there is depicted an arterial cannula 10 constructed in accordance with the principles of the present invention implanted within an arterial lumen 20. The cannula is shaped generally like a "T" and is comprised of two primary sections; the tubular body 25 and the access leg 30. The intravascular tube 25 is an elongated tube having a single lumen 26, open on both ends. When implanted within the lumen 20, the tubular body 25 will have an upstream end 27, and a downstream end 28, determined by the direction of blood flow in the vascular structure 20. In FIG. 1 the direction of blood flow is indicated by the arrow 21. The cannula however, can be implanted in either orientation.

[0038] The access leg 30 is an elongated tube having a single lumen 31. A distal end 32 of the access leg 30 is connected to the tubular body 25, generally near the midpoint thereof. The access leg 30 may extend from the tubular body 25 at any angle, including a 90 degree angle, but it is preferred that the access leg 30 of the cannula 10 extend

from the tubular body **25** in a direction which is inclined toward the upstream end **27** of the tubular body **25**. The angle formed between the access leg **30** and the upstream end **27** of the tubular body **25** is an acute angle. The angle formed between the access leg **30** and the downstream end **28** of the intravascular tube **25** is an obtuse angle. A preferred angle between the access leg **30** and the upstream end **27** of the tubular body **25** is between 30° and 60°, usually being approximately 45 degrees.

[0039] A valve **40** is preferably located at the point of connection between the distal end **32** of the access leg **30** and the tubular body **25**. The preferred valve **40** is a slit valve. Such valves are well known in the art. As best shown in **FIG. 3**, the slit valve is comprised of a membrane **41** which has a slit **42** extending partially across the membrane **41** and completely through the membrane **41**. The membrane **41** acts to prevent fluid flow through the lumen **31** of the access leg **30**, except when adequate differential pressure exists on opposite sides of the membrane **41** to cause the slit **42** to open, as is shown in **FIG. 4**. The membrane **41** is located such that the side of the membrane **41** located towards the vascular structure is essentially flush with the inner wall of the intravascular tube **25**. When the catheter **10** is not in use, the membrane **41** of the valve **40** and the inner surface of the tubular body **25** form a continuous tube that has minimal impact on normal blood flow through the arterial lumen.

[0040] In the preferred embodiment, the membrane **41** is comprised of a portion of the side wall of the tubular body **25**. To create the valve **40**, a slit **42** is cut in the side wall of the tubular body **25** to correspond to the point of connection of the access leg **30**. In this manner, when the valve is closed, the inner surface of the tubular body **25** is a continuous smooth surface which has minimal impact on normal blood flow. When the valve **40** opens, fluid flow between the lumen **31** and the access leg **30** and the lumen **26** of the intravascular tube **25** occurs.

[0041] The outer circumference of the tubular body **25** is provided with expanded barbs **29** to hold cannula **10** in place within the vascular structure **20**. One each of these expanded barbs **29** may be placed proximate the upstream end **27** and proximate the downstream end **28** of the tubular body **25**. The expanded barbs **29** have an enlarged outer circumference which tends to slightly distend the wall of the arterial lumen **20**, providing a snug fit, but not preventing the continued viability of the arterial wall. Additional areas of expanded outer diameter (not shown) may be spaced along the outer surface of the tubular body **25**. The fit between the arterial wall and the tubular body **25** must be of sufficient tightness to prevent passage of blood between the arterial wall and the outer surface of the tubular body **25**. Optionally, it may be possible to place ties or clamps (not shown) about the outer wall of the artery adjacent to the expanded barbs **29** to hold the cannula **10** in place. All blood flowing through the arterial lumen should pass through the lumen **26** of the tubular member **25**.

[0042] In use, the proximal end **33** of the access leg **30** of the cannula **10** may be connected to a subcutaneous port, or may extend transcutaneously (i.e. through the skin).

[0043] The cannula **10** is suitable for use with any device requiring or facilitating intermittent vascular access. The cannula **10** of the present invention is particularly useful for

arterial access in hemodialysis, since such treatment requires large quantity blood flow, and requires relatively frequent vascular access over a long period of time. For such use two cannulas **10** may be surgically implanted. One of the devices is implanted in an artery. The other device is implanted in a vein. Usually, however, a conventional in-dwelling catheter will be used for the venous access since vein access is easier to establish. In this manner both the venous and arterial circulations are accessed separately, without fistulous communication. Current use of shunts, which create a fistulous connection between artery and vein, not only involve a more extensive surgical procedure, but are fraught with problems including increased cardiac output requirements, damage to the vein due to arterial pressure waves, and frequent shunt occlusion or thrombosis.

[0044] During hemodialysis, blood is removed from the arterial cannula **10** implanted in an artery and is subjected to the extracorporeal dialysis circuit. Removal occurs by reducing the pressure in the access leg **30** of the cannula **10**, until the slit valve **40** opens, and blood flows from the tubular body **25** into the access leg **30**. The treated blood is returned to a cannula implanted in a vein. At the completion of the dialysis treatment of the access leg **30** of cannula **10** is filled with anti-coagulant fluid, to discourage thrombosis and occlusion of the access legs **30**. A similar process may be used for apheresis or exchange transfusion procedures. Additionally, a single arterial cannula **10** may be used for frequent administration of medication into artery or vein, or for large volume fluid infusions.

[0045] Surgical implantation of the arterial cannula **10** is a straight forward procedure. The chosen artery is located and isolated, and a small incision is made in the luminal wall. The tubular body **25** of the cannula **10** is inserted into the incision, with the access leg **30** extending out of the lumen through the incision. The incision is then sutured to provide a snug fit around the access leg **30**. The proximal end **33** of access leg **30** of the cannula **10** is then attached to a subcutaneous port (described hereinafter) or other device requiring intermittent vascular access.

[0046] Materials of construction well known in the art may be used for the manufacture of the cannula **10**. However, it is important that the tubular body **25** be particularly biocompatible with the arterial wall **20**, since it is intended that the wall in contact with the cannula **10** remain viable. Since the cannula **10**, unlike most prior art catheters, is not designed to be pushed or threaded some distance into a blood vessel, the access tube of the cannula may be comprised of relatively flexible material. This may be accomplished by including a spring or other reinforcement element (not shown) within the walls of the cannula **10** to maintain hoop strength. The materials of construction of the tubular body should be of sufficient rigidity to maintain the preferred angle between the access leg **30** and the tubular body. The dimensions of the catheter **10** depend upon the size of the vascular structure **20** to be accessed. Typically the outer diameter of the tubular body **25** will be between 3 and 10 mm, with a wall thickness of approximately 0.5 to 1 mm, yielding a lumen **26** diameter of between 1 and 8 mm. A typical length of the tubular body **25** from upstream end **27** to downstream end **28** is between 10 and 50 mm. The maximum diameter of the outer surface of the expanded barbs **29** is approximately 30 percent greater than the diameter of the tubular body **25** where no expanded barb **29**

is present. The length and flexibility of the access leg can vary depending upon the use of the catheter **10**. For use with subcutaneous ports an access leg **30** length of approximately 25 mm to 700 mm, usually about 100 mm is generally sufficient.

[0047] Referring now to FIGS. 5-8, an exemplary implantable port **100** will be described. The implantable port **100** may be used with either the arterial cannula **10** described above, or with more conventional in-dwelling cannula which may be used in systems for venous access, as described in more detail hereinafter. The port **100** includes a single hematologic chamber **125**, where the base and sides are formed by a circumferential wall **126**. The port **100** further includes wall **126** and a cover **120** which holds a replaceable diaphragm **127** in place. The cover **120** is removable to allow replacement of the diaphragm **127** if needed. A base **129** of the port **100** comprises a flange having apertures **130** which permit fastening of the port to underlying tissue, typically using sutures. A connector **128** open to one end of the chamber **125** is connectable to the free end of access leg **30** which forms part of the arterial cannula **10** described above.

[0048] Referring now to FIGS. 9 and 10, an alternative embodiment of an arterial cannula **200** constructed in accordance with the principles of the present invention will be described. The cannula **200** includes both a tubular body **202** and an access leg **204**. The access leg **204** comprises a portion adjacent to the tubular body **202** including a plurality of circumferential ribs or corrugations **206** which provides substantial hoop strength to the leg without diminishing the desired flexibility. The remainder of the access leg **204** comprises larger sections **208**, with the distal end **210** being suitable for attachment to the vascular port **100** at connector **128**, as described previously.

[0049] The tubular body **202** comprises a molded insert **230** including a main body portion **32** and a branch portion **234**. An isolation valve **36** is formed at the end of branch **234**, generally as described above with previous embodiments. Tubular body **202** is connected to the adjacent end of the access leg **206** by over molding an exterior body **238**. Usually, a titanium tube **240** is placed within the junction between the end of access leg **206** and the end of branch portion **234**. The tube may be titanium or other biocompatible metal. The insert **230** is typically formed from a relatively soft material, such as 40D to 50D silicone rubber. The outer portion **238** of the tubular body **202** is formed from a similar material, such as 50 D silicone rubber. The access tube may be also formed from silicone having a hardness of 40D to 50D. Conventional molding techniques may be used to form all these parts.

[0050] Referring now to FIG. 11, the tubular body **202** of the arterial cannula **200** may be implanted within an artery **A** by first surgically exposing the artery and thereafter forming an incision in the side of the artery. The tubular body **202** is introduced through the incision, and the incision sutured to hold the body within the arterial lumen. The access leg **204** is then moved to a location where the arterial port **100** is to be implanted. Note that the entire assembly of the arterial cannula **200** and arterial port **100** may be implanted together within a single incision. Alternatively, the arterial cannula **200** and the arterial port **100** may be separately implanted, with the access leg **204** being separately positioned therebetween.

[0051] Although the foregoing invention has been described in some detail by way of illustration and example, for purposes of clarity of understanding, it will be obvious that certain changes and modifications may be practiced within the scope of the appended claims.

What is claimed is:

1. An arterial cannula comprising:

a tubular body having a first end, a second end; and a lumen therebetween, wherein the tubular body is adapted to be implanted within an arterial lumen; and

a tubular access leg having a first end connected to the tubular body at a junction, a second end, and a lumen therebetween, wherein the access tube lumen is fluidly coupled to the tubular body lumen at the junction.

2. An arterial cannula as in claim 1, wherein the tubular body has a length in the range from 10 mm to 50 mm and an outer diameter in the range from 3 mm to 10 mm.

3. An arterial cannula as in claim 1, wherein the access leg has a length in the range from 25 mm to 700 mm and an outer diameter in the range from 3 mm to 10 mm.

4. An arterial cannula as in claim 1, wherein at least a portion of the access leg is sufficiently compliant so that no substantial forces may be transmitted to the tubular body through the access leg.

5. An arterial cannula as in claim 4, wherein at least a portion of the access leg adjacent to the tubular body has a bending stiffness which is less than that of the adjacent tubular body.

6. An arterial cannula as in claim 5, wherein said portion of the access leg has a hoop strength sufficient to withstand an internal pressure of -250 mmHg.

7. An arterial cannula as in claim 1, wherein the tubular body is circumferentially reinforced.

8. An arterial cannula as in claim 7, wherein the circumferential reinforcement comprises a helical wire or circumferential corrugation.

9. An arterial cannula as in claim 7, wherein the access leg is circumferentially reinforced.

10. An arterial cannula as in claim 9, wherein the circumferential reinforcement comprises a helical wire or circumferential corrugation.

11. An arterial cannula as in claim 1, further comprising a pressure-responsive valve at the junction, said valve inhibiting blood flow across the junction in the absence of a pressure differential thereacross.

12. An arterial cannula as in claim 11, wherein the valve is incorporated in the tubular body so that no structure of the valve intrudes into the vascular lumen.

13. An arterial catheter as in claim 12, wherein the valve is a slit valve formed in the tubular body at the junction.

14. A method for implanting an arterial access cannula within a lumen of an artery, said method comprising:

surgically exposing the artery;

making an incision in a wall of the artery;

introducing a tubular body of the access cannula through the incision and into the lumen of the artery so that a lumen of the tubular body is evenly aligned with the arterial lumen and an access leg of the cannula is aligned through the incision; and

closing the incision and securing the tubular body within the arterial lumen.

15. A method as in claim 14, wherein the artery is selected from the group consisting of the proximal ulnar, proximal radial, brachial artery, axillary artery, subclavian artery and synthetic arteries.

16. A method as in claim 14, wherein the lumen of the tubular body is selected to have a cross-sectional dimension substantially equal to that of the blood vessel.

17. A method as in claim 16, further comprising the steps of determining a cross-sectional dimension of the artery and selecting a tubular body having a cross-sectional dimension substantially equal to that of the arterial lumen.

18. A method as in claim 14, wherein the tubular body has an outer diameter in the range from 10 mm to 50 mm and a length in the range from 3 mm to 10 mm.

19. A method as in claim 14, further comprising subcutaneously introducing an arterial port wherein the arterial port is connected or connectable to the access leg of the arterial access cannula.

20. A method as in claim 19, wherein the arterial port is introduced through the incision.

21. A method as in claim 19, wherein the arterial port is introduced through a separate incision remote from the first incision, and thereafter connected to the access leg of the arterial access cannula.

22. A method as in claim 14, further comprising surgically exposing a vein;

introducing a venous cannula through the wall of the vein; and

introducing a venous port subcutaneously, wherein the venous port is connected or connectable to the venous catheter.

23. A method as in claim 22, wherein the venous cannula and the venous port are introduced through a single incision.

24. A method as in claim 22, wherein the venous cannula and the venous port are introduced through separate incisions and thereafter connected.

25. A cannula comprising:

a tubular body having a first end, a second end, and a lumen therebetween;

a tubular access leg having a first end connected to the tubular body at a junction; and

a pressure-responsive valve at the junction, said valve inhibiting fluid flow across the valve in the absence of a pressure differential thereacross.

26. A cannula as in claim 25, wherein the tubular body has a length in the range from 10 mm to 50 mm and an outer diameter in the range from 3 mm to 10 mm.

27. A cannula as in claim 26, wherein the access leg has a length in the range from 25 mm to 700 mm and an outer diameter in the range from 3 mm to 10 mm.

28. A cannula as in claim 25, wherein at least a portion of the access leg is sufficiently compliant so that no substantial forces may be transmitted to the tubular body through the access leg.

29. A cannula as in claim 28, wherein at least a portion of the access leg adjacent to the tubular body has a bending stiffness which is less than that of the adjacent tubular body.

30. A cannula as in claim 29, wherein said portion of the access leg has a hoop strength sufficient to withstand an internal pressure of -250 mmHg.

31. A cannula as in claim 25, wherein the tubular body is circumferentially reinforced.

32. A cannula as in claim 31, wherein the circumferential reinforcement comprises a helical wire or circumferential corrugation.

33. A cannula as in claim 31, wherein the access leg is circumferentially reinforced.

34. A cannula as in claim 33, wherein the circumferential reinforcement comprises a helical wire or circumferential corrugation.

35. A cannula as in claim 25, further comprising a pressure-responsive valve at the junction, said valve inhibiting blood flow across the junction in the absence of a pressure differential thereacross.

36. A cannula as in claim 35, wherein the valve is incorporated in the tubular body so that no structure of the valve intrudes into the vascular lumen.

37. A cannula as in claim 36, wherein the valve is a slit valve formed in the tubular body at the junction.

38. A cannula as in claim 25, wherein the tubular body is adapted to be implanted in a blood vessel.

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