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(54) **INTRAVASCULAR FOLDED TUBULAR ENDOPROSTHESIS**

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Related U.S. Application Data

(62) Division of application No. 09/299,512, filed on Apr. 26, 1999, now Pat. No. 6,287,335.

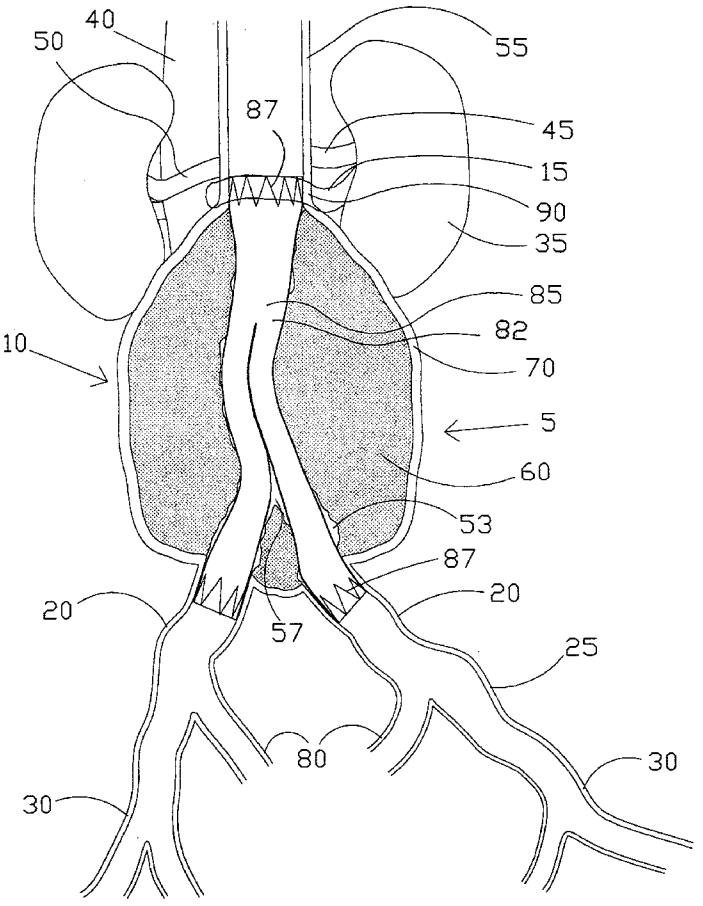
Publication Classification

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A61F 2/82 (2006.01)

(52) **U.S. Cl.** **623/1.15**

(57) **ABSTRACT**

A bifurcated or straight intravascular folded tubular member is deliverable percutaneously or by small cutdown to the site of a vascular lesion. Its inserted state has a smaller nondeployed diameter and a shorter nondeployed length. The intravascular tubular member has a folded tubular section that is unfolded following insertion into the blood vessel. The length of the intravascular folded tubular member is sized in situ to the length of the vessel lesion without error associated with diagnostic estimation of lesion length. The folded tubular member is self-expandable or balloon-expandable to a larger deployed diameter following delivery to the lesion site. An attachment anchor can be positioned at the inlet or outlet ends of the intravascular folded tubular member to prevent leakage between the tubular member and the native vessel lumen and to prevent migration of the tubular member. The attachment anchor has a short axial length to provide a more focal line of attachment to the vessel wall. Such attachment is valuable in attaching to a short aortic neck in the treatment of abdominal aortic aneurysm. The attachment anchor can have barbs which are held in a protected conformation during insertion of the tubular member and are released upon deployment of the attachment anchor. The intravascular tubular member can be formed of woven multifilament polymeric strands with metallic strands interwoven along with them. Double weaving is incorporated to prevent leakage at crossover points.



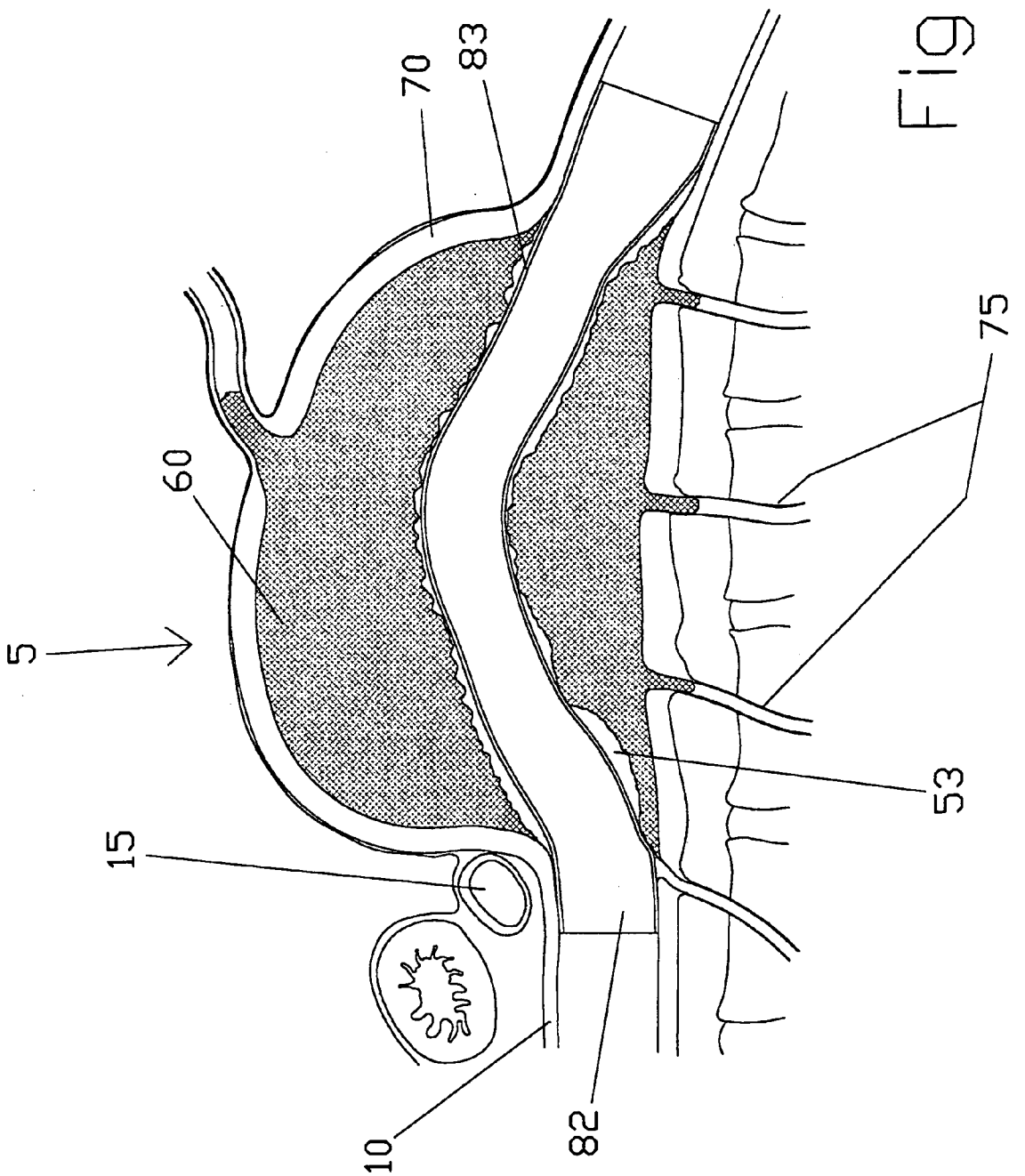


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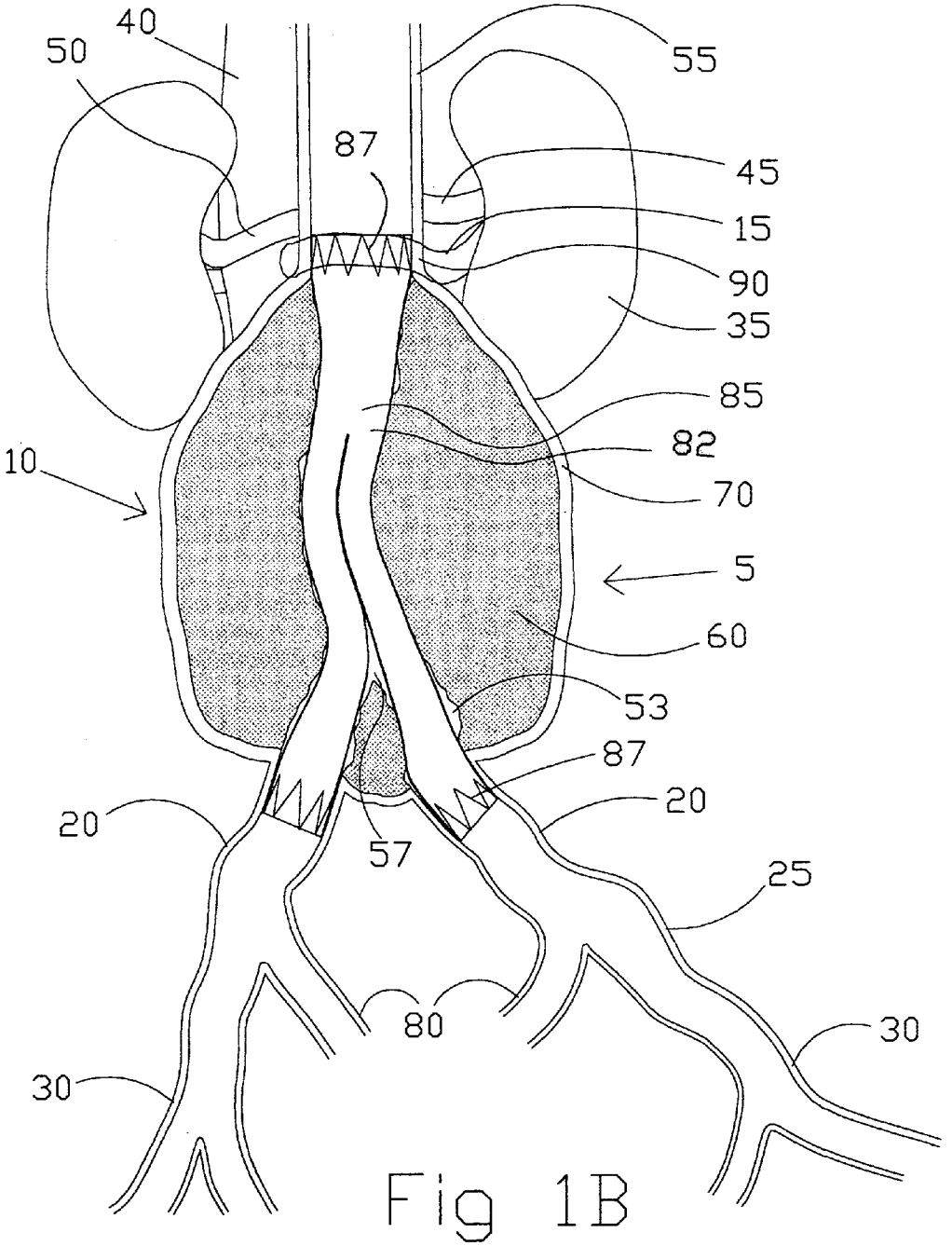


Fig 1B

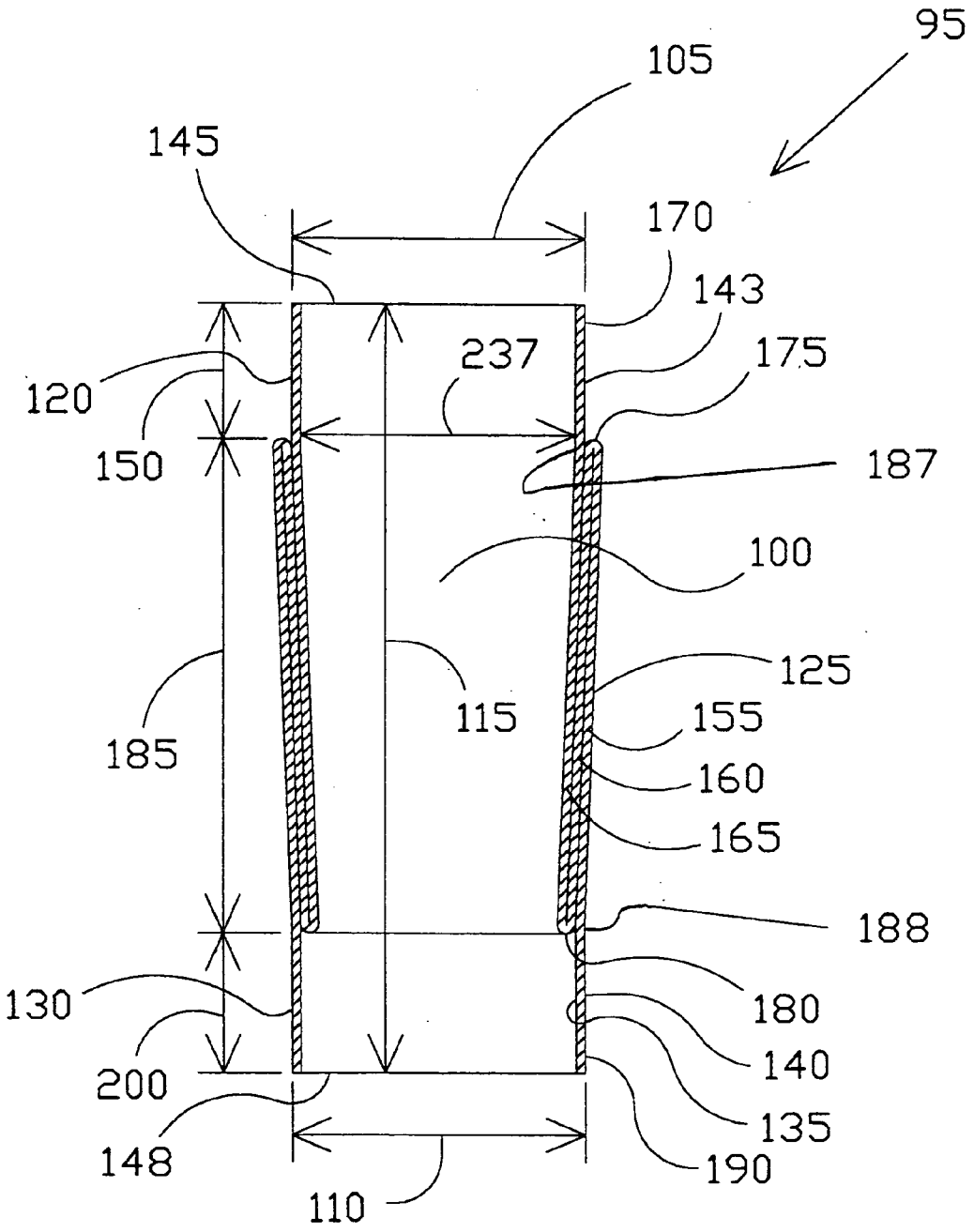

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Fig 2A

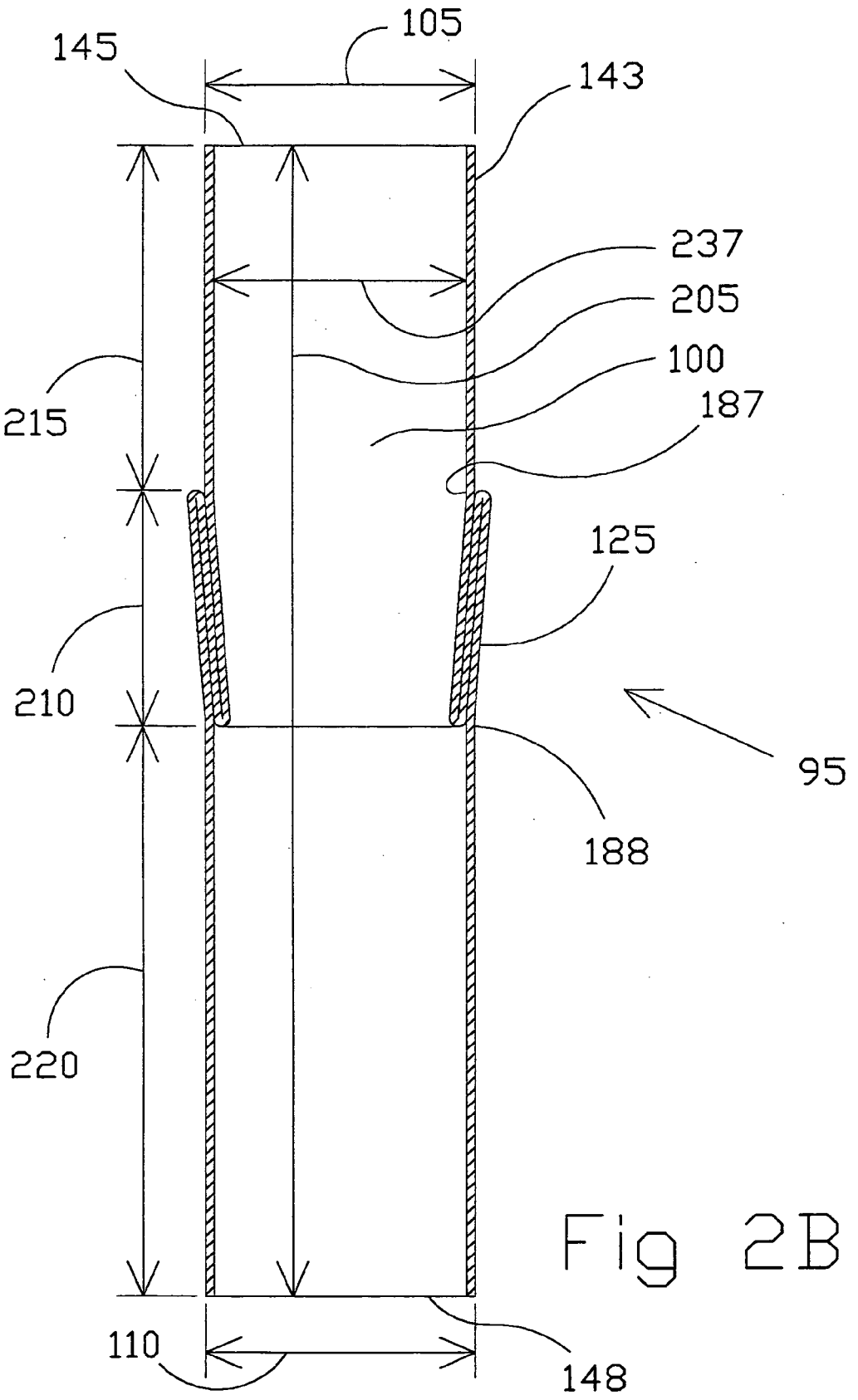


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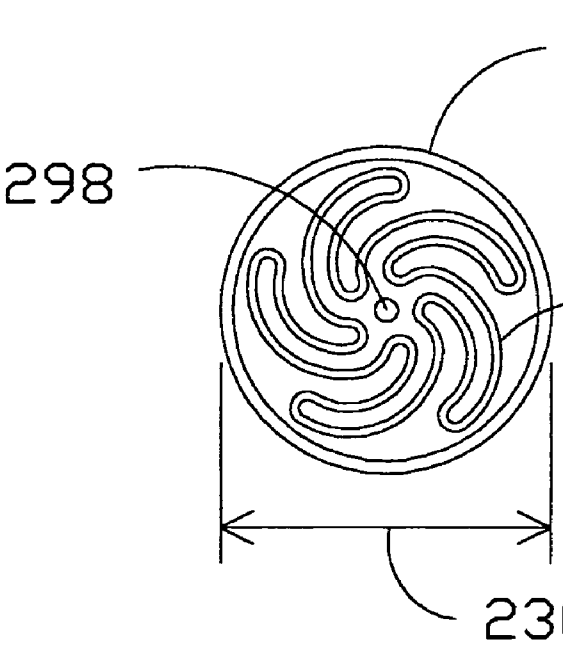


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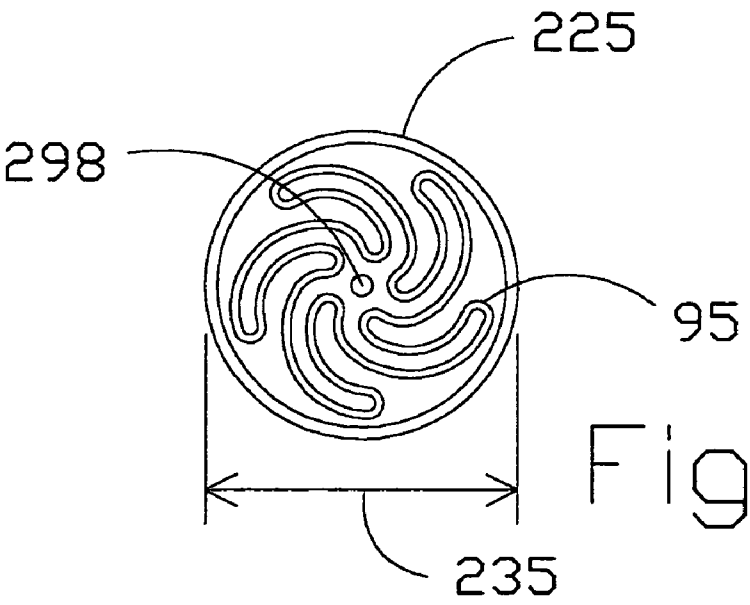


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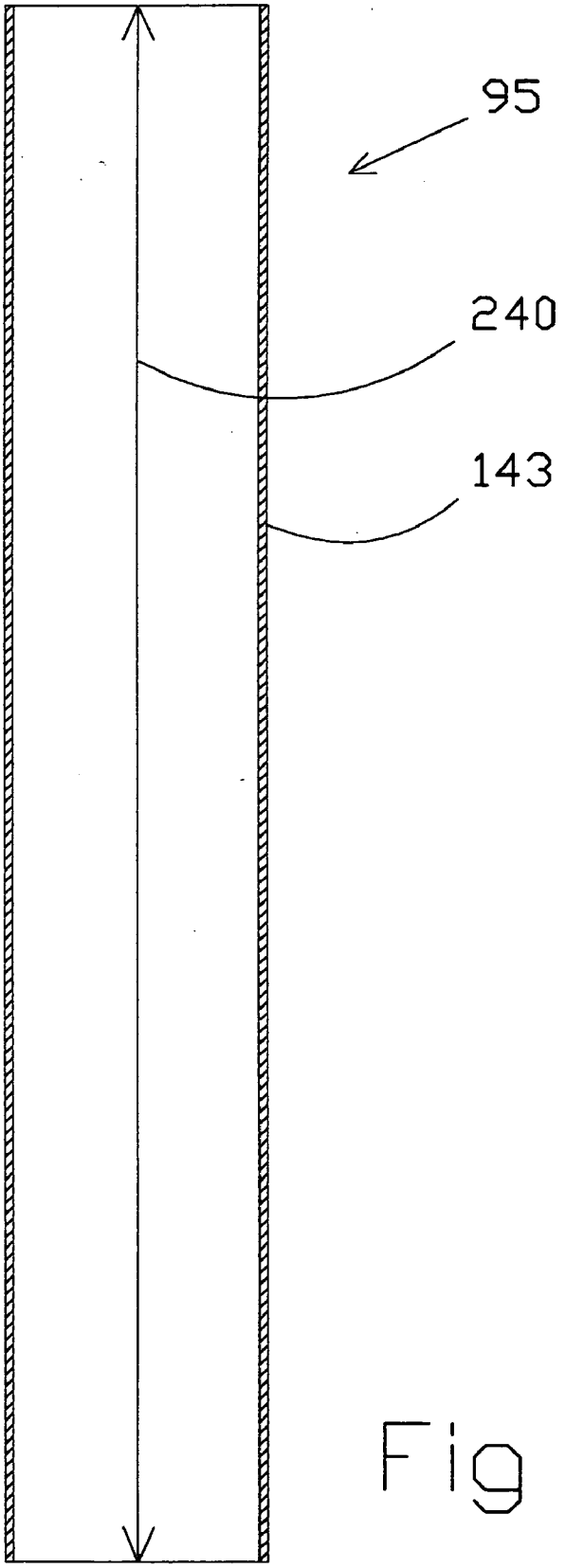


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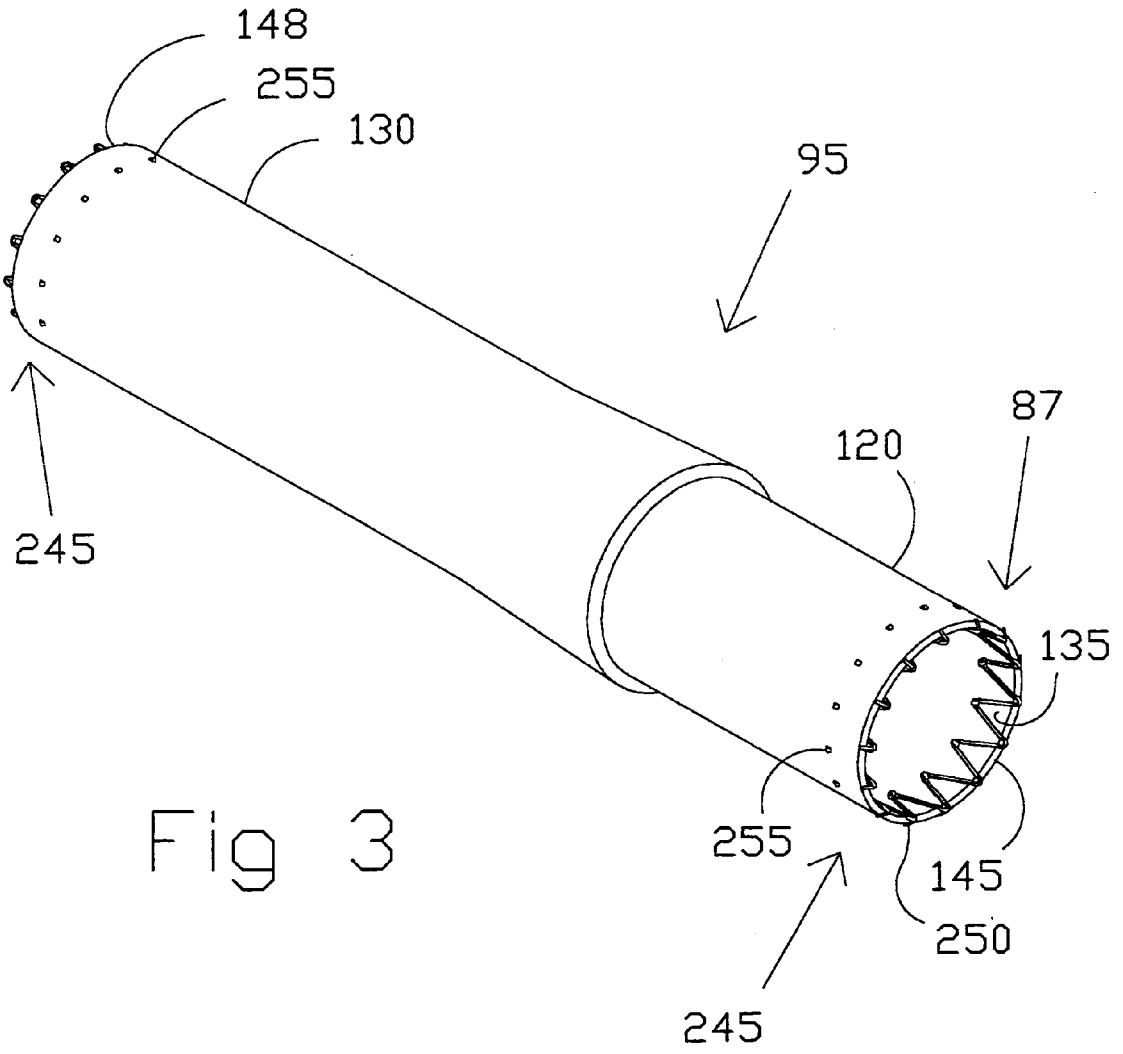


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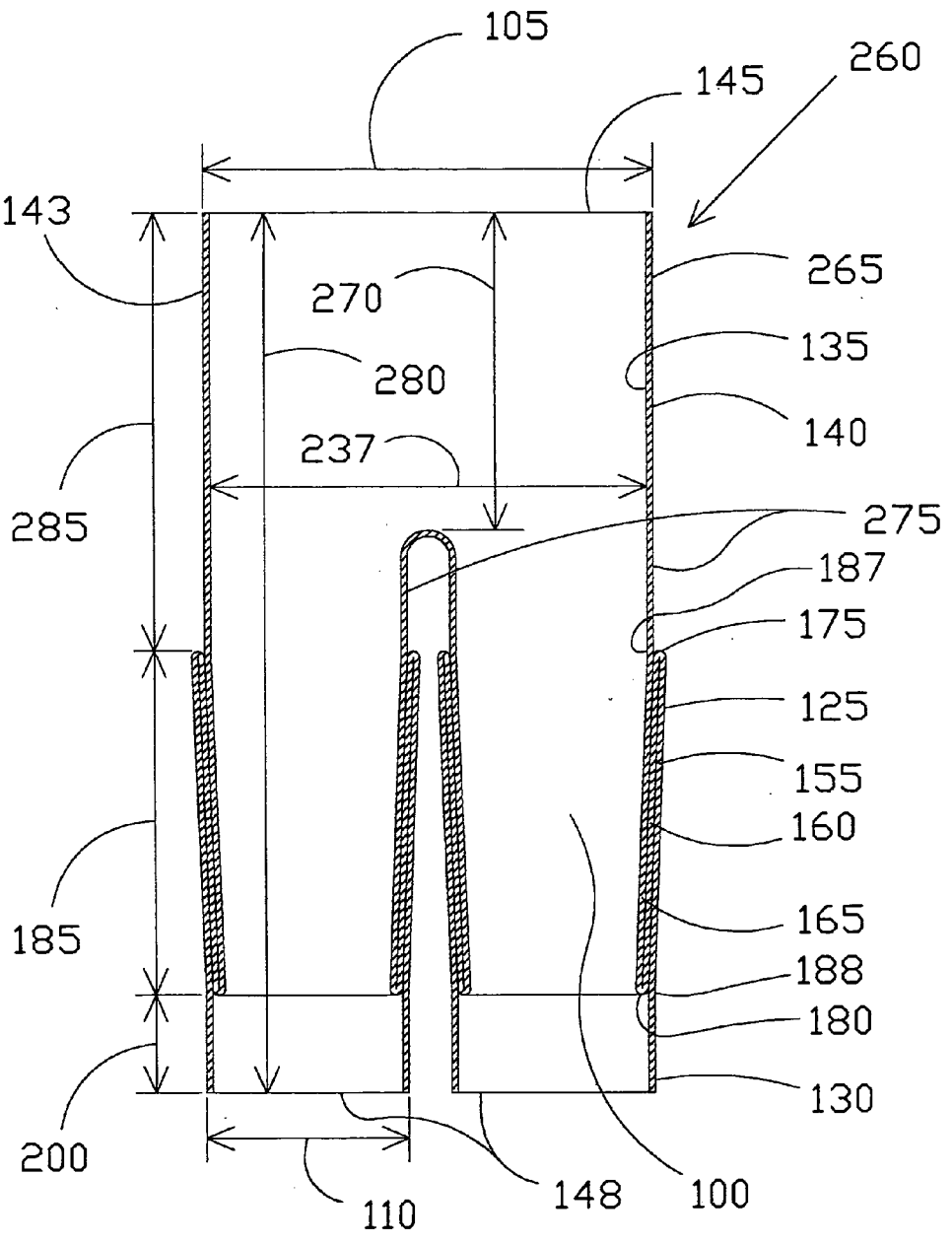

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Fig 4A

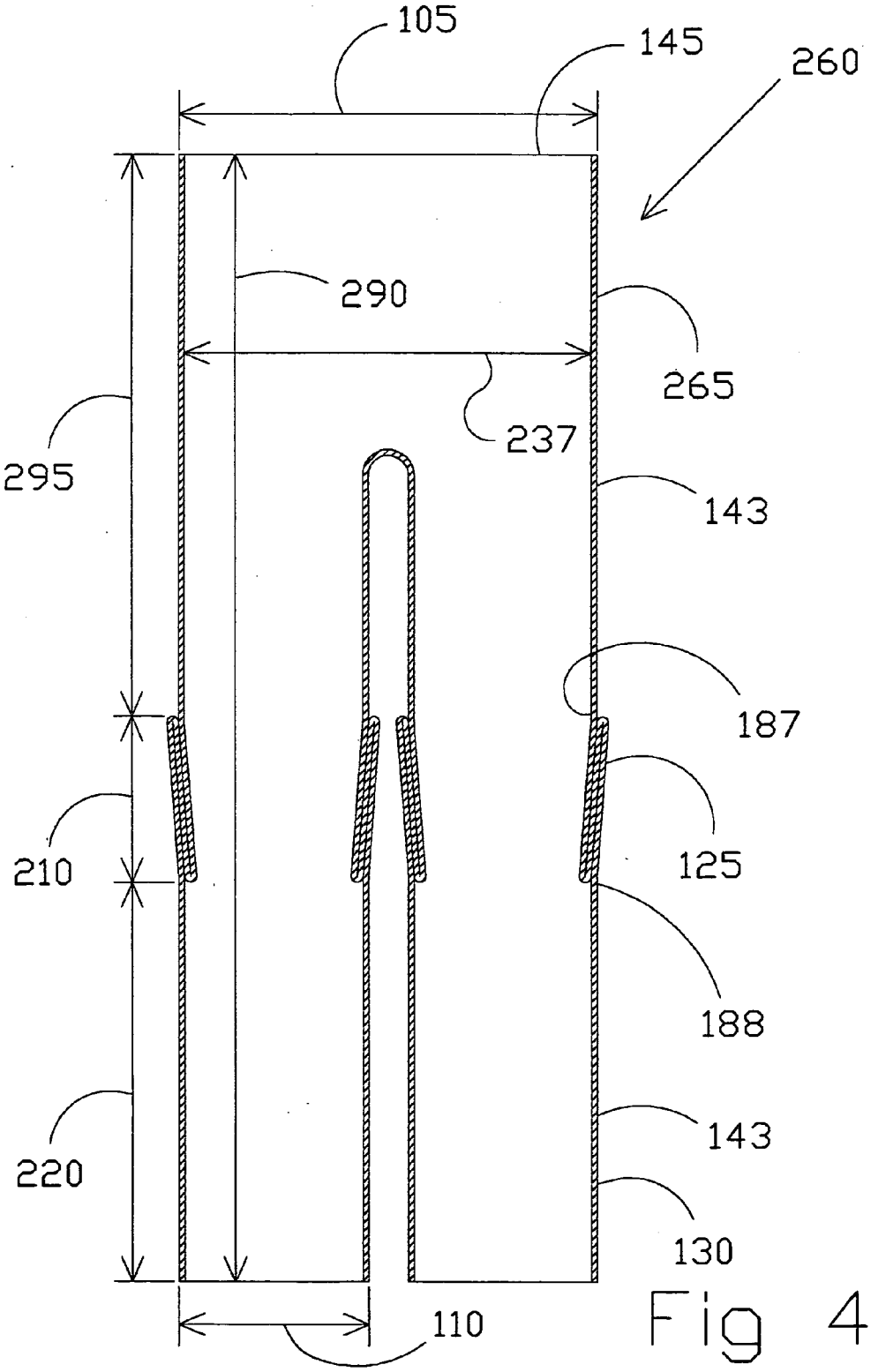


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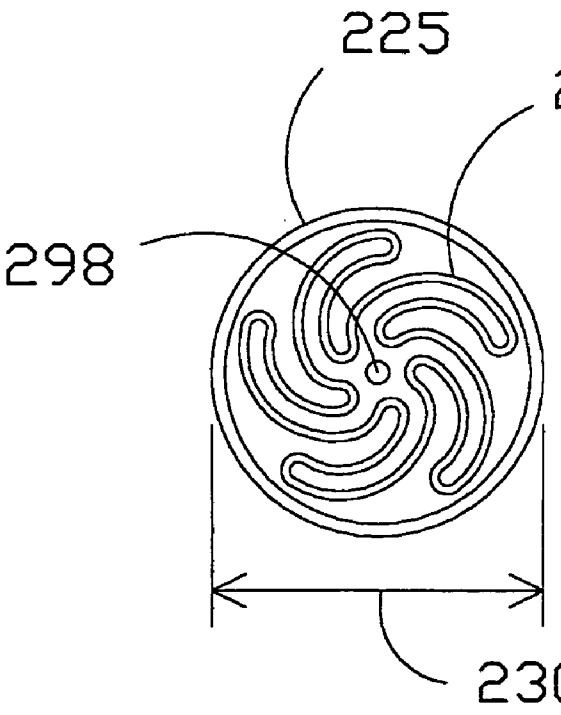


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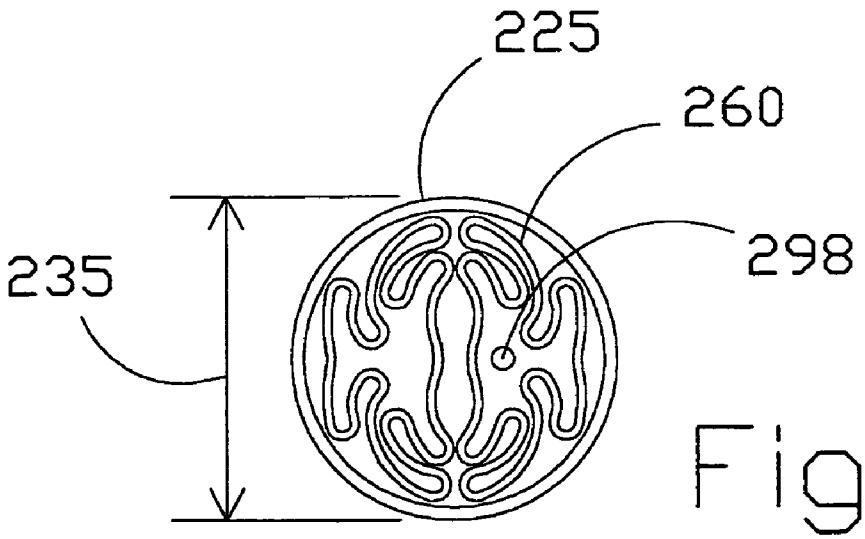


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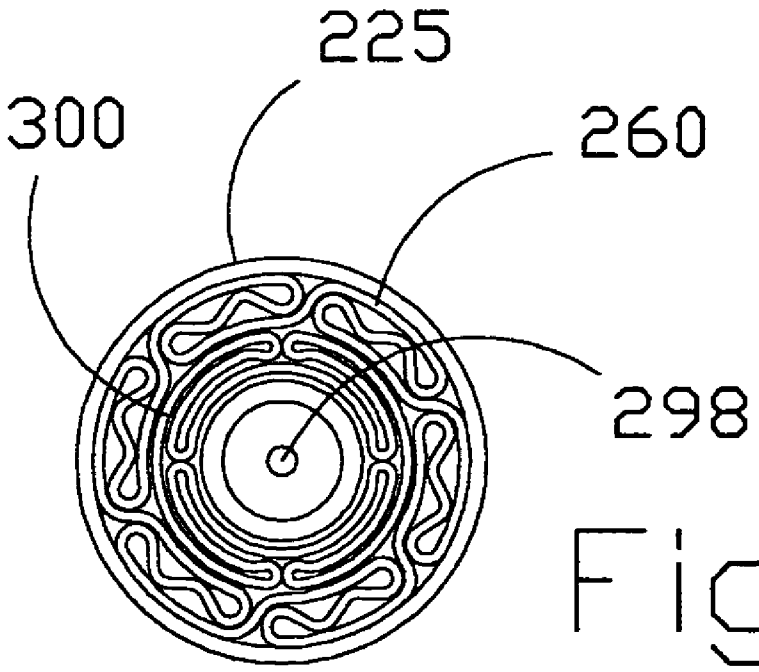


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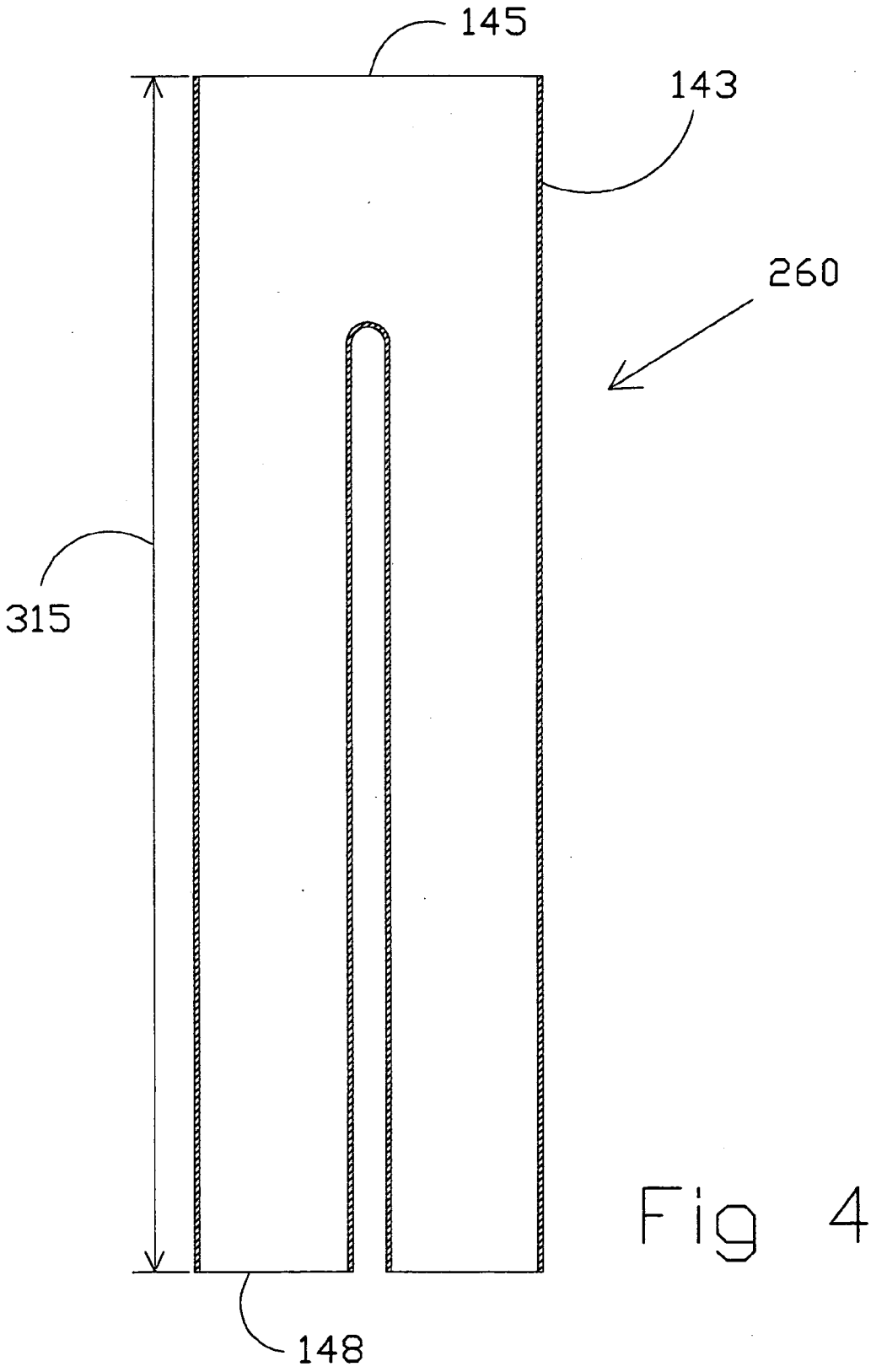


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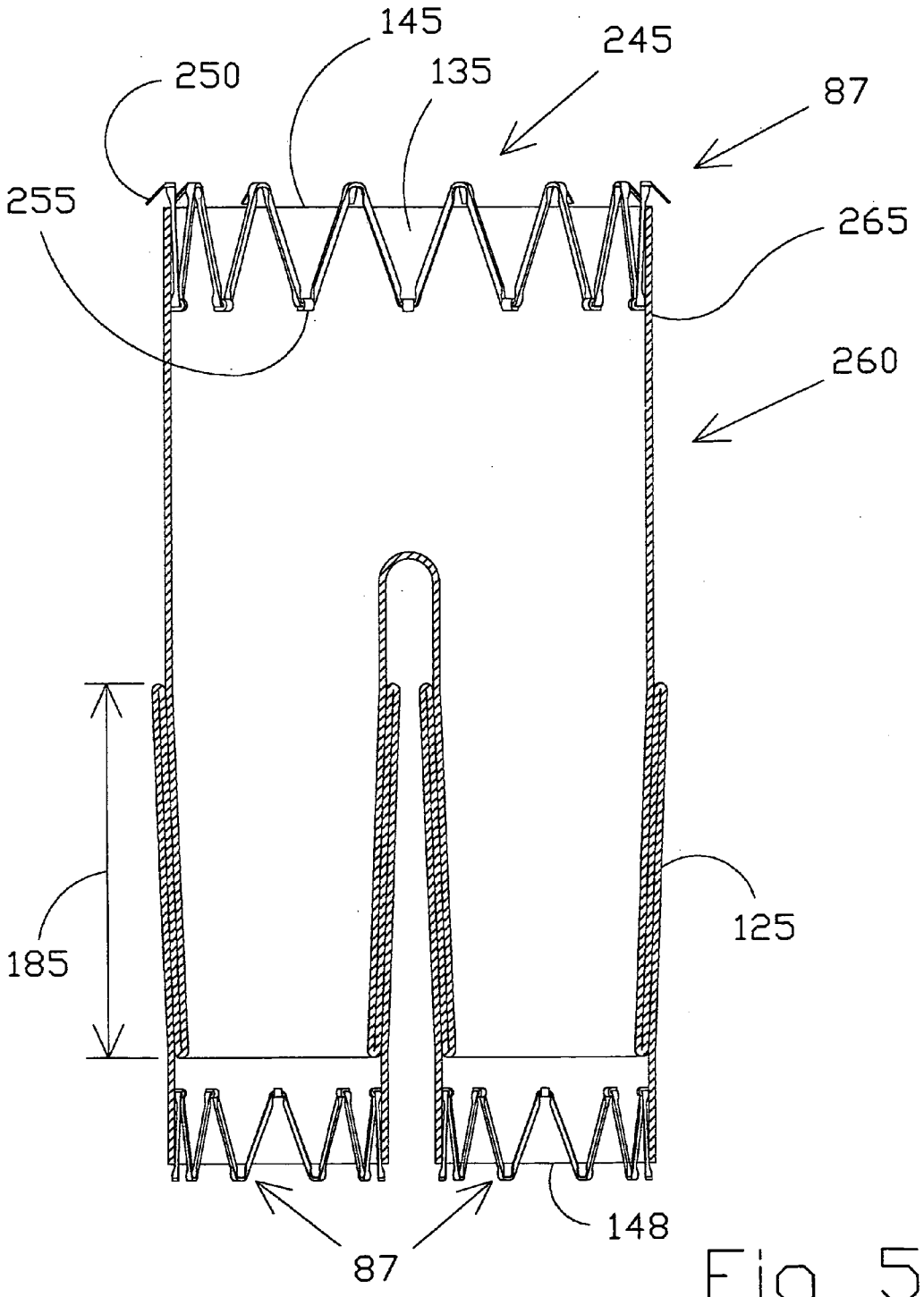


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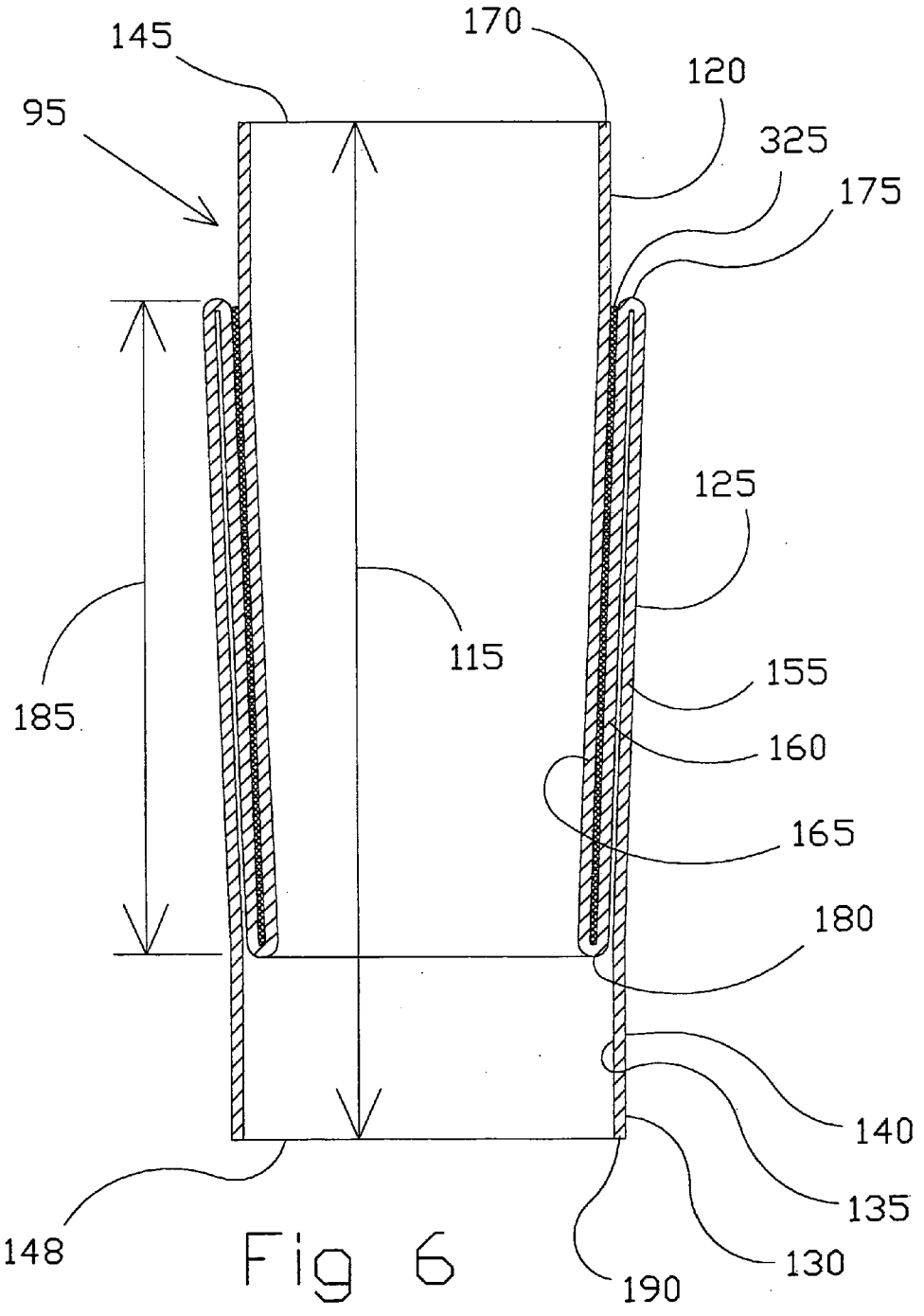
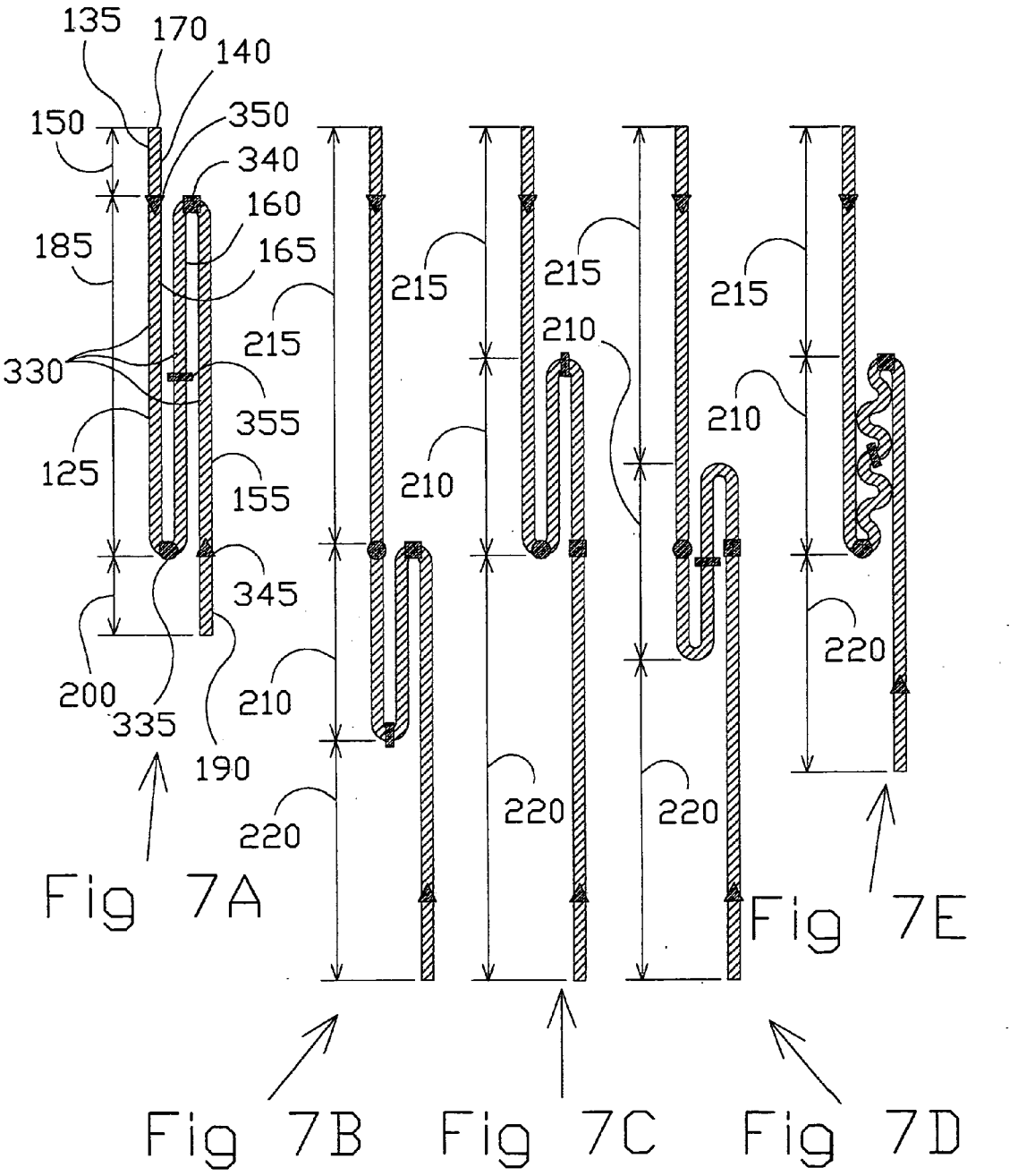

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Fig 6


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Fig 7A
Fig 7B
Fig 7C
Fig 7D
Fig 7E

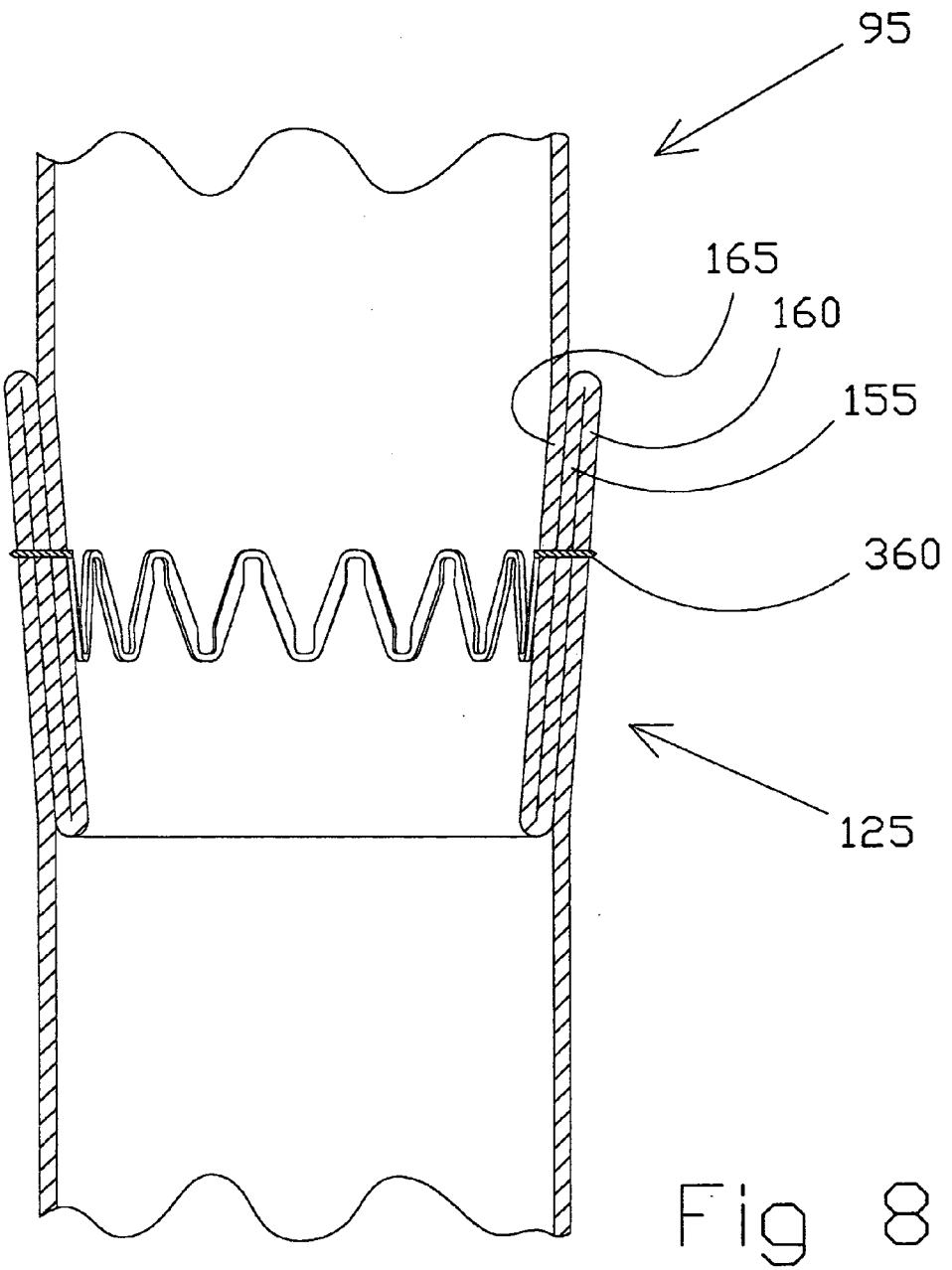


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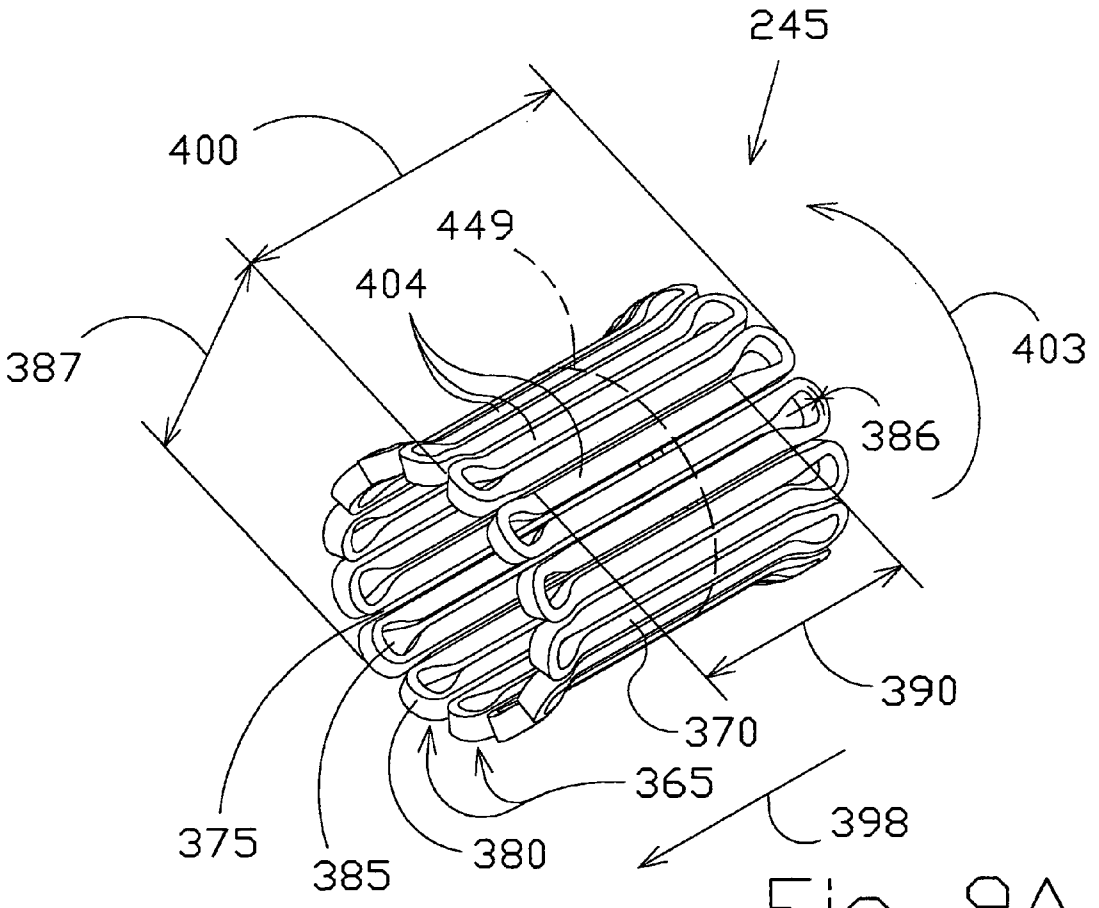


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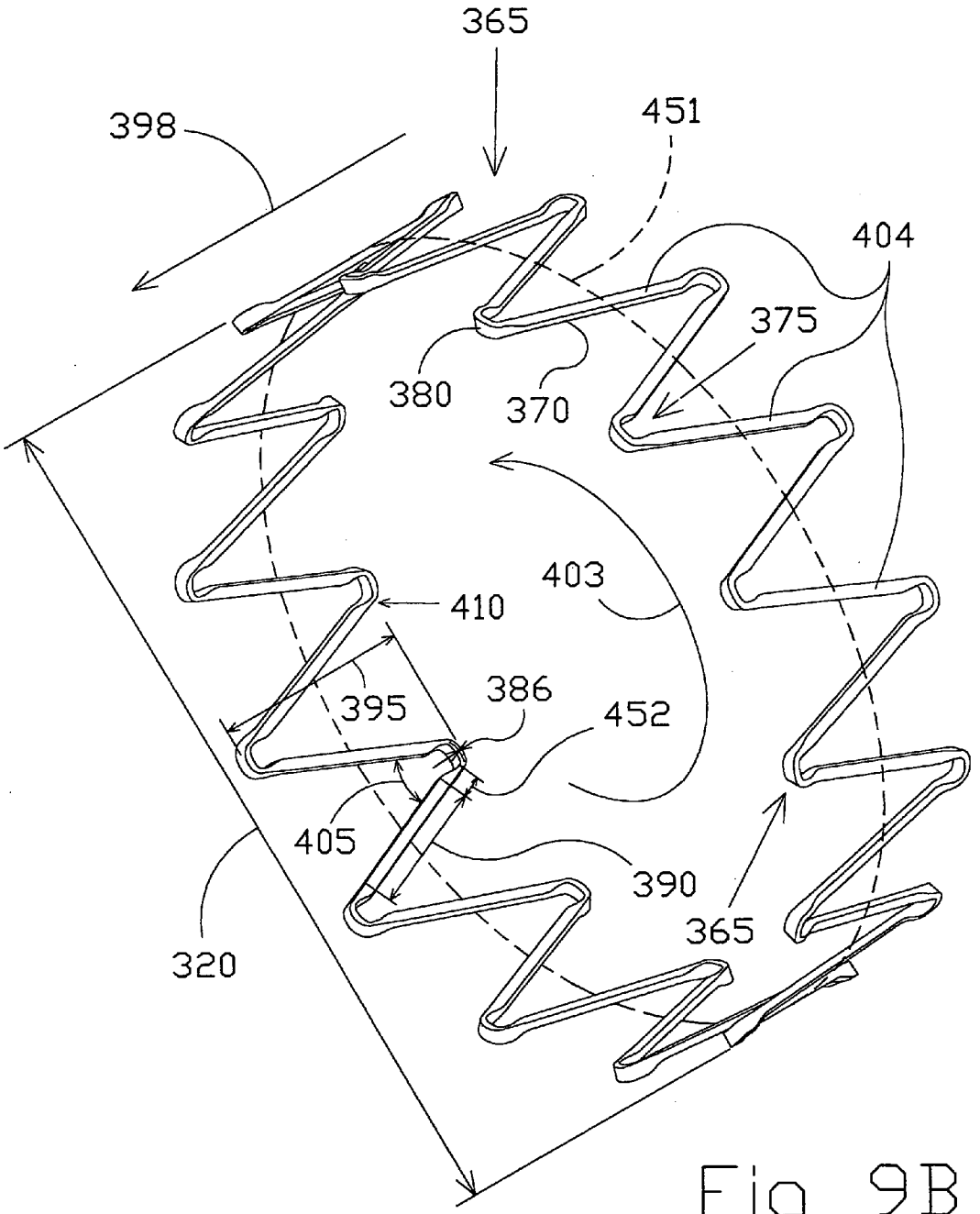


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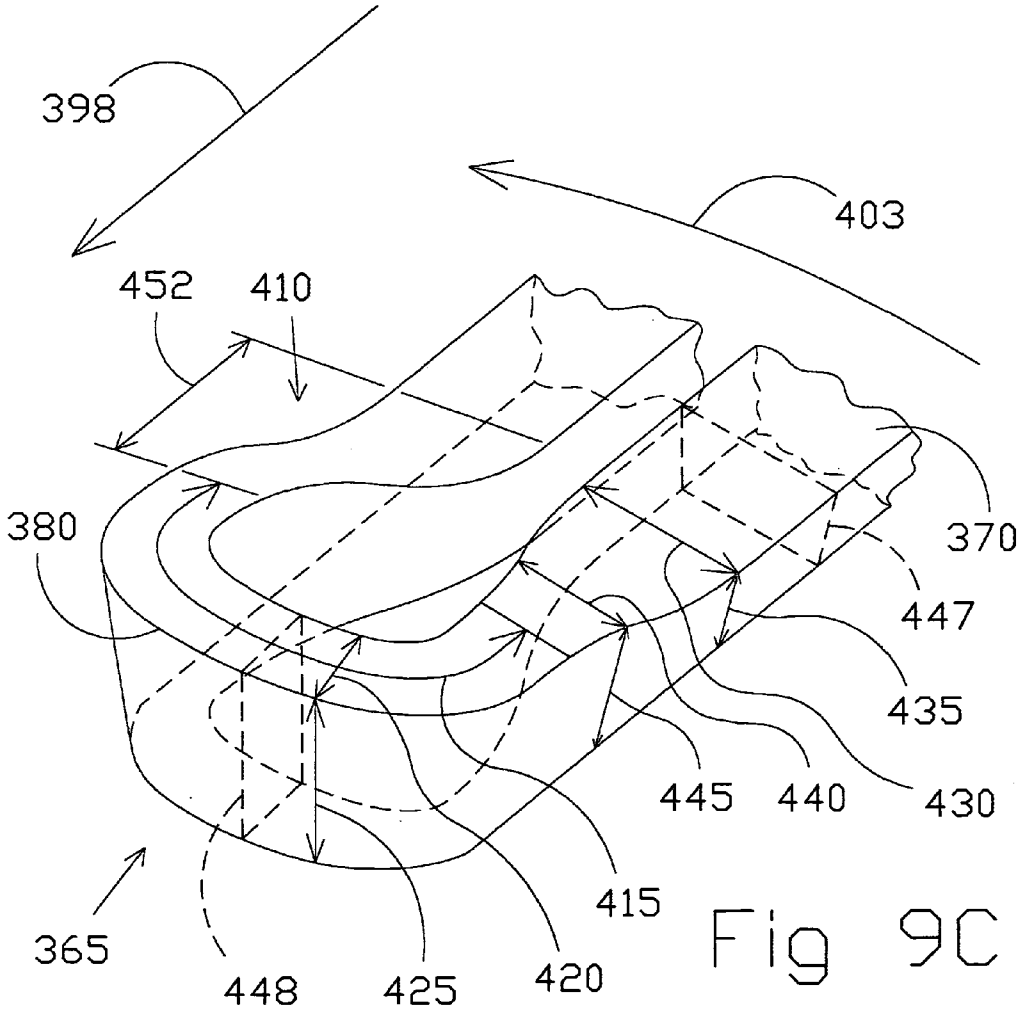


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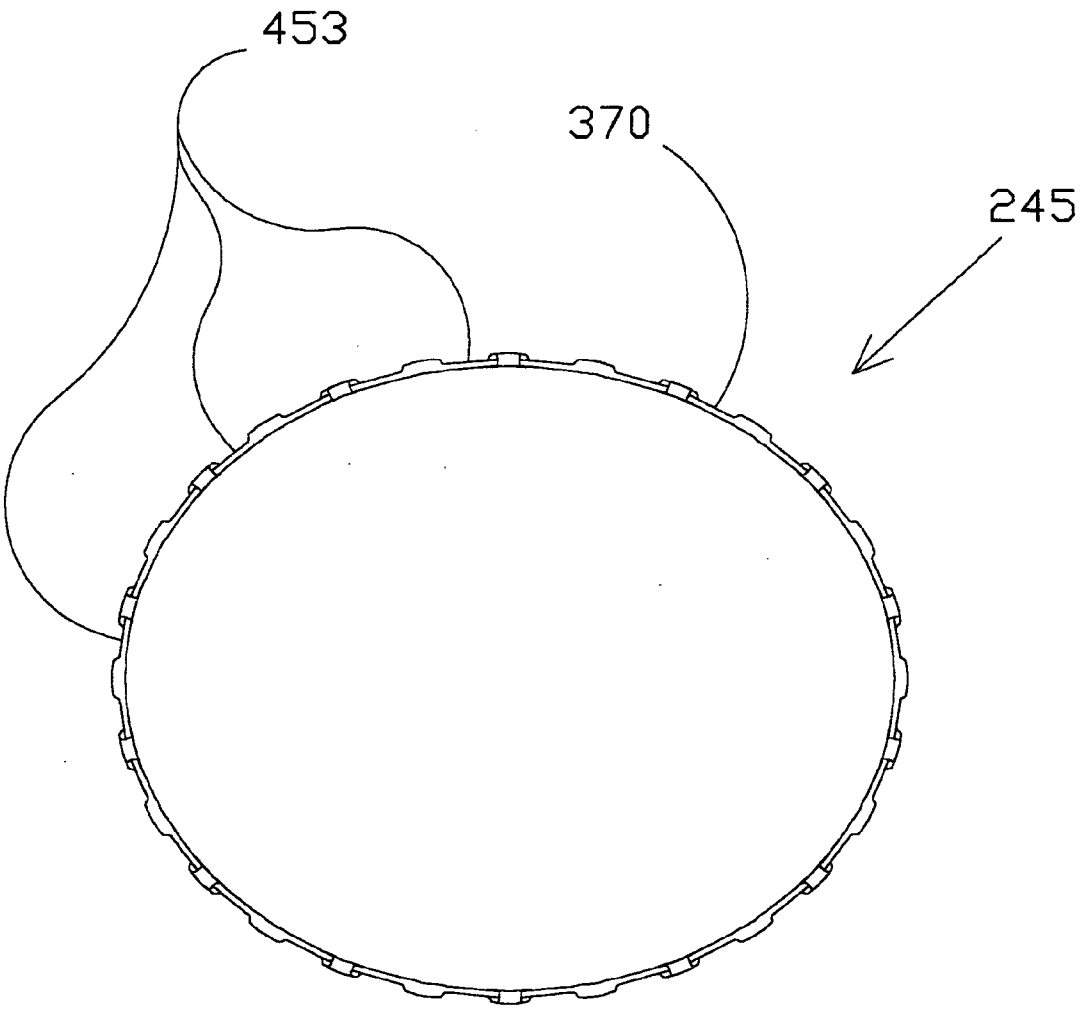


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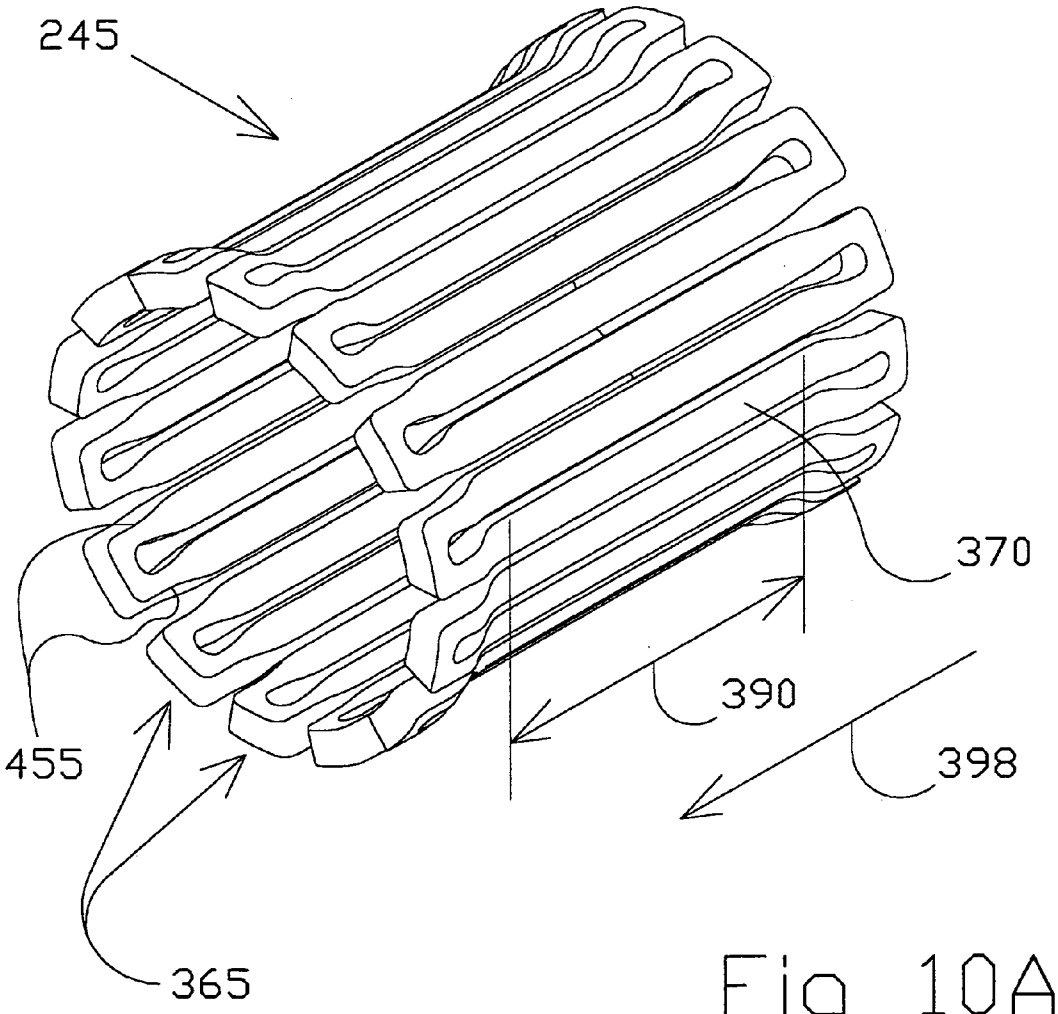


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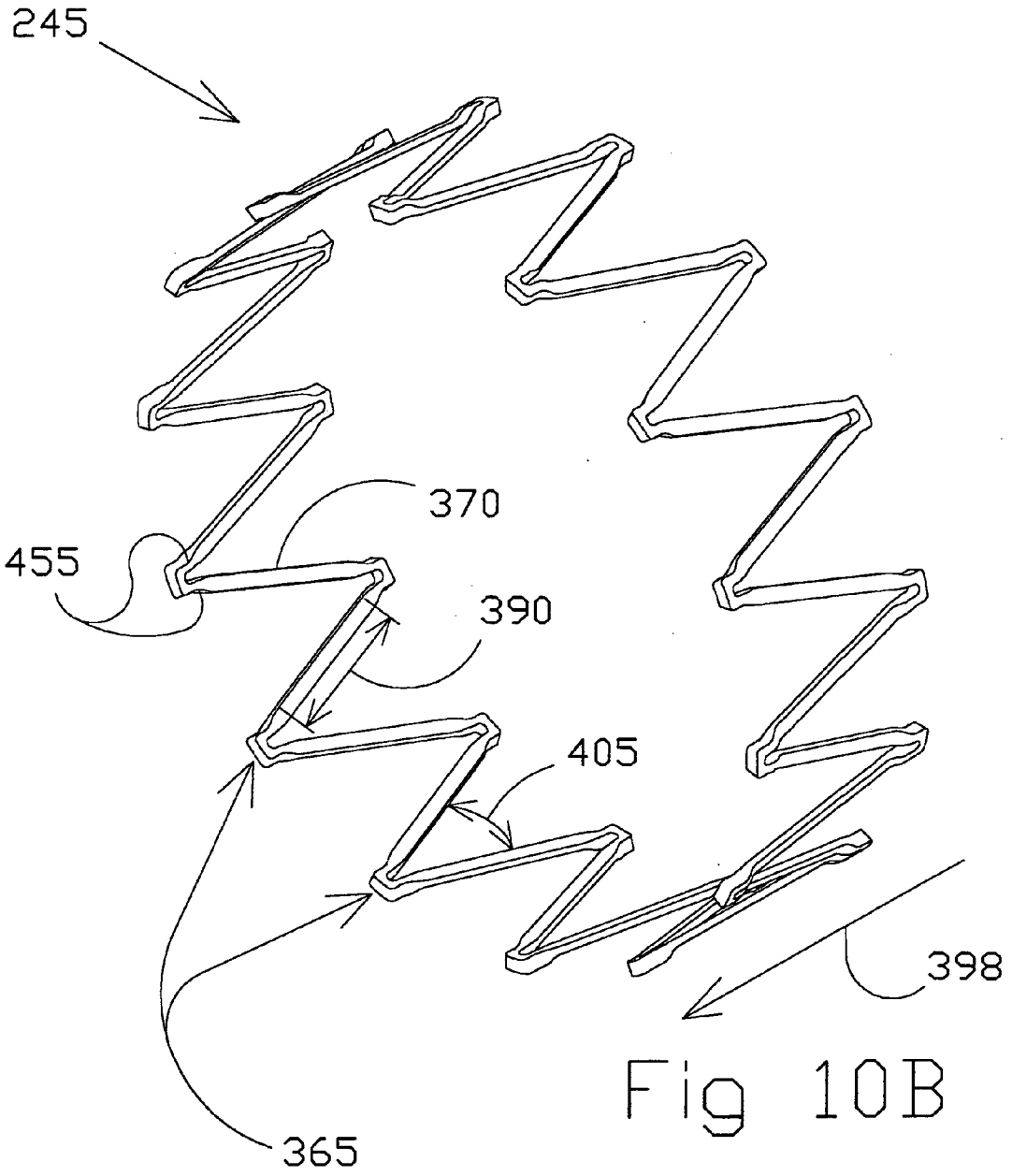


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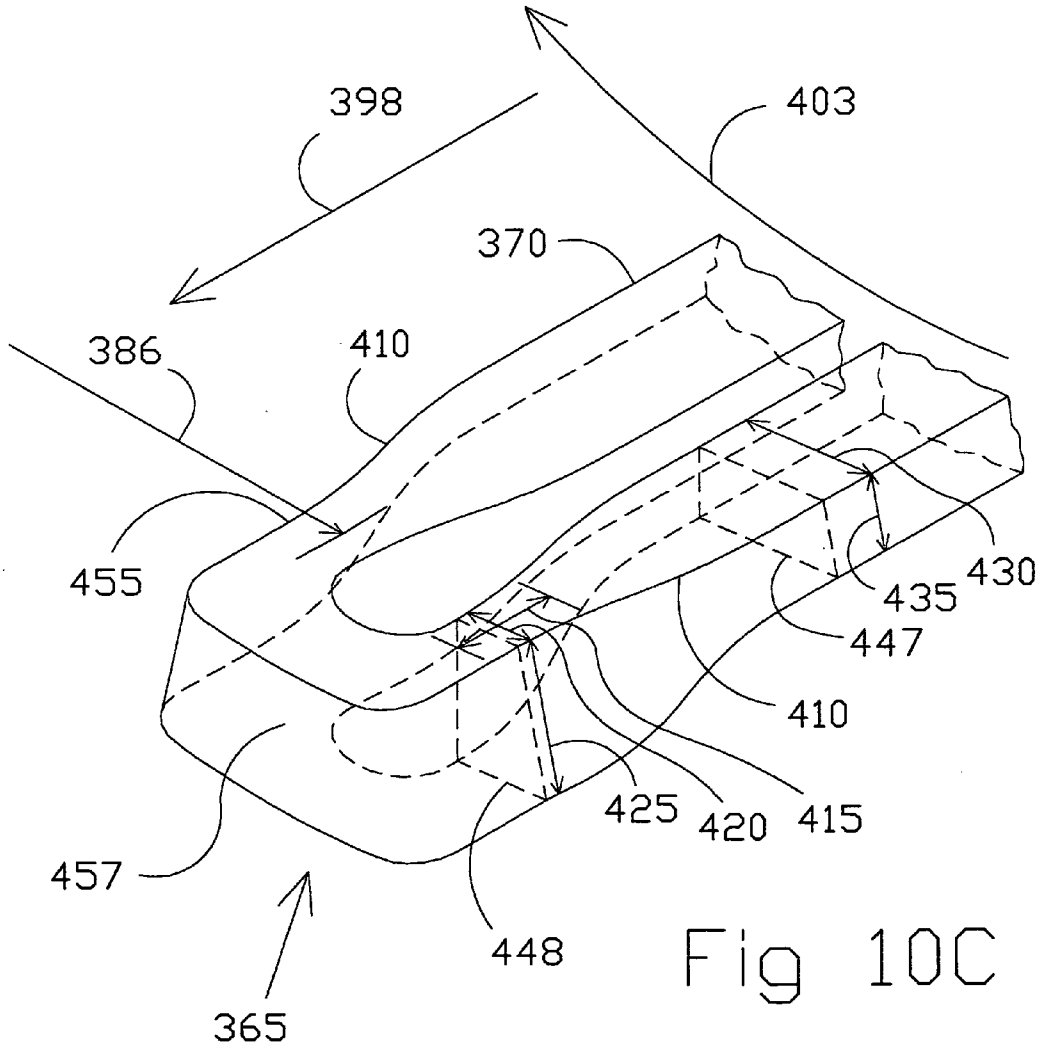


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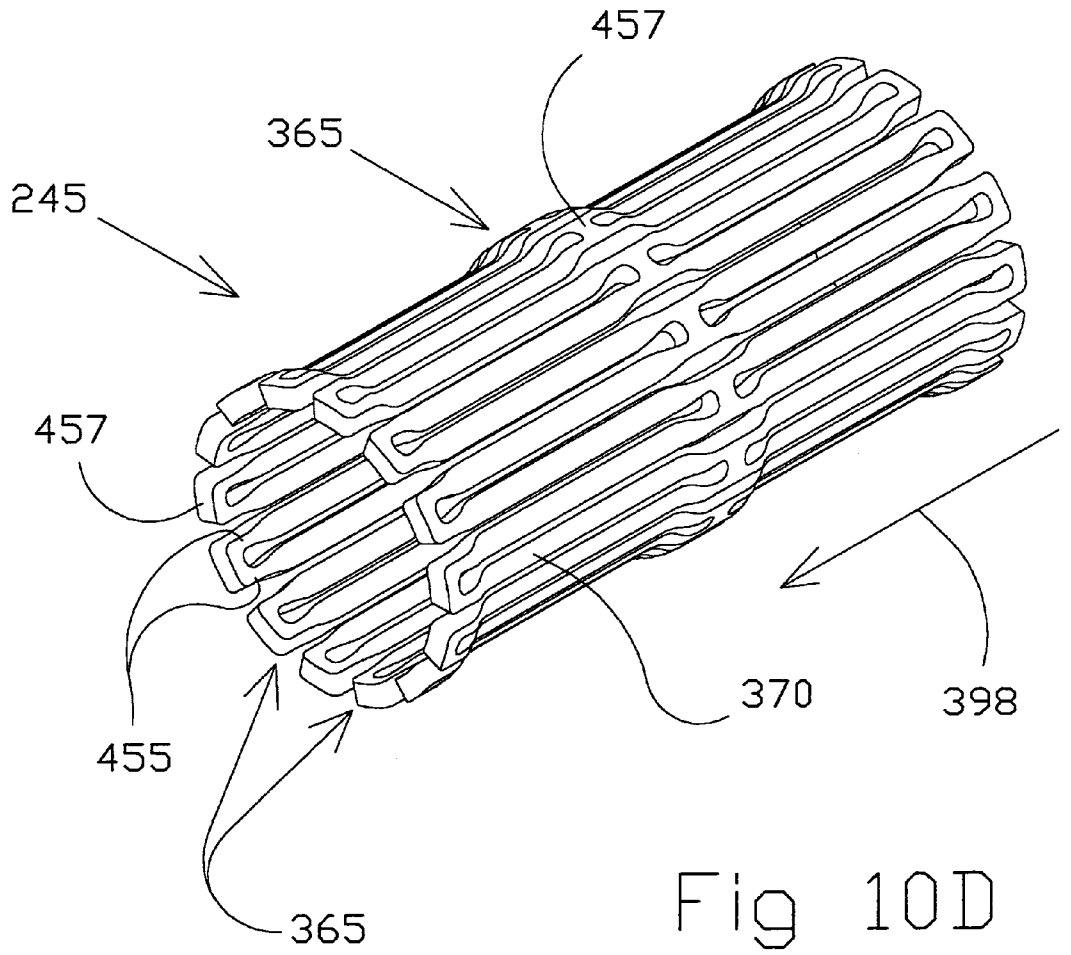


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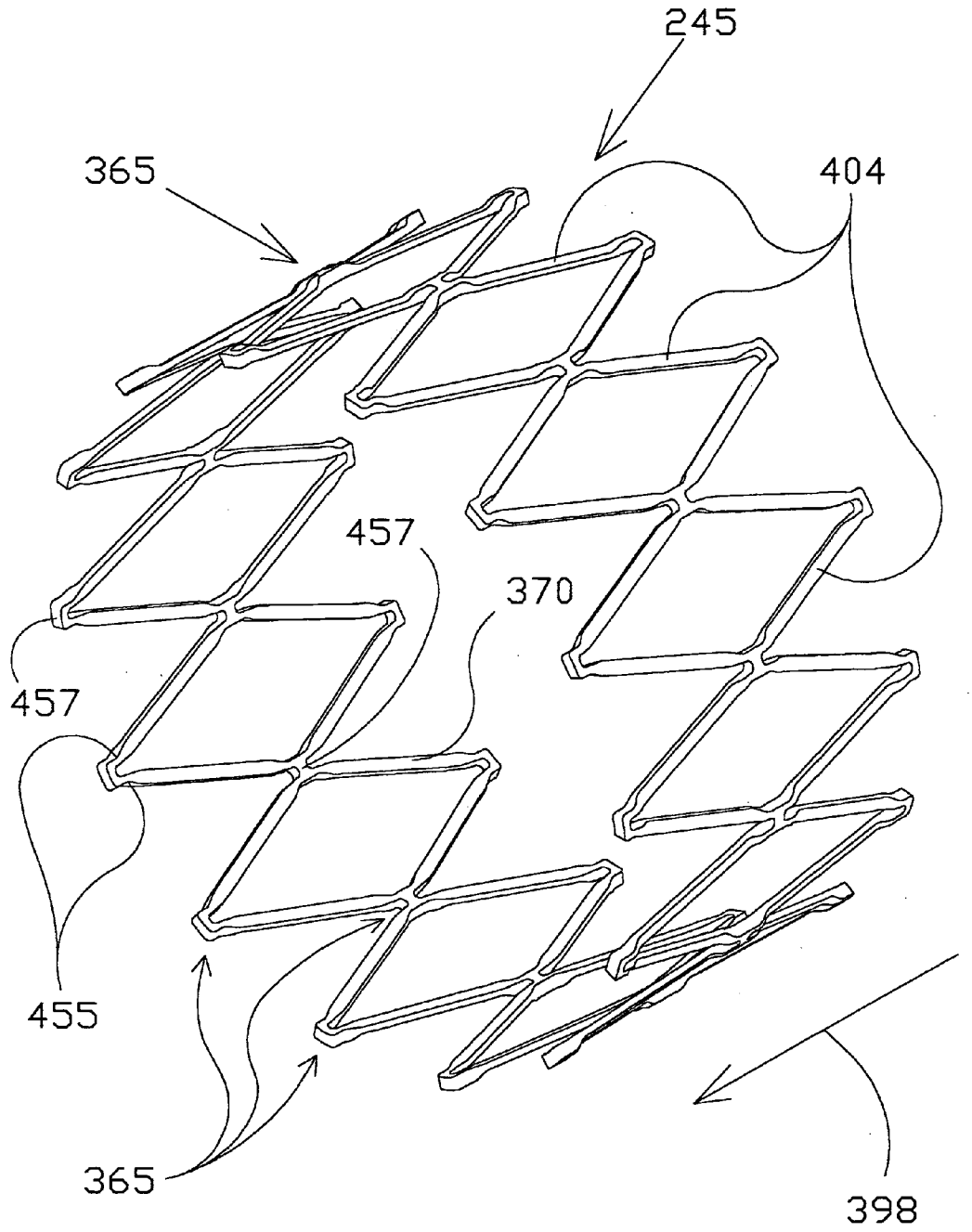


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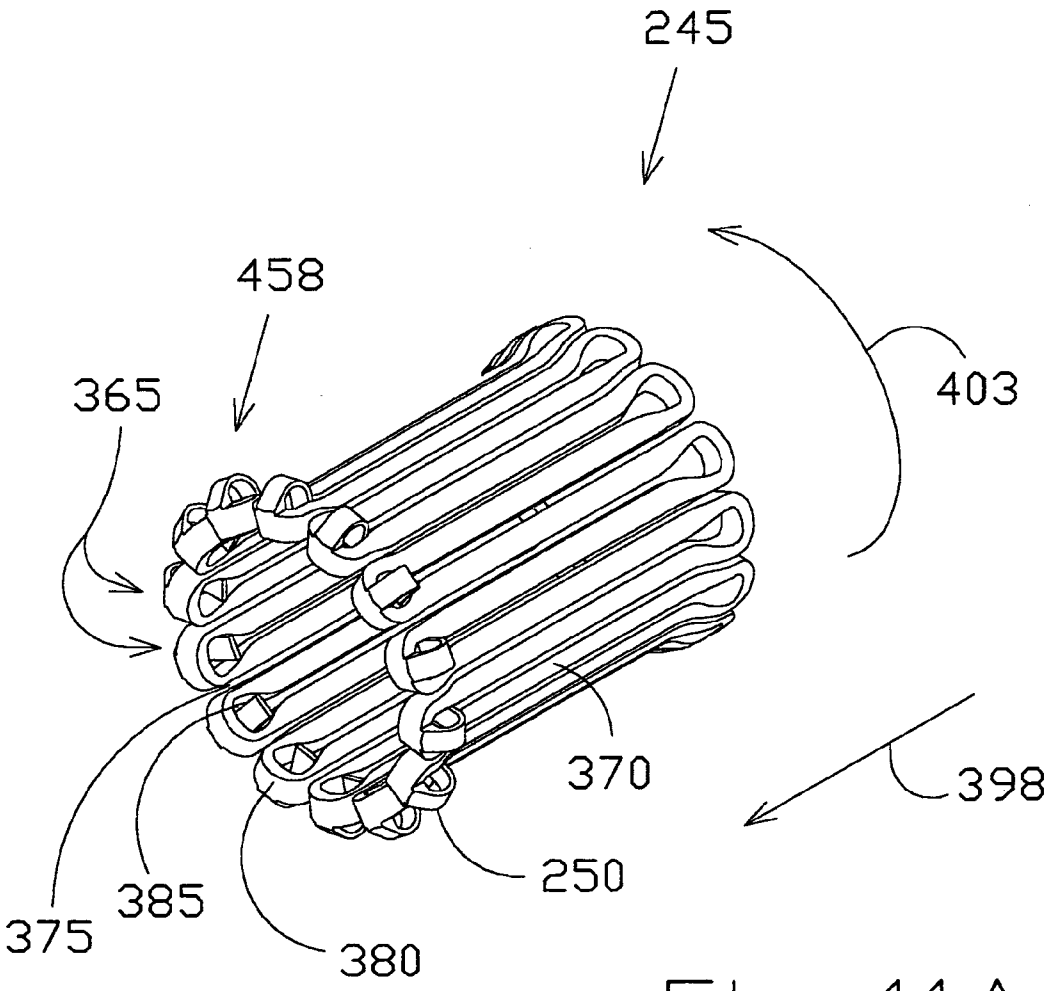


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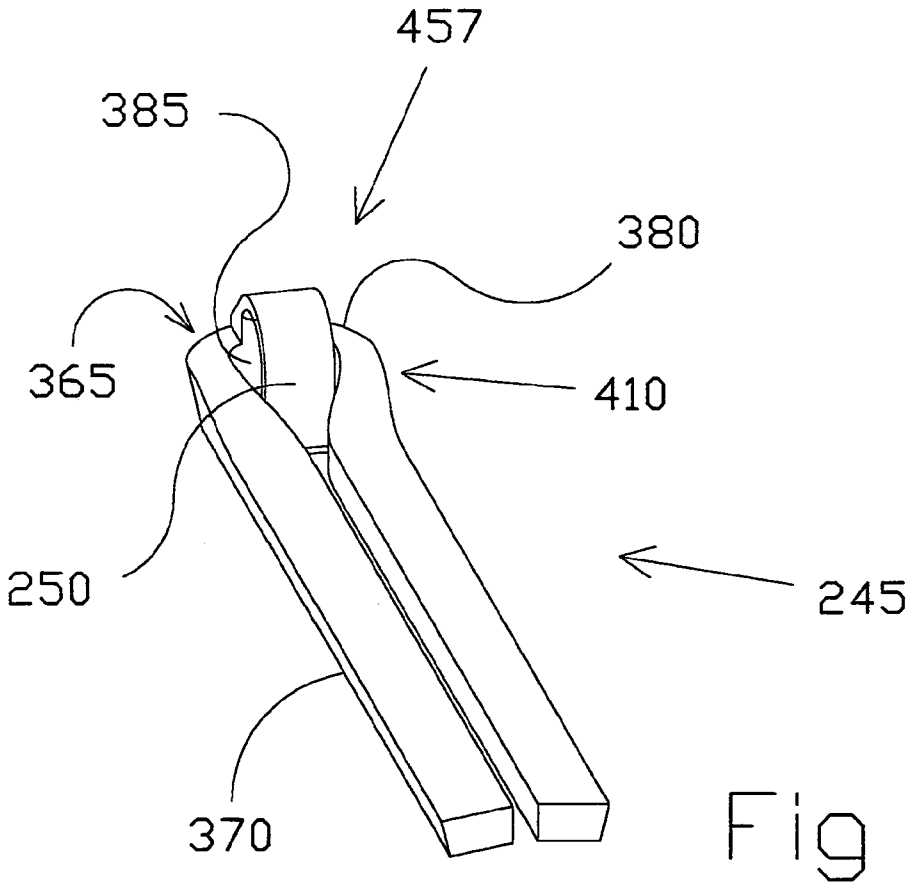


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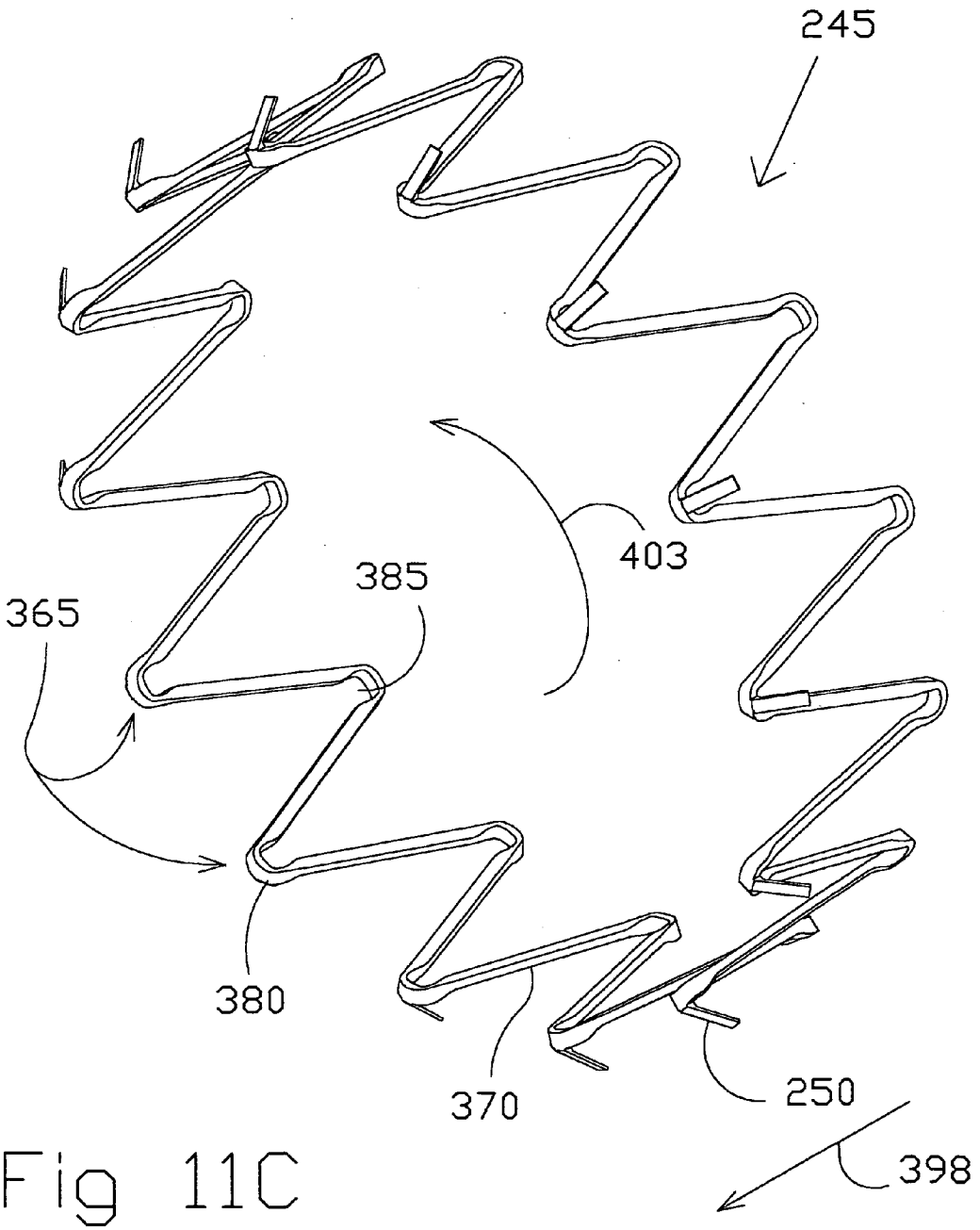


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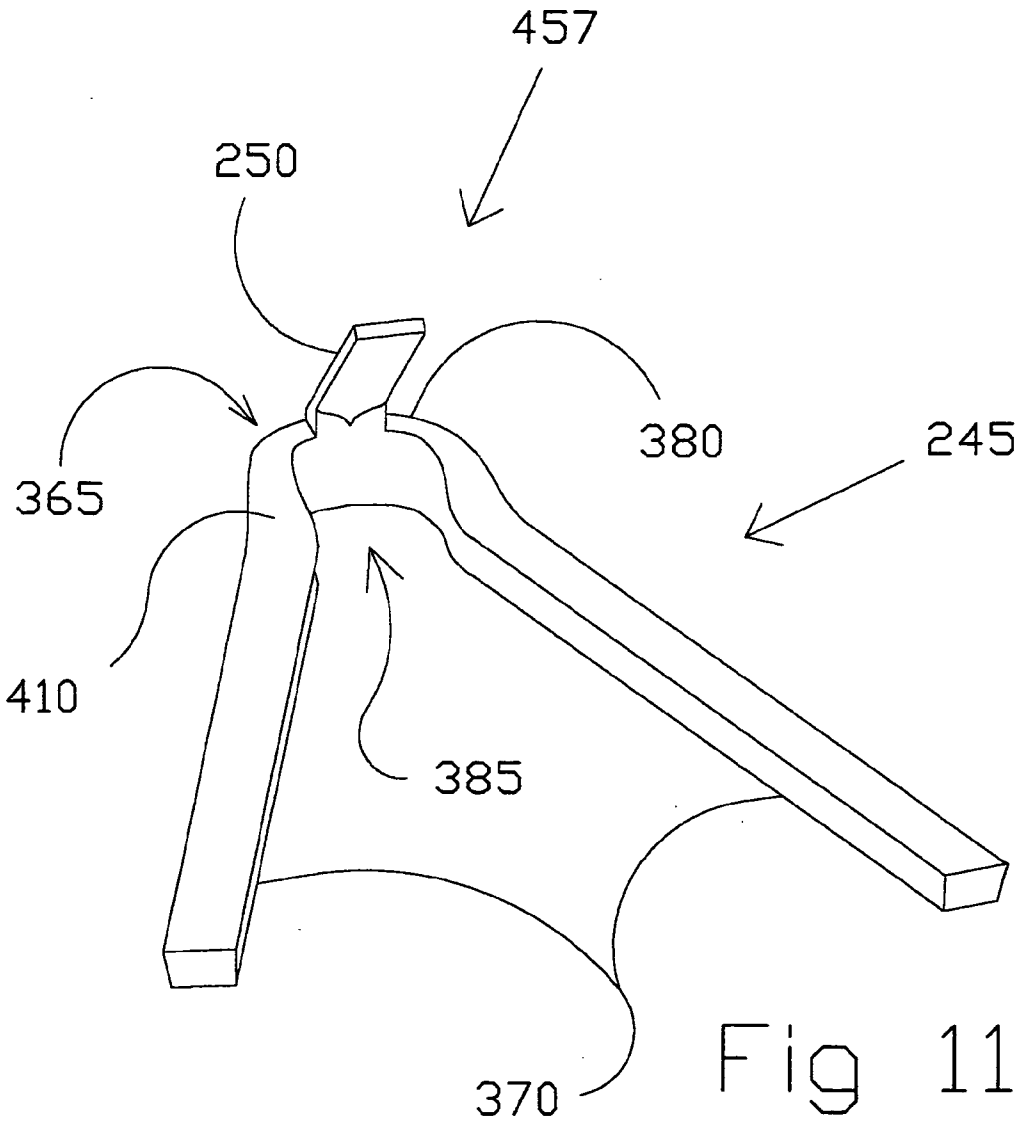


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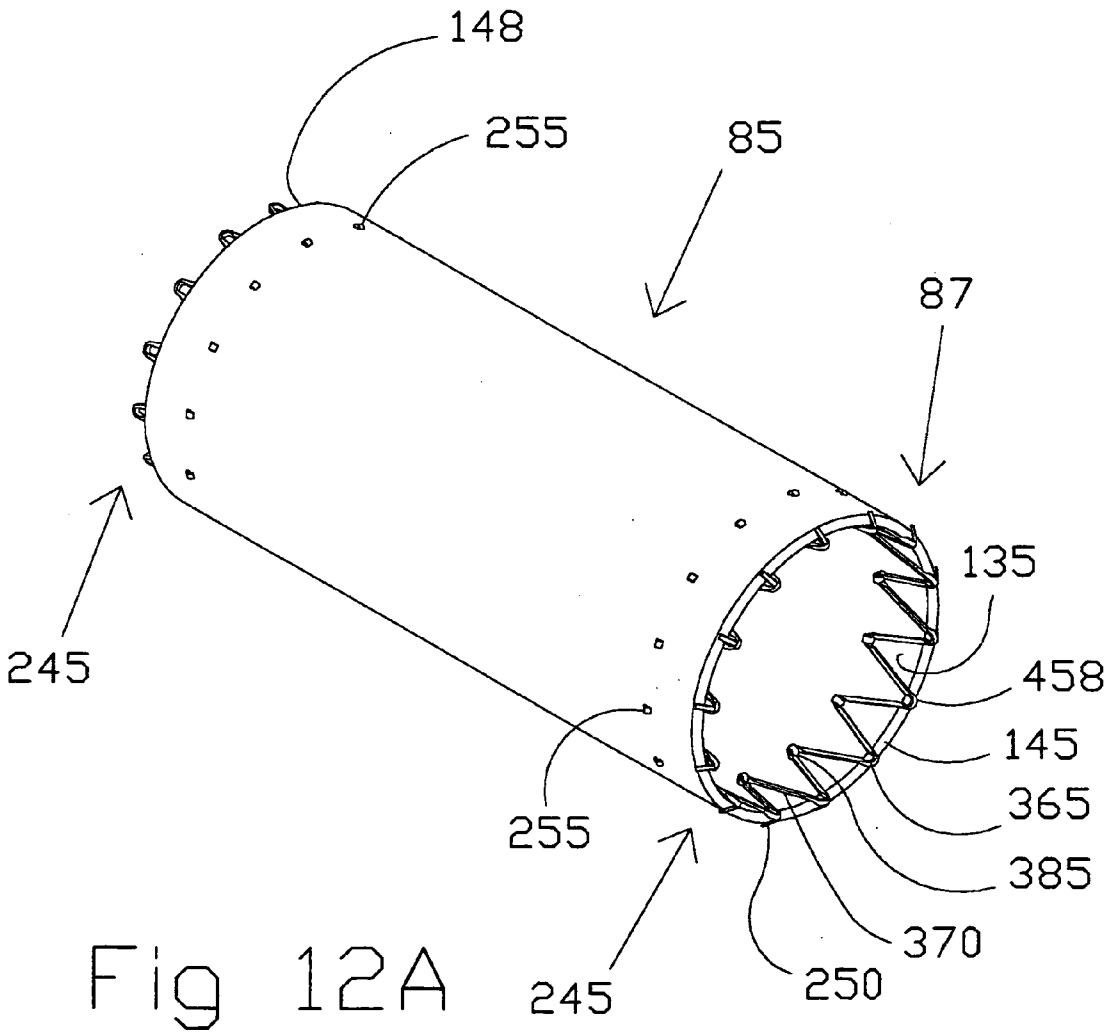


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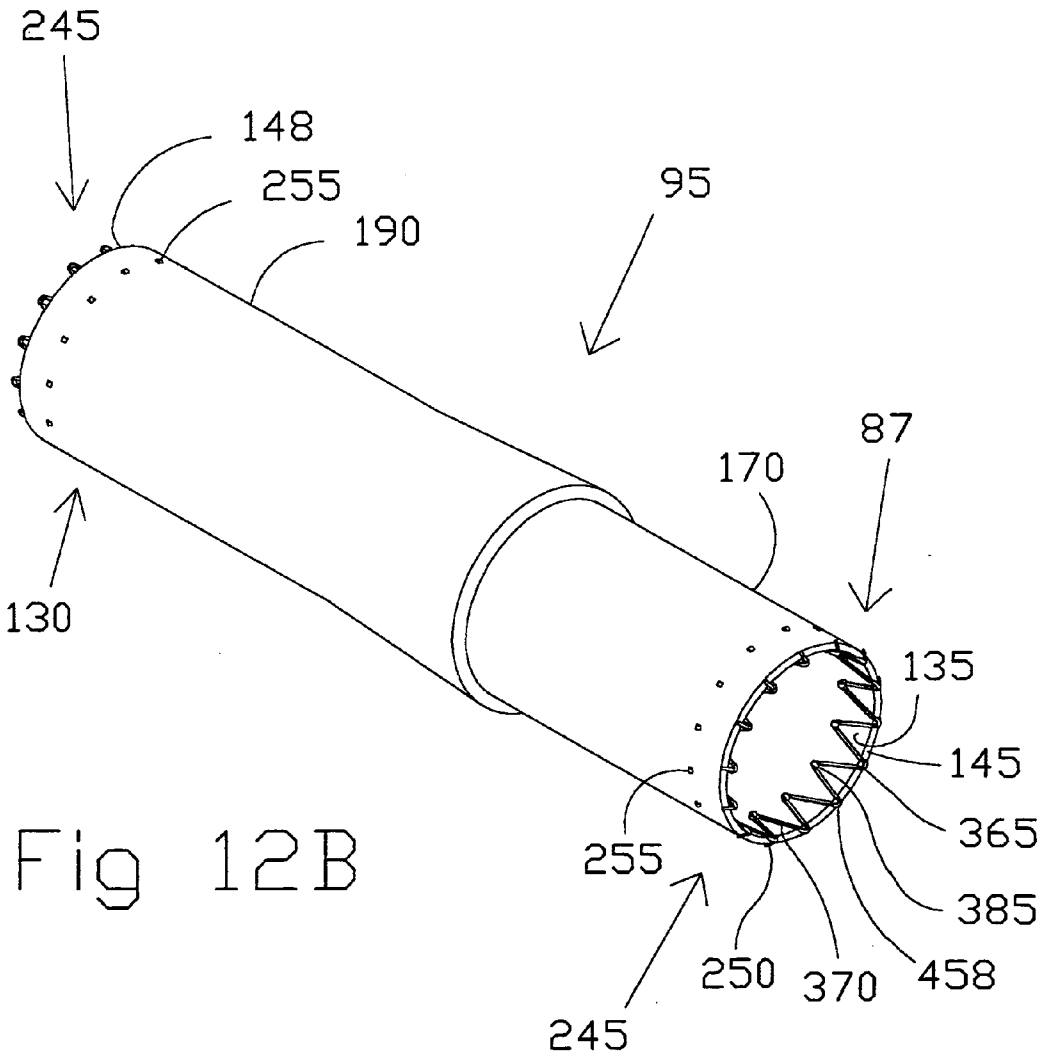


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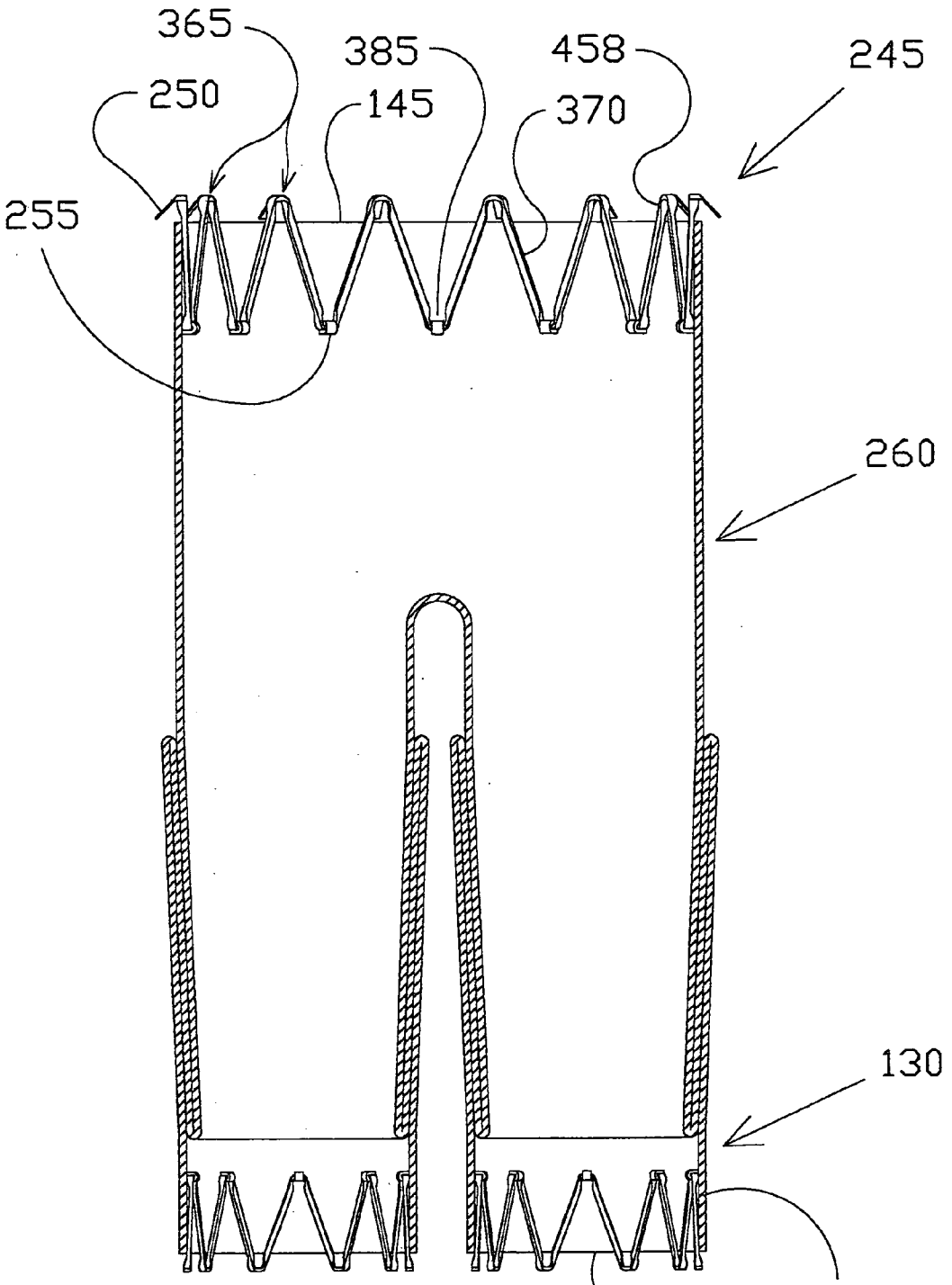


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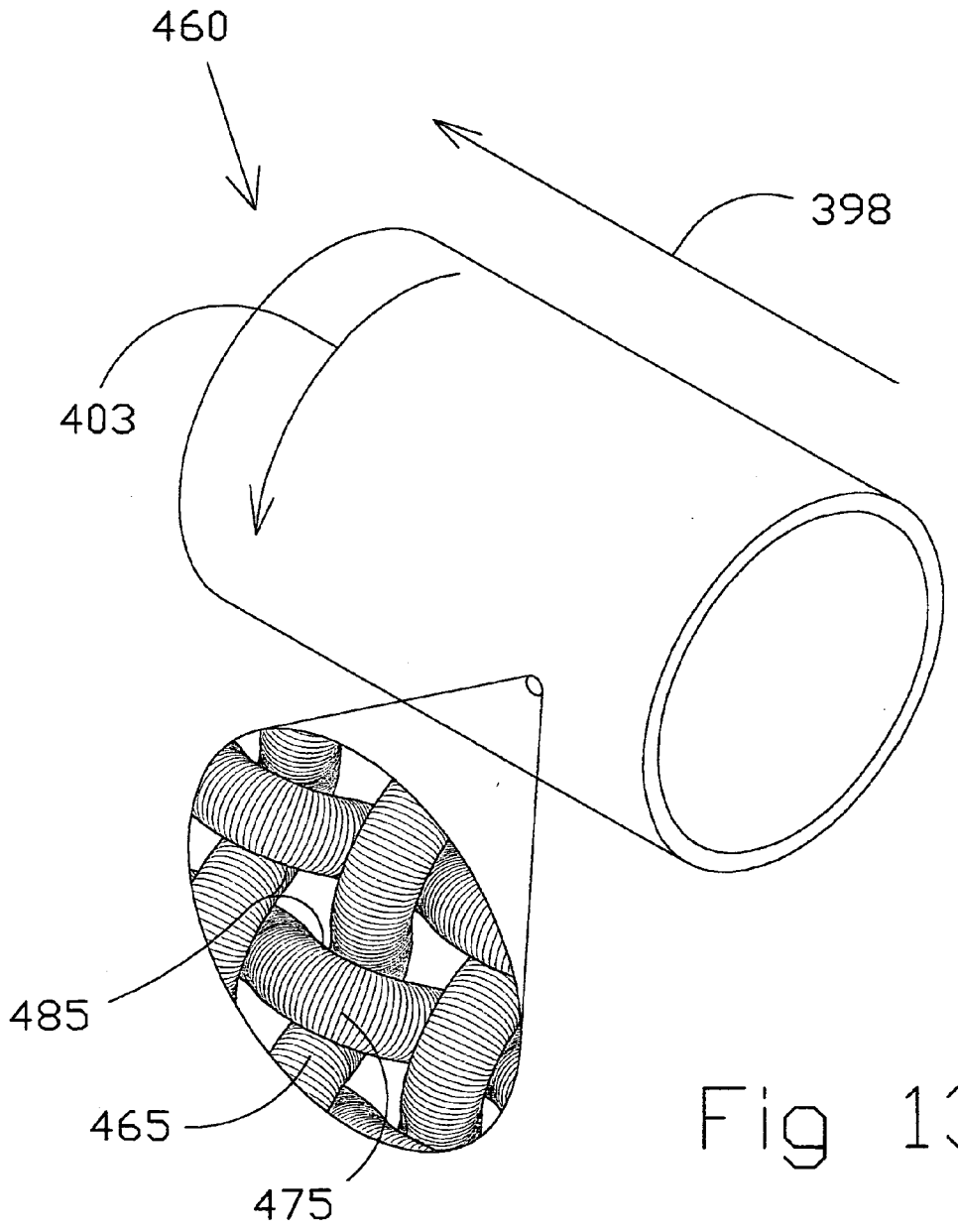


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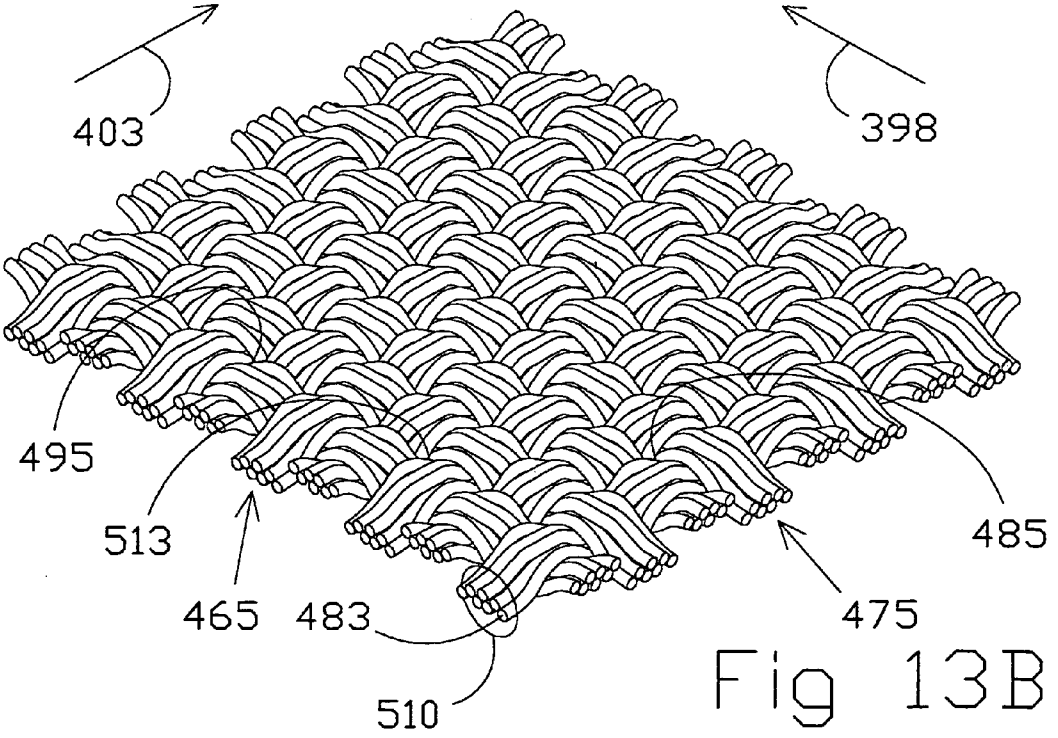


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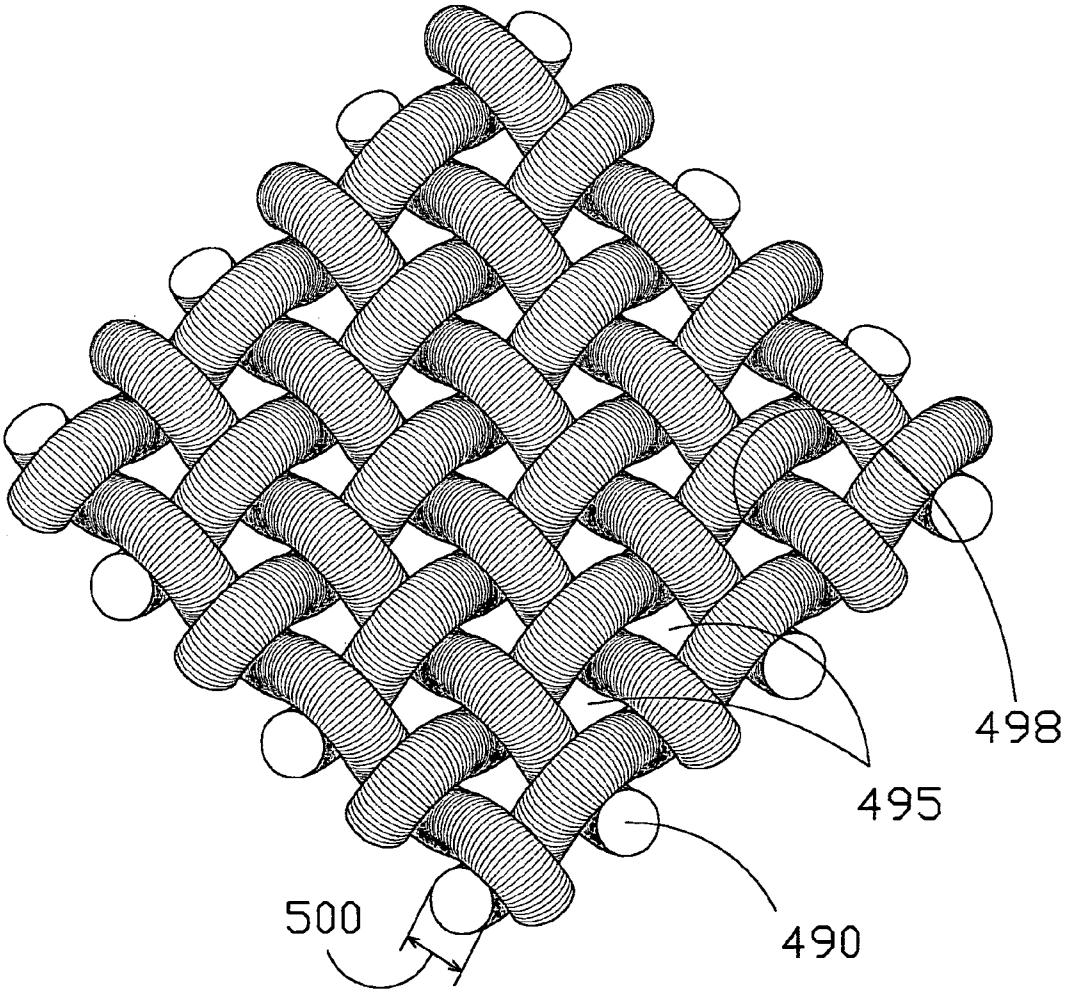


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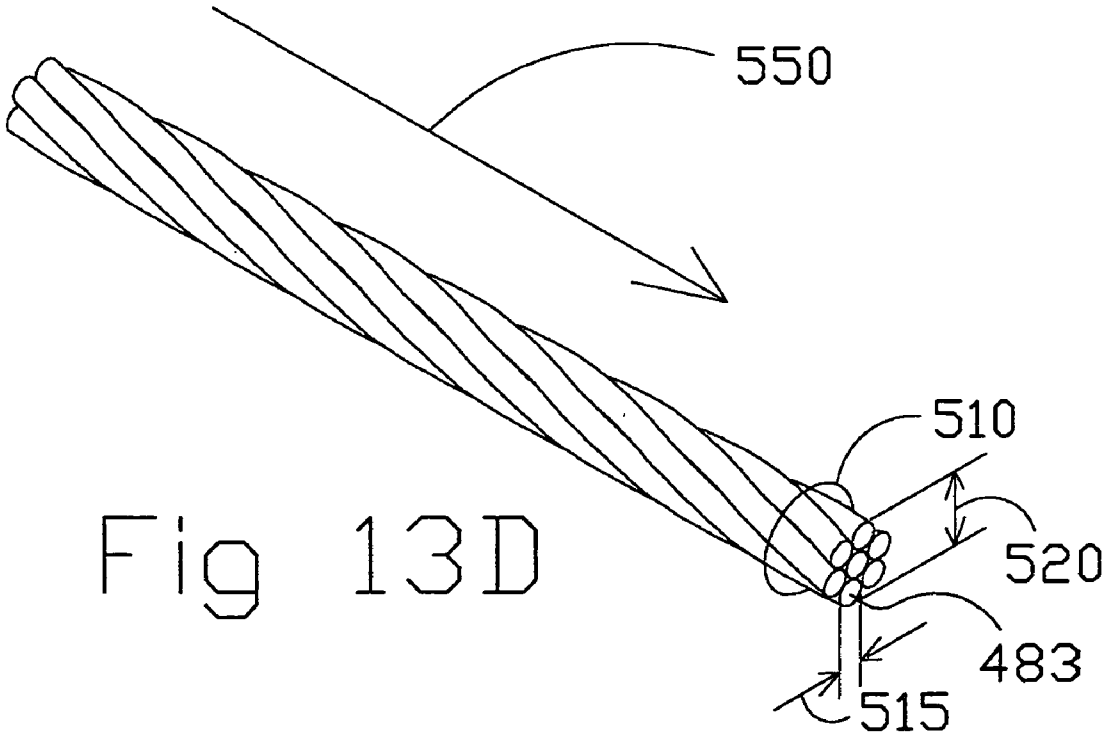


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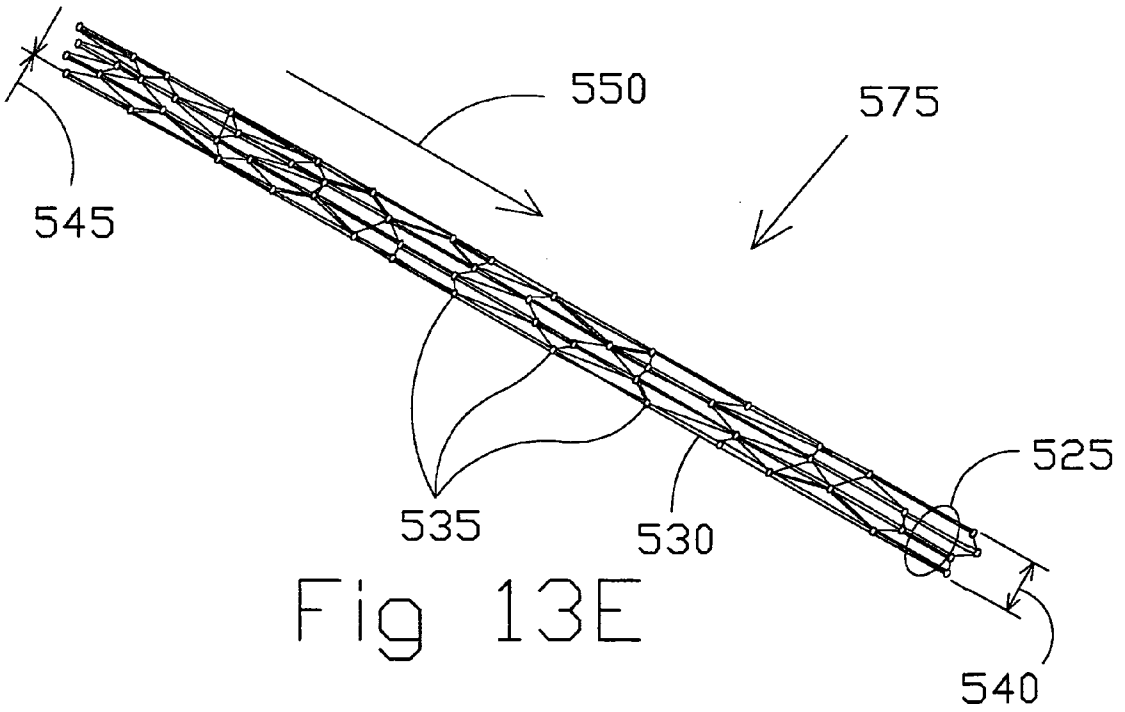


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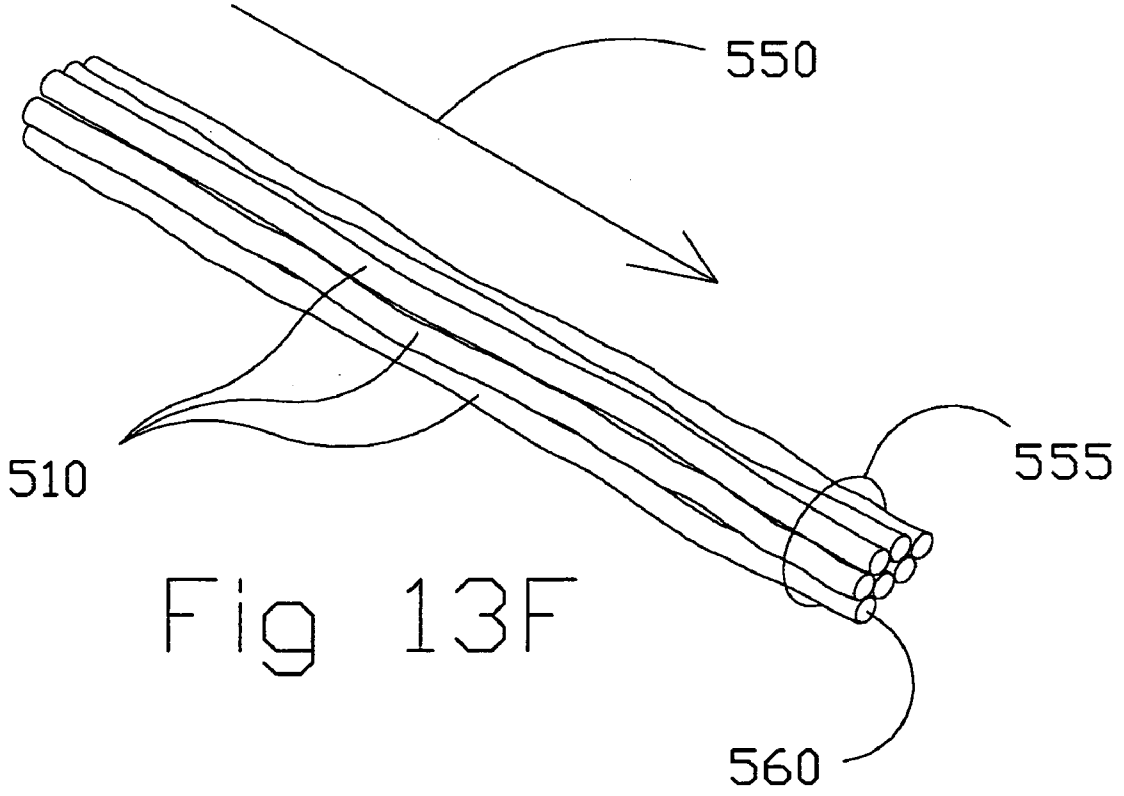


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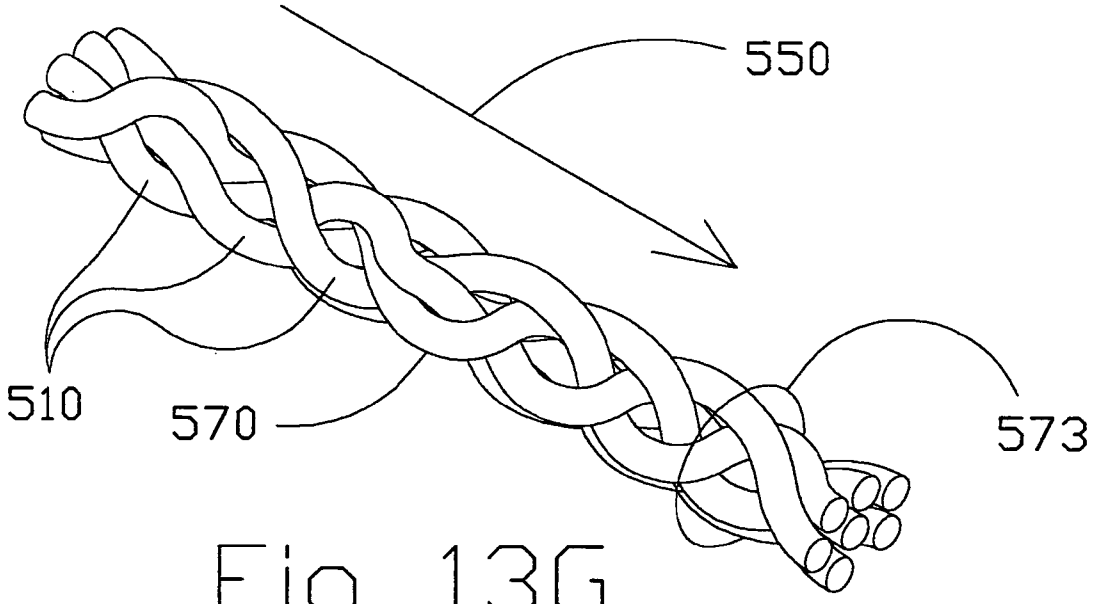


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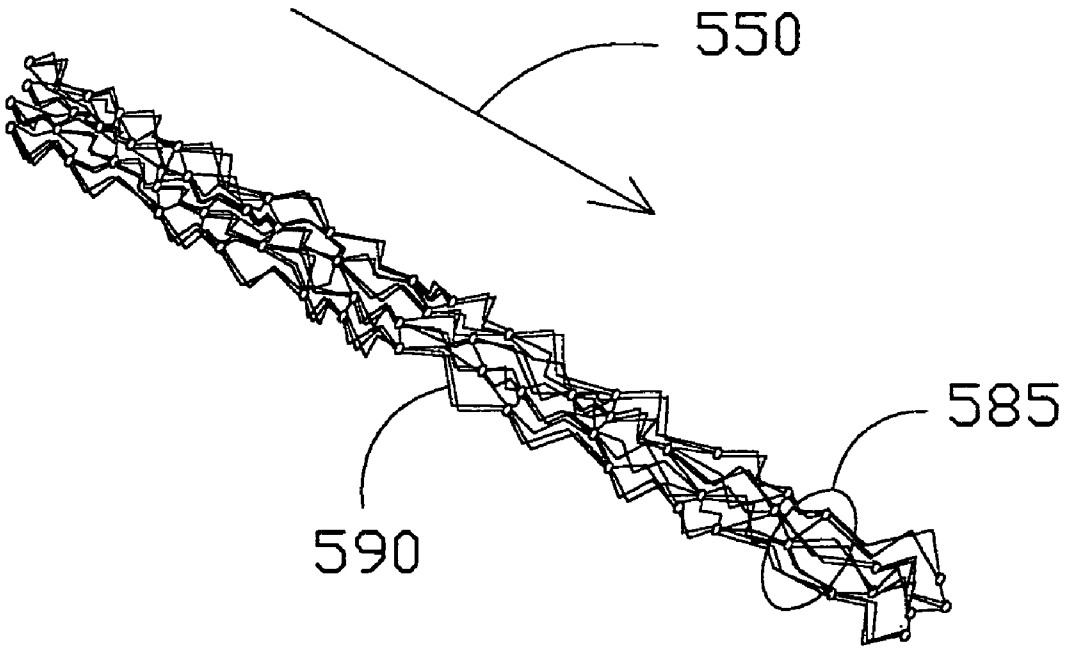


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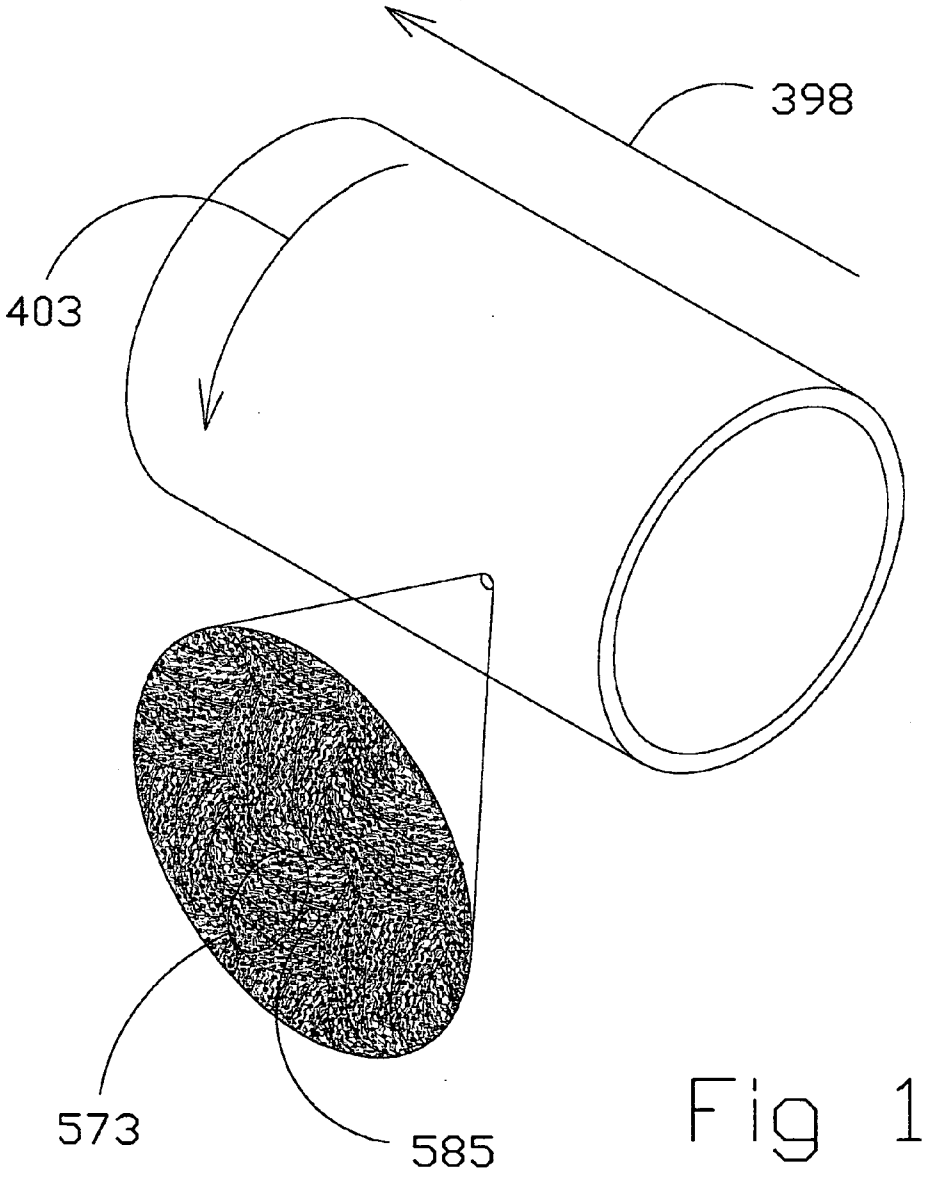


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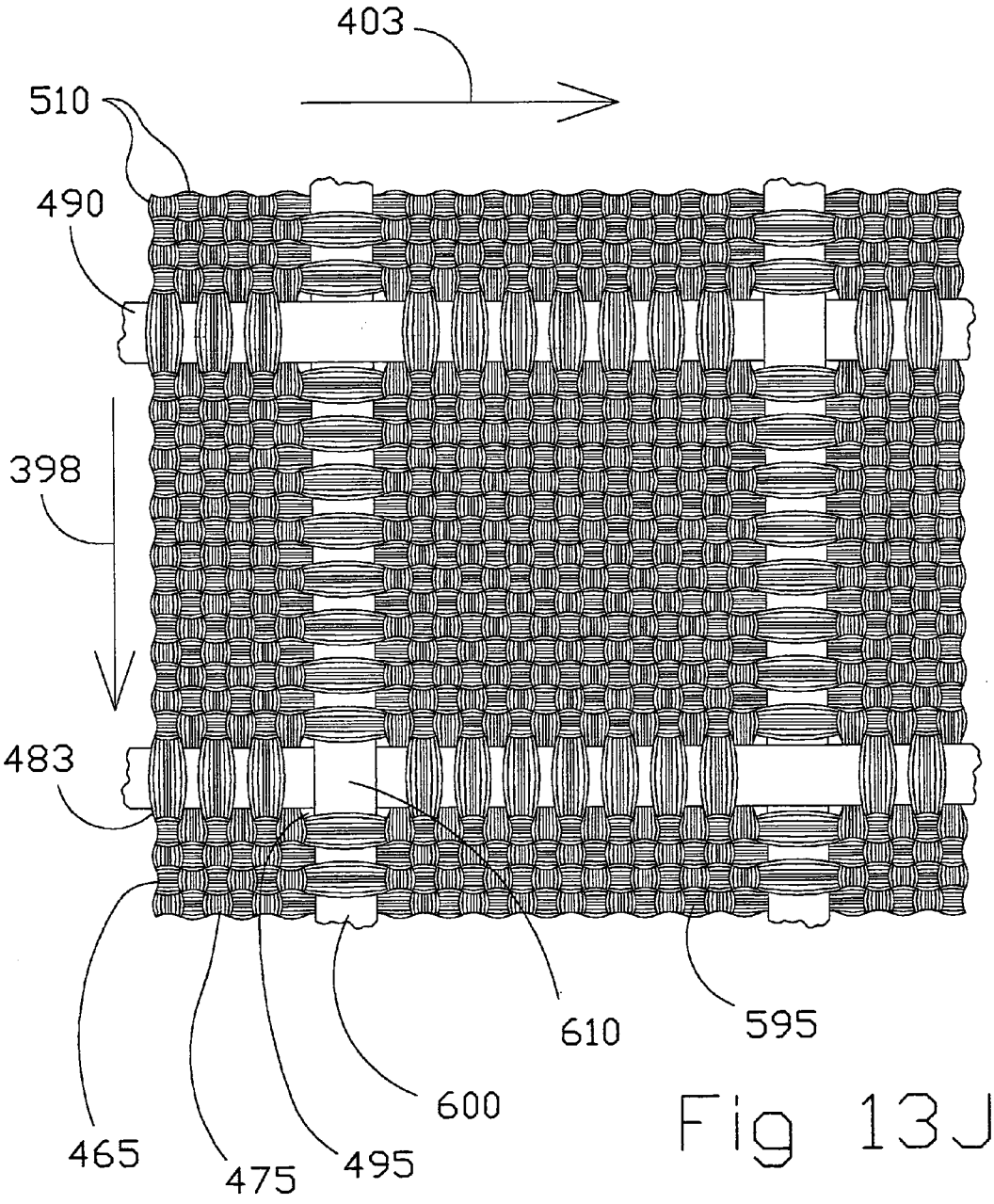


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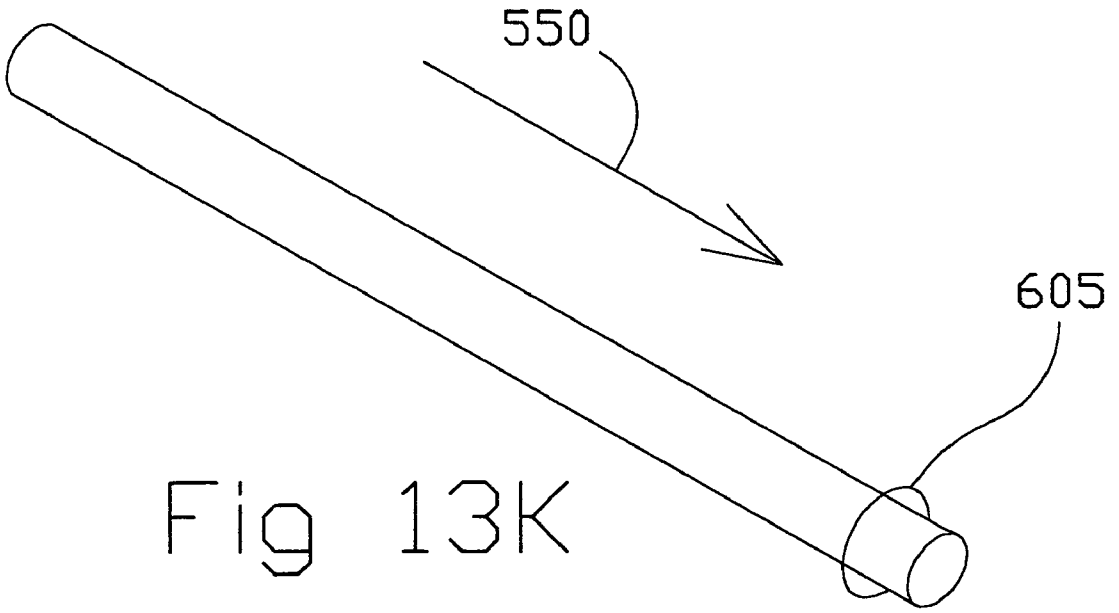


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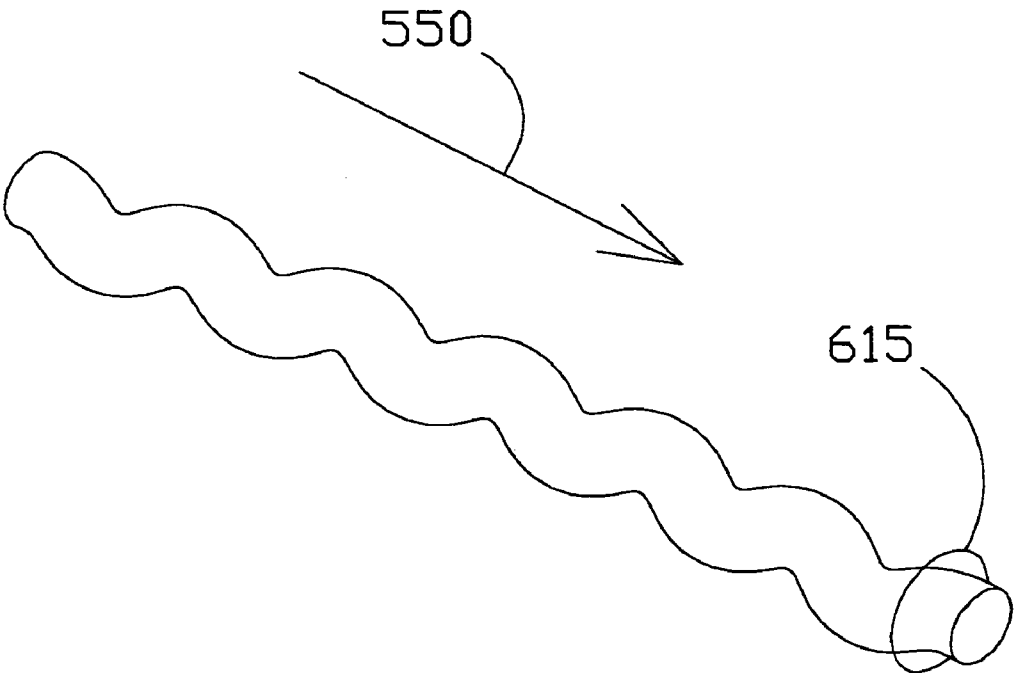


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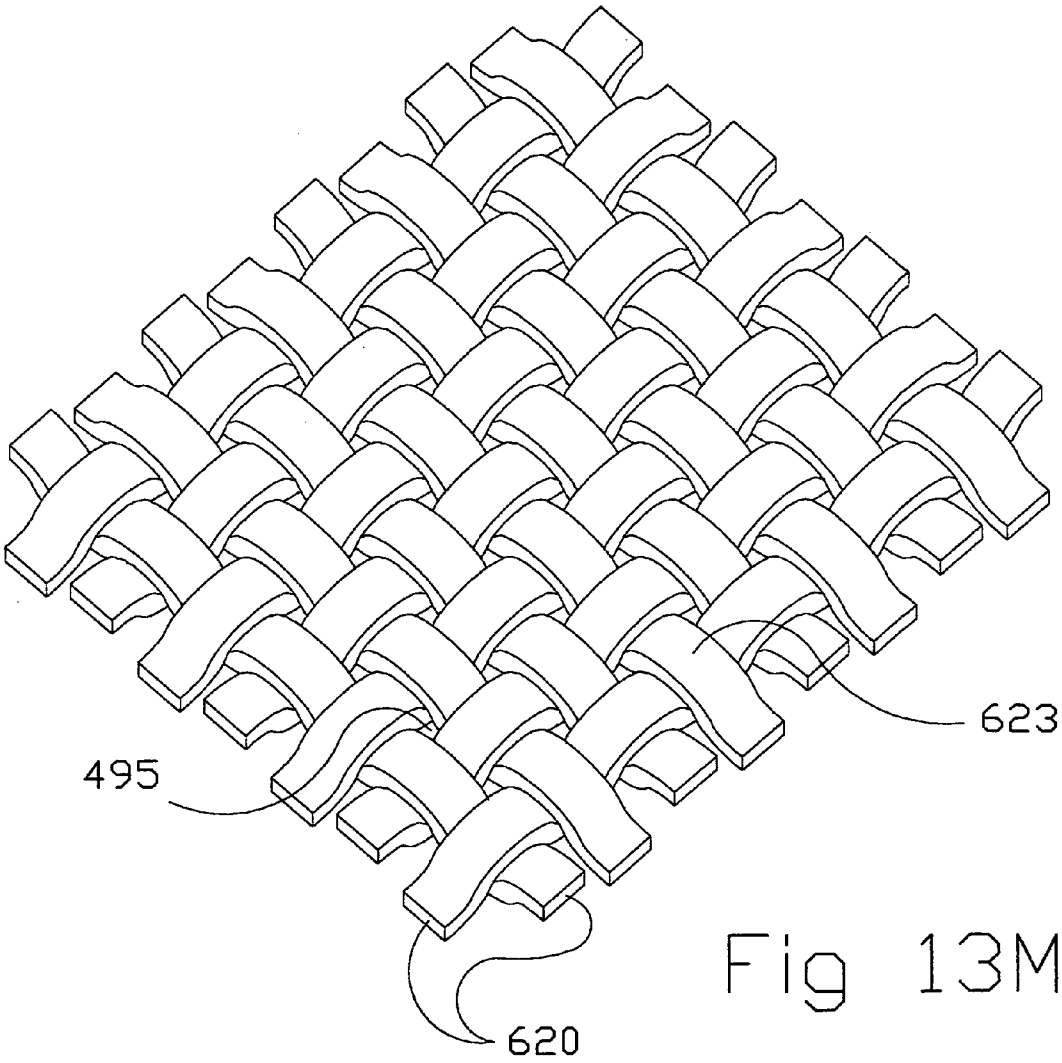


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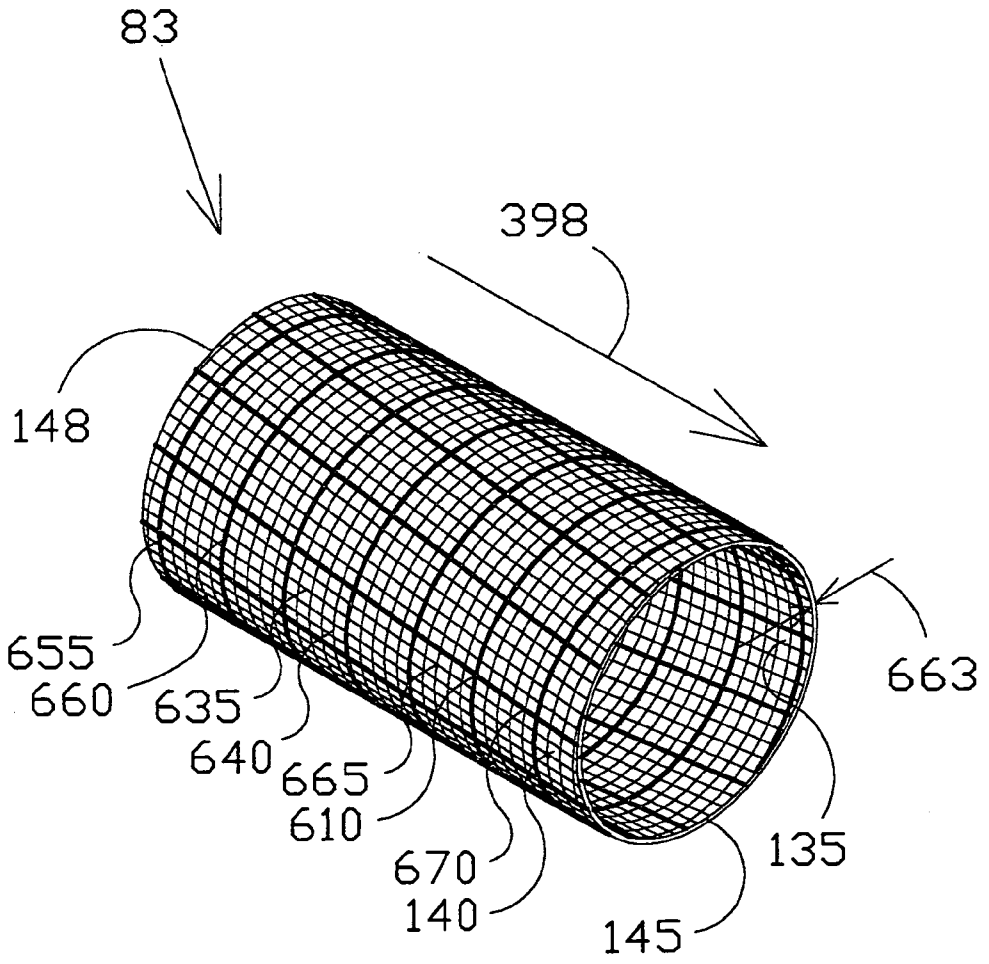


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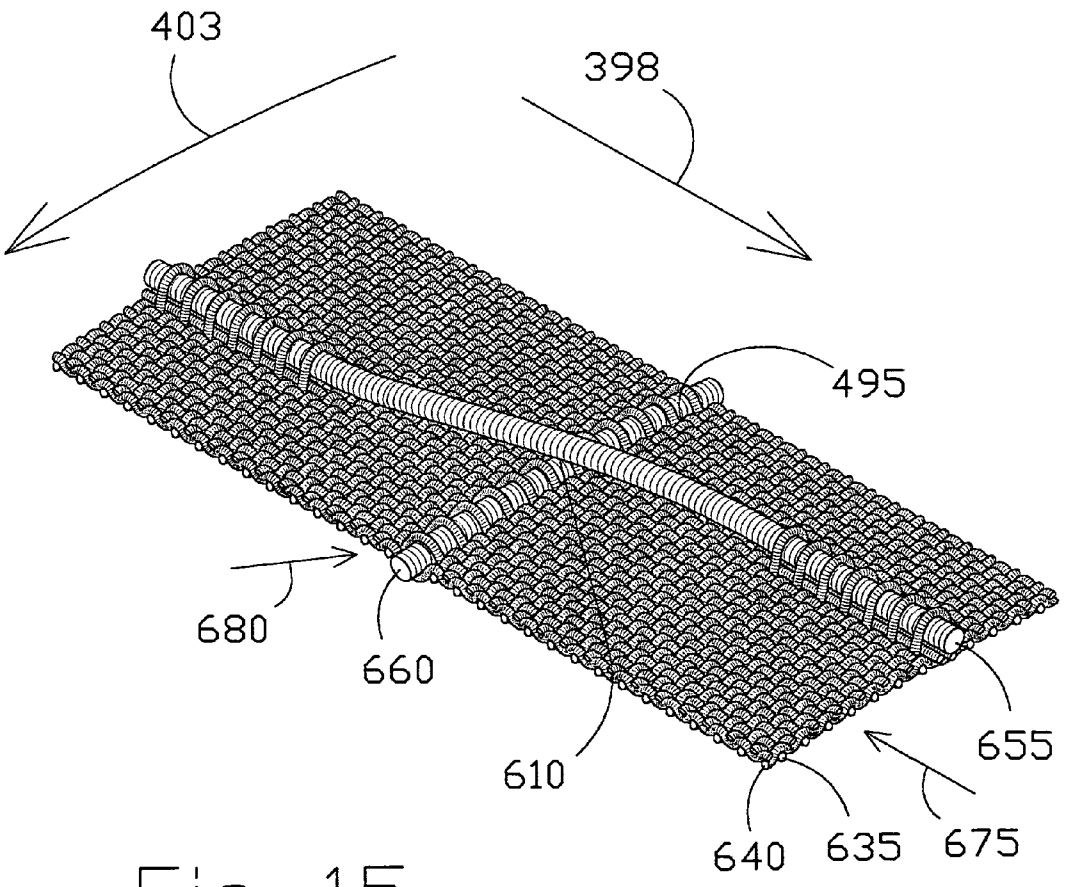


Fig 15

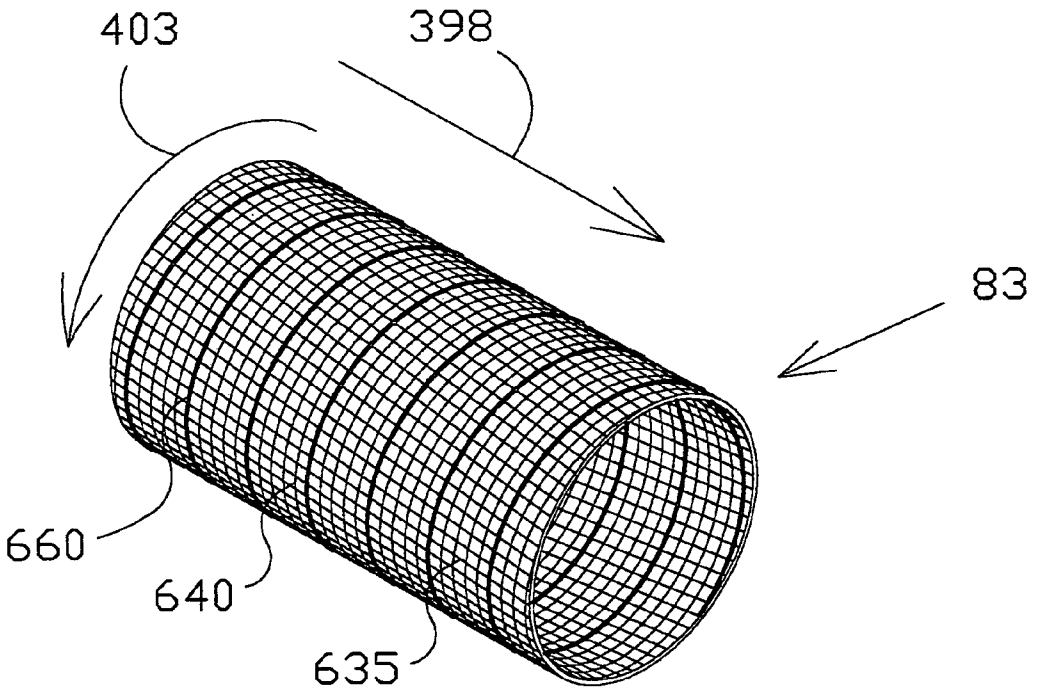


Fig 16A

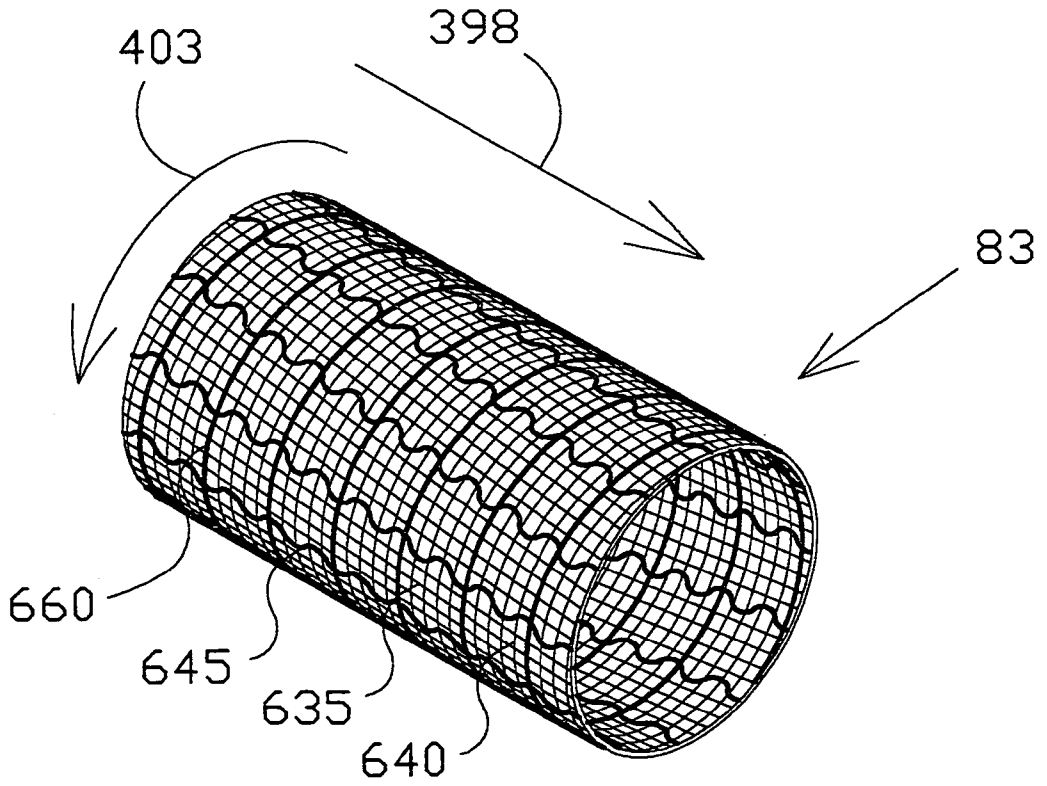


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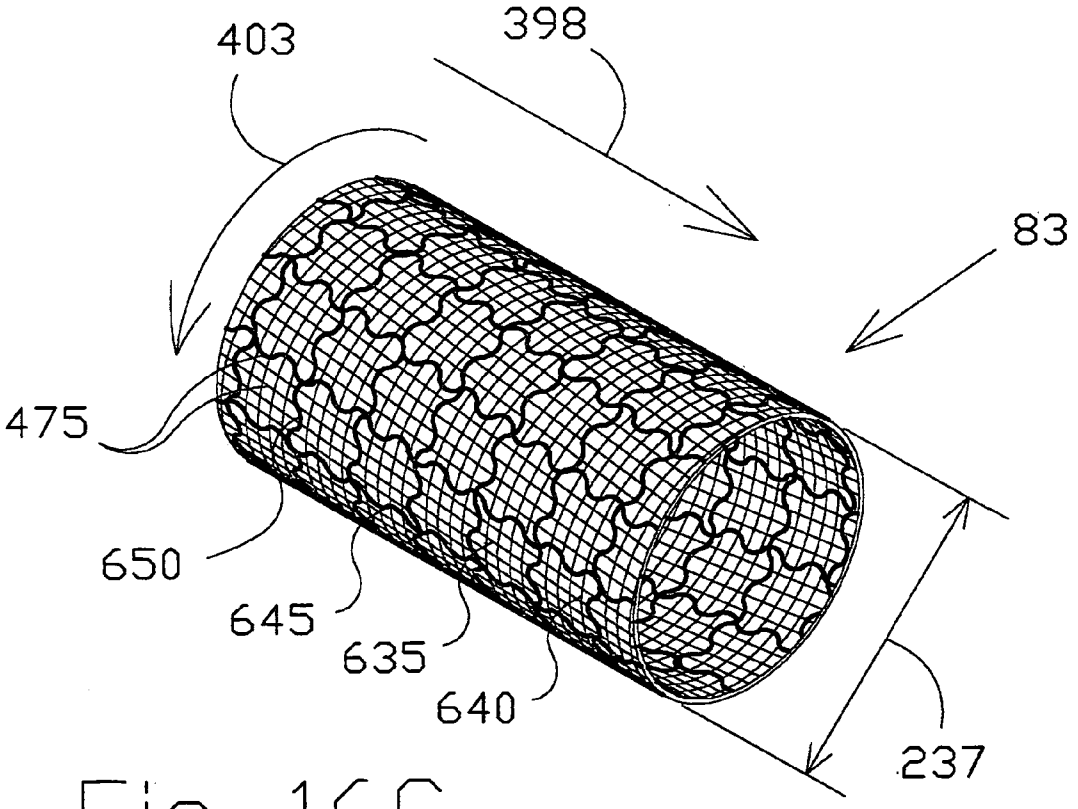


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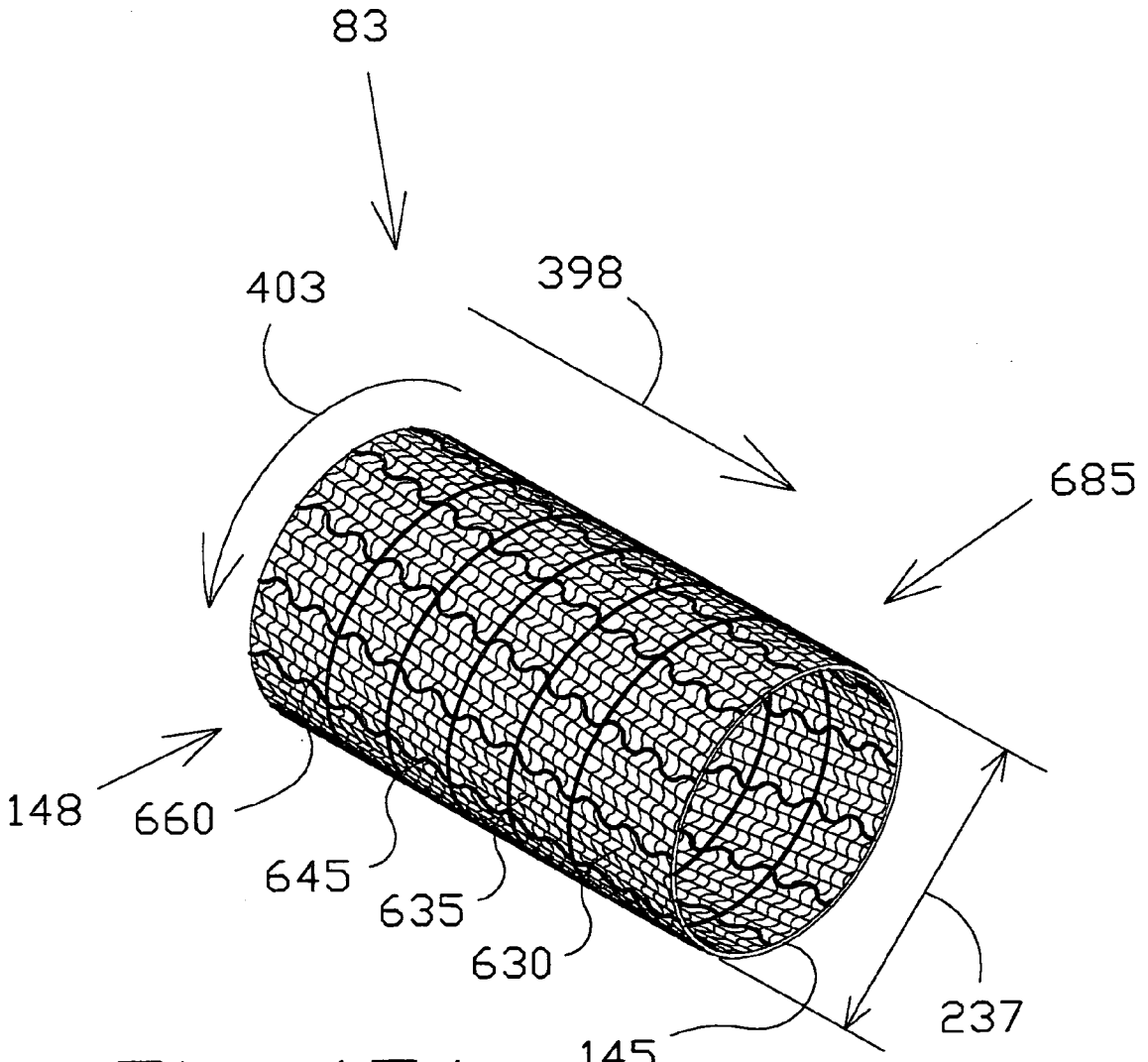


Fig 17A

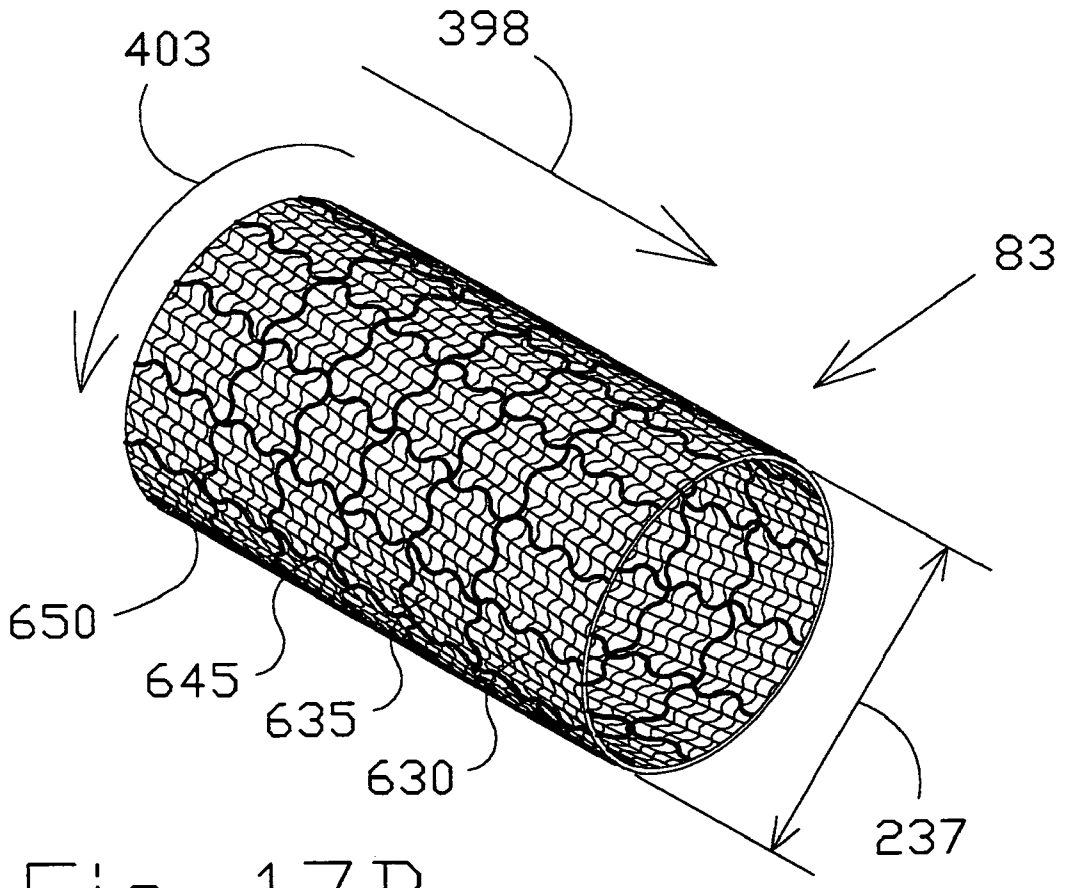


Fig 17B

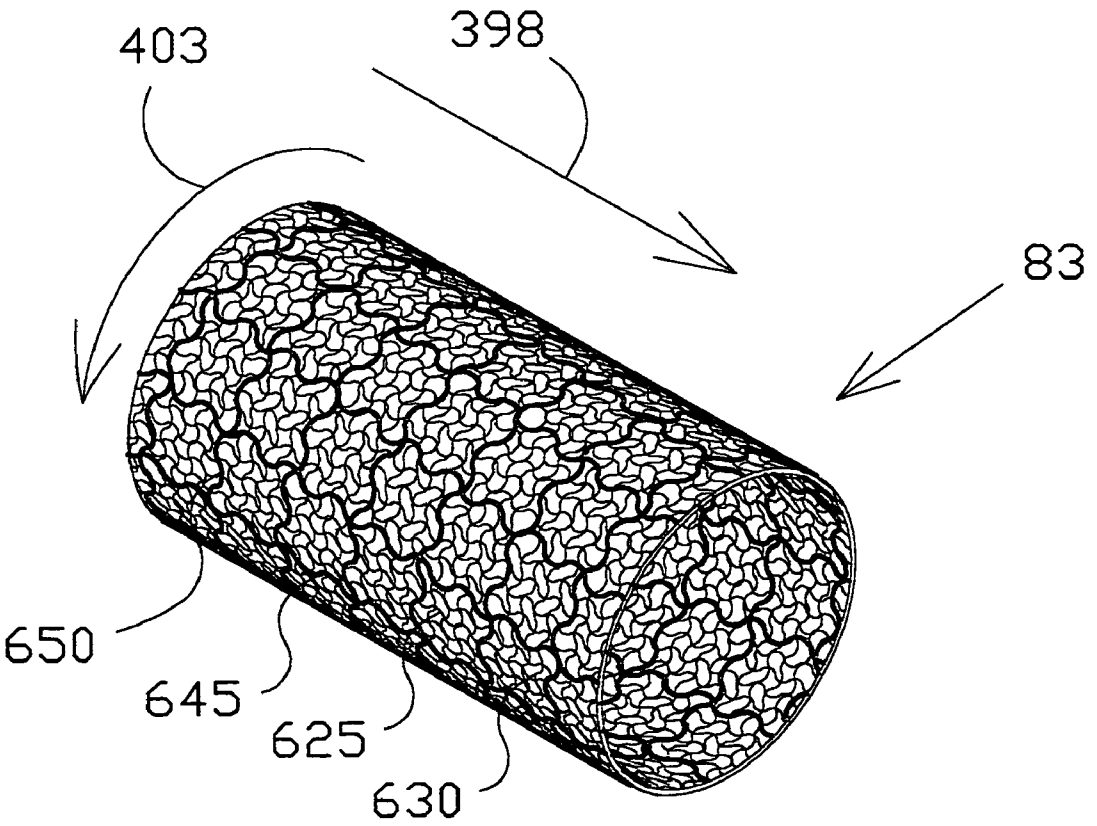


Fig 17C

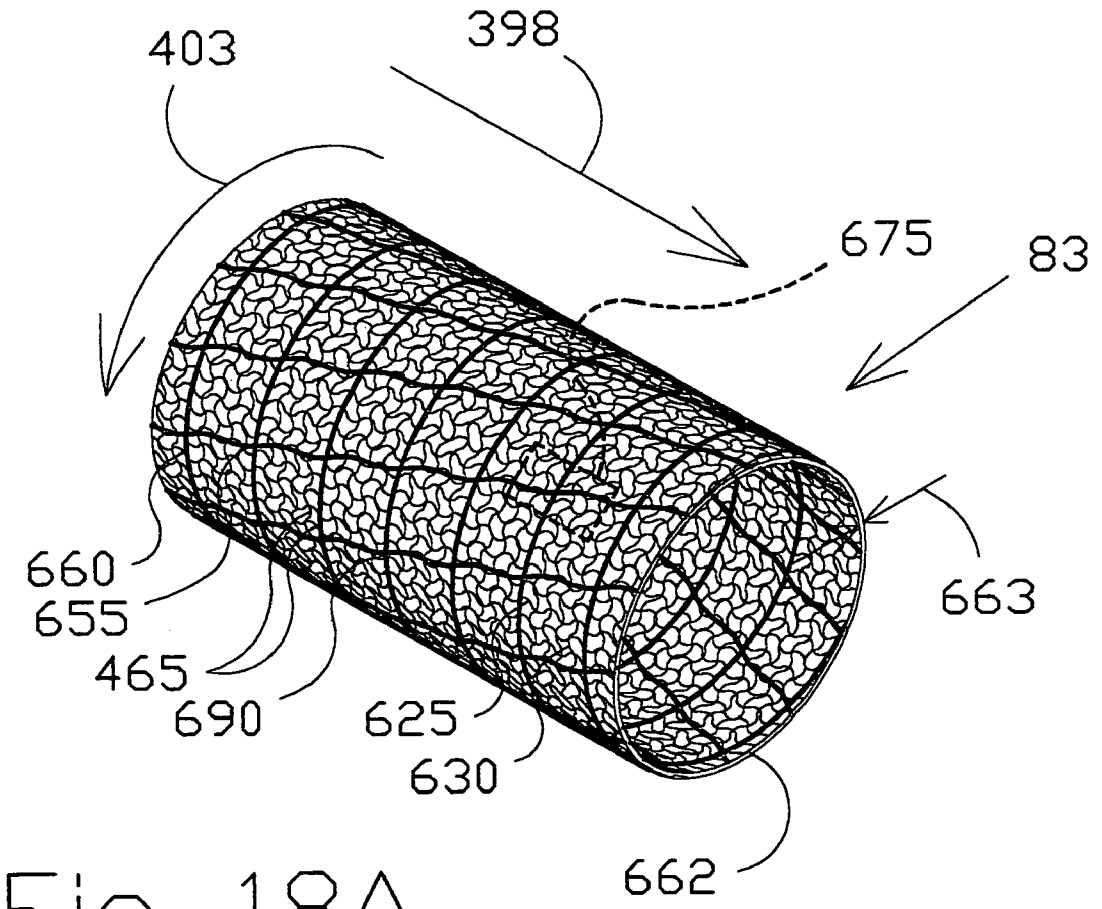


Fig 18A

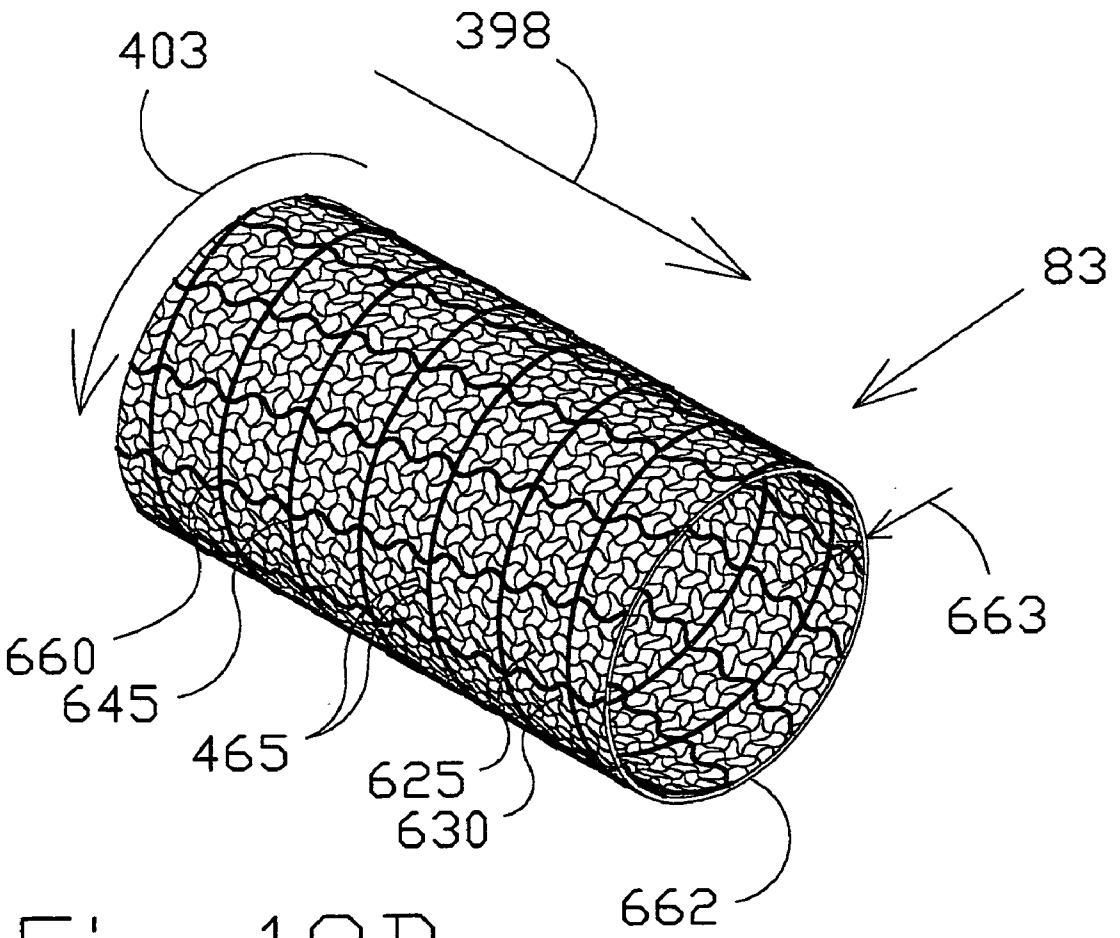


Fig 18B

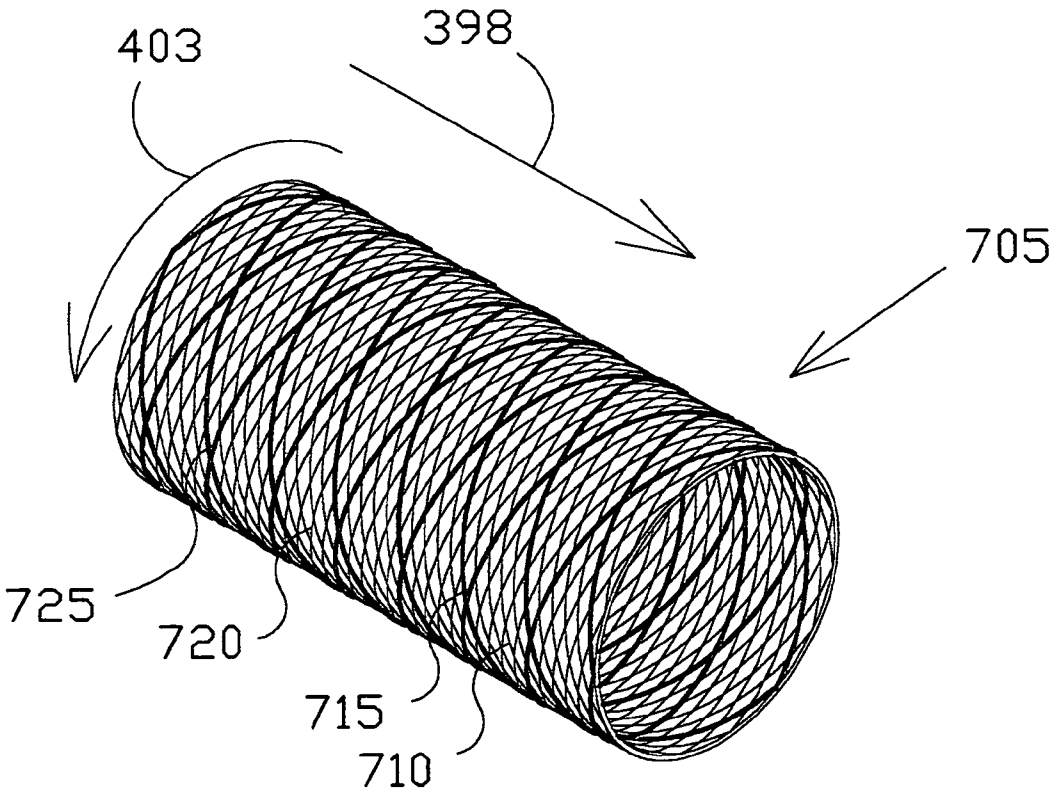


Fig 19

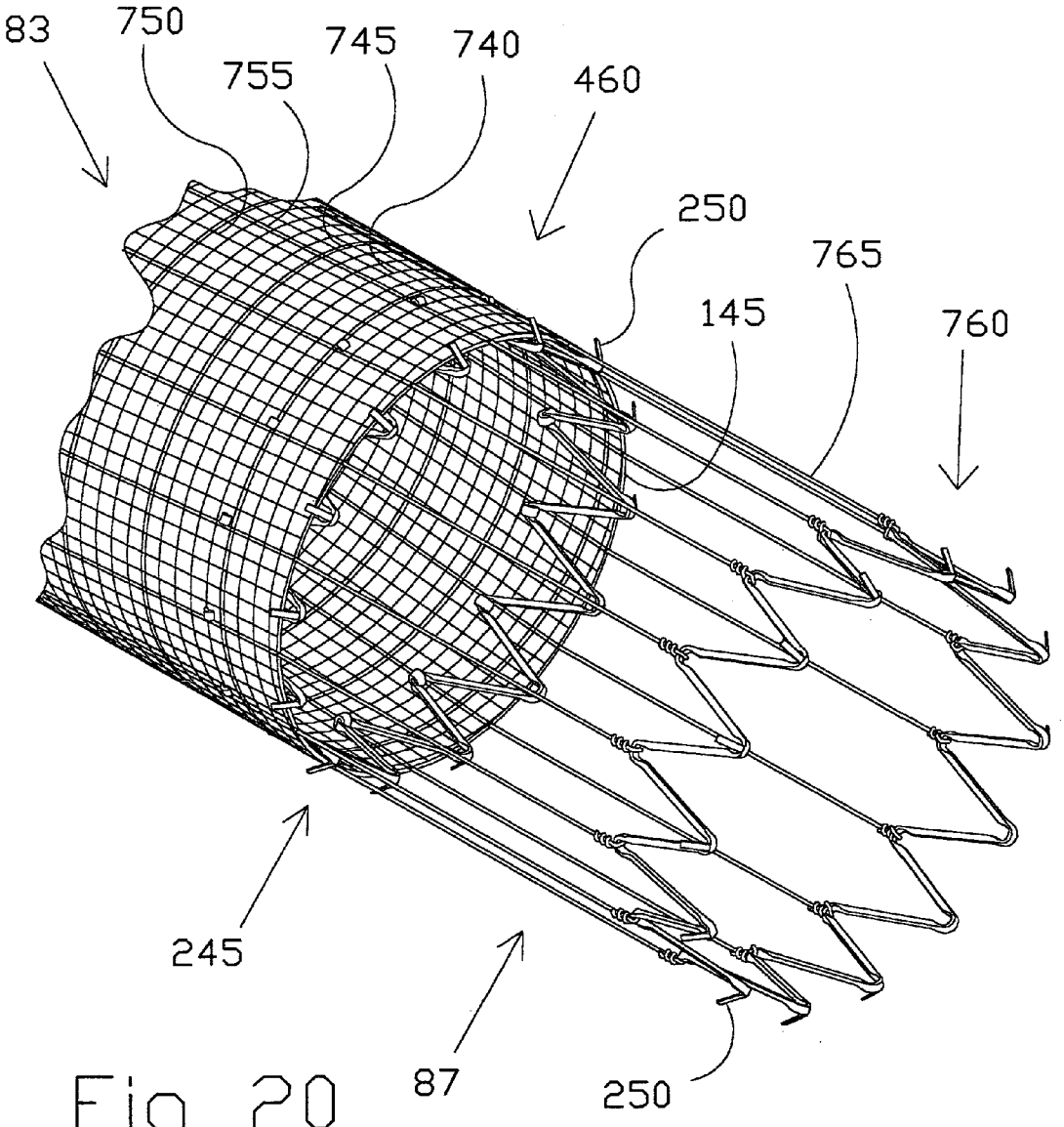


Fig 20

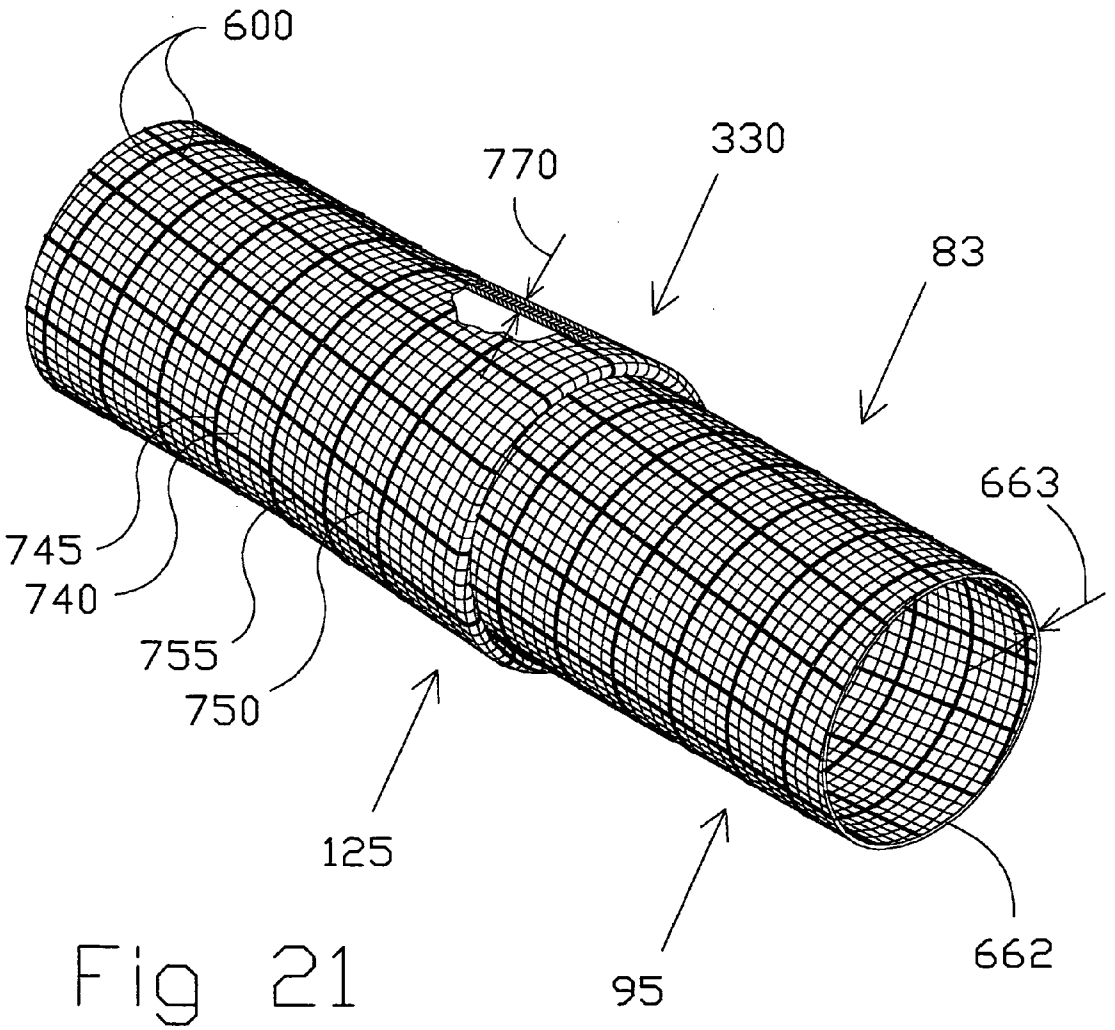


Fig 21

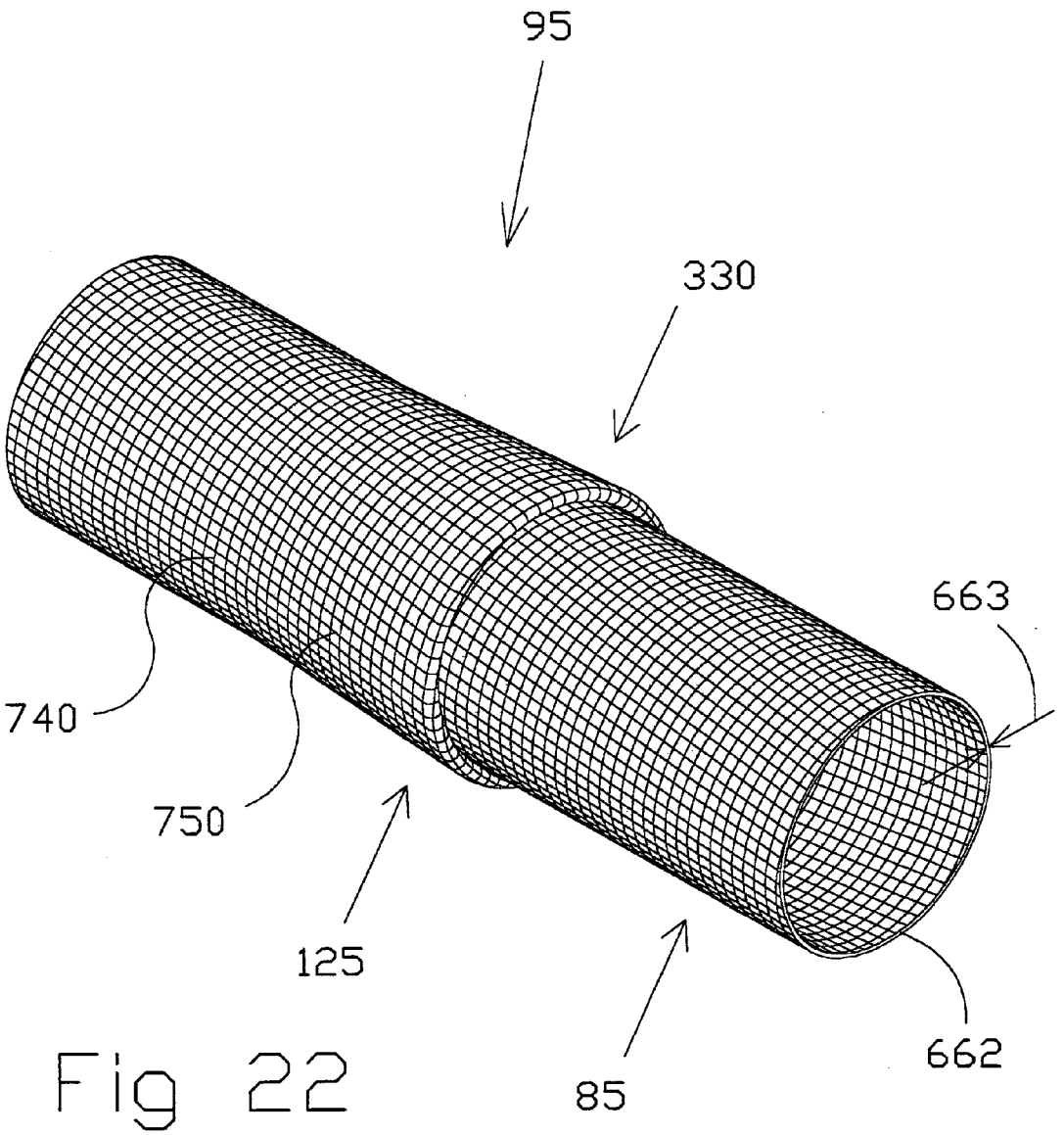


Fig 22

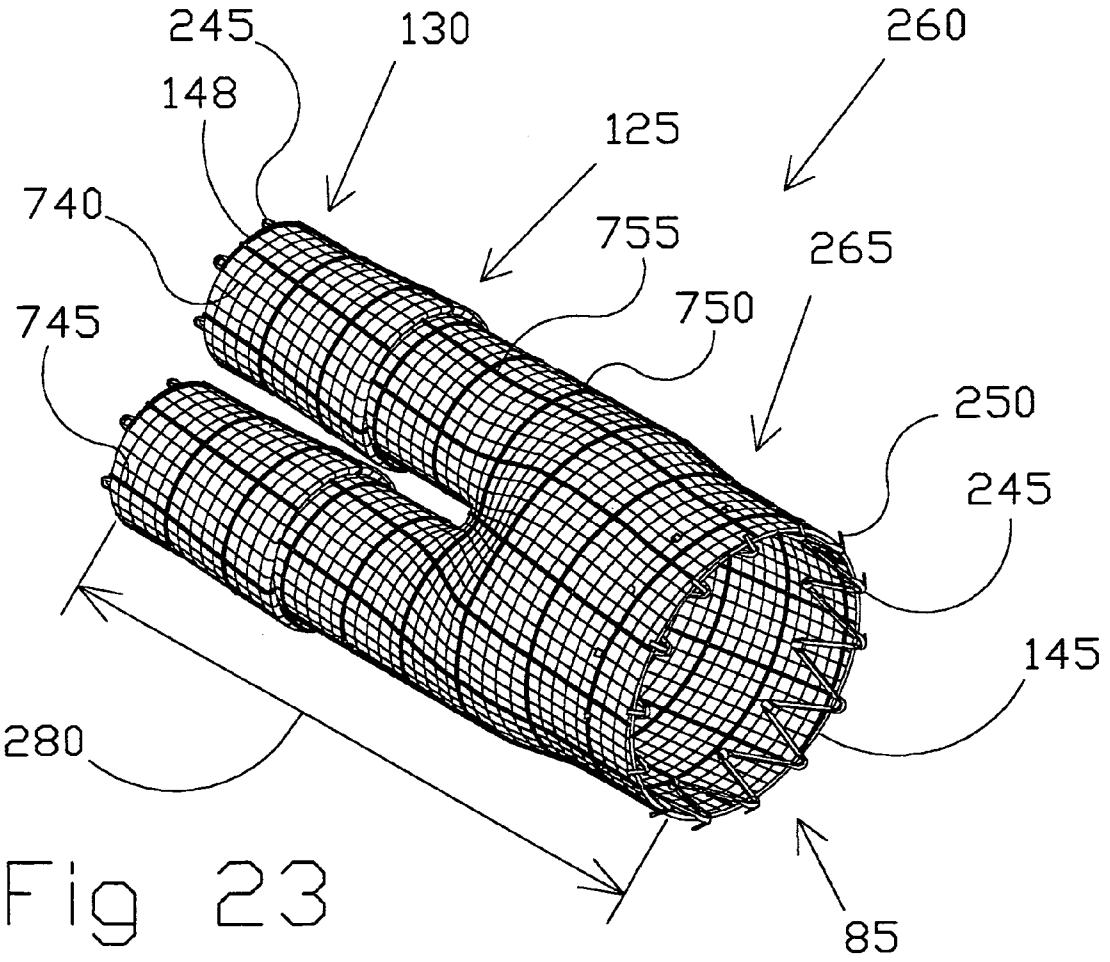


Fig 23

INTRAVASCULAR FOLDED TUBULAR ENDOPROSTHESIS

BACKGROUND OF THE INVENTION

[0001] 1. Field of Invention

[0002] The present invention relates to a vascular implant that is implanted into an artery for repair or bypass of arterial injury. The vascular implant includes a stent-graft that is delivered intraluminally into an artery for repair of a vascular lesion and more specifically for repair of abdominal aortic aneurysm. The vascular implant further includes an attachment means that provides attachment of a stent-graft to a vessel wall.

[0003] 2. Description of Prior Art

[0004] An abdominal aortic aneurysm is an outpouching of the wall of the aorta that can continue to expand over time possibly leading to rupture and mortality. The outpouched wall is generally filled with thrombus except for a generally tortuous pathway for blood flow through an opening in the thrombus. This thrombus can become organized over time as fibroblasts and other cell types infiltrate and form a more organized matrix material containing collagen and other tissue. Typically such aneurysms occur below or caudal to the renal arteries or veins and can extend distally into the right or left common iliac arteries or further distally into the right or left femoral arteries. The right renal vein which crosses over the ventral surface of the aorta can provide some support to the ventral surface of the aorta an help resist aortic distention. Aortic distention can occur very abruptly just distal to the renal vessels reaching a diameter of six centimeters or greater and causing the onset of accompanying symptoms and requiring repair. Generally the blood flow pathway through the thrombus does not follow these abrupt changes found in the vessel wall but rather continues on in a more direct albeit tortuous path through the thrombus found in the aneurysmal aorta. The abdominal aortic aneurysm can sometimes have a proximal neck or region where the aortic diameter appears to be of normal diameter. This proximal neck region is sometimes found just caudal to the renal vessels. The abdominal aortic aneurysm can sometimes also have a distal neck region located just proximal to the aorto-iliac bifurcation. In this minority of patients the abdominal aortic aneurysm does not extend to the iliac arteries or further distally. Aortic distention in the majority of patients can extend into one or both of the iliac or femoral arteries; repair of this abdominal aortic aneurysm can involve treatment of the iliac and femoral arteries as well. The common iliac artery divides to form the external and internal iliac arteries. The internal iliac artery (also called the hypogastric artery) is important in providing a supply or blood to the pelvic region, genital organs, and other areas and is most often not aneurysmal. The external iliac artery is commonly involved in the aneurysm and extends distally along an oftentimes very tortuous path to form the common femoral artery.

[0005] Surgical repair of an abdominal aortic aneurysm is an extensive procedure associated with a high incidence of morbidity and mortality and requiring many days of hospital stay. Older patients are often not capable of withstanding the trauma associated with this surgery. Repair of abdominal aortic aneurysm intraluminally through access from the common femoral artery can provide the patient with an alternate method of treatment for abdominal aortic aneurysm without the accompanying surgical trauma and long hospital stay. Placement of an intraluminal stent-graft can be performed by an interventionalist using a minimal surgical cutdown to an ipsilateral common femoral artery for access of the device to the arterial system of the body. Generally an additional access site is placed percutaneously in the contralateral common femoral artery. It is often preferred to place at least one more access site cranial to the abdominal aortic aneurysm generally through an axillary artery or other artery of the arm. Spiral computed tomography, duel-plane angiography, intravascular ultrasound, magnetic resonance imaging, and fluoroscopy provide some of the diagnostic techniques used to determine the position, diameter, and length of the aneurysm such that an appropriate intraluminal prosthesis can be selected for intraluminal implantation. Placement of the intraluminal stent-graft requires that a leak tight seal be made between the stent-graft and the aorta and between the stent-graft and each of the iliac or femoral arteries if they are involved in the aneurysm. Failure to provide such a leak tight seal will allow blood flow at arterial pressure to access the space between the stent-graft and the outpouched aorta. Continued exposure to arterial blood pressure can result in further expansion of the aneurysmal sac and could lead to sac rupture. Several intraluminal stent-grafts have been described for use in treatment of abdominal aortic aneurysms.

[0006] Barone describes in U.S. Pat. No. 5,578,072 an apparatus for repairing an abdominal aortic aneurysm. He describes a one-piece bifurcated aortic graft having a balloon expandable stent at one end to secure main trunk of the stent-graft to the aorta caudal to the renal arteries. The one-piece aortic graft has additional expandable stents positioned at the end of each leg of the bifurcated graft to secure the stent-graft to the iliac arteries. This design requires that the length of the main trunk and length of each limb be established prior to implantation using the diagnostic techniques described earlier. Due to the tortuous nature of the blood flow pathway, it is impossible to properly size the length of the graft using these diagnostic techniques prior to implatation. If the stent-graft is sized too short, then a portion of the aneurysm may be left unprotected. If the stent-graft is sized too long for example, then the blood flow to one or both of the internal iliac arteries may be compromised. The method of securing the main trunk of the stent-graft to the aorta caudal to the renal arteries described by Barone is also inadequate in many situations. A balloon expandable stent placed caudal to the renal vessels will very often be located within thrombus and will not have the strength or stability of the aortic vessel wall to support the stent or the stent-graft from migration caudally. Barone teaches that a securing means that is expanded outwardly over an axial length will hold the cranial end of the main trunk in position near the renal vessels. Barone also does not describe any means to prevent the stent-graft from being kinked or crushed as it travels through the thrombus laden blood flow pathway within the aortic aneurysm. Forces imposed upon the stent-graft due to the surrounding thrombus or thrombus organization could easily cause the stent-graft of Barone to become kinked or stenotic thereby impairing its performance. Barone discusses the need to place a stent proximal to the renal arteries for the case that the abdominal aortic aneurysm extends through the aortic region containing the renal arteries. He does not provide a suitable stent-graft for treating infrarenal aortic aneurysm with abrupt wall distension just distal to the renal vessels.

[0007] Parodi describes in U.S. Pat. No. 5,591,229 stent-graft devices that are similar to those described by Barone in the above patent. Additionally, Parodi describes a stent-graft

for treatment of an abdominal aortic aneurysm that does not extend into the iliac region. This straight tubular stent-graft has a balloon expandable stent positioned at its cranial end for placement into the proximal neck of the aorta distal to the renal vessels. A balloon expandable malleable wire is placed at the distal end of the stent-graft to provide contact of the stent-graft with the aortic wall in the distal neck of the aorta. This stent-graft has a similar problem associated with estimating the graft length due to the tortuosity associated with the blood flow pathway through the thrombus laden aortic aneurysm. The other problem sited with the device described by Barone are similarly shared by the Parodi device.

[0008] Chuter describes in U.S. Pat. No. 5,693,084 a one-piece bifurcated stent-graft for treatment of abdominal aortic aneurysm having self expanding springs positioned at the proximal end of the main body and at the distal ends of each limb of the graft. The springs expand radially upon release to conform the ends of the stent-graft to the lumen of the aorta. This stent-graft suffers the same problem described for Barone in determining the length of the stent-graft prior to implant. Further, the stent-graft material is not supported throughout the entire stent-graft length thereby providing ample opportunity for stent-graft kinking and deformation within the aneurysm. Chuter has positioned six barbs that extend outward from the self expanding spring on the proximal end of the stent-graft. Due to the geometry of the springs, the positioning of the barbs into aortic wall rather than into the thrombus contained within the aneurysmal wall is not very precise. This can lead to stent-graft migration after a period of time post implant. Other problems associated with the Barone device similarly apply to the Chuter device.

[0009] McDonald describes in U.S. Pat. No. 5,676,697 a two-piece component bifurcated intraluminal stent-graft for treatment of abdominal aortic aneurysm. The first stent-graft component is a flexible tubular member with a side cut near the middle of the tubular member that opens up via a self expanding stent to form a waist region that is seated in the aorto-iliac bifurcation region. Two legs of the first stent-graft component are seated into each iliac artery using stents attached to the distal end of each leg. A second stent-graft component is introduced through one leg of the first component and allowed to self expand in the main trunk of the aorta and form a seal with the waist of the first component. The proximal end of the second component extends proximally within the aorta and makes a seal as it expands outwardly against the flow lumen. This device would have difficulty with positioning the proximal end of the second component within the proximal neck of the aorta. Extreme tortuosity found in the flow lumen of the aortic aneurysm would not allow this device to conform to its shape and would not allow a tight seal to be formed between the proximal end of the second component and the aorta. Difficulty in determining the appropriate length for each of the two components would limit the usefulness of this device.

[0010] Glastra describes in U.S. Pat. No. 5,632,763 a bifurcated component stent-graft assembly for treatment of abdominal aortic aneurysm. The assembly consists of a base stent-graft that is introduced into the main trunk of the aorta from an intraluminal approach. The base stent-graft has a generally cylindrical shape with a conical region located at the distal end. Two secondary cylindrical stents are introduced through two branching arteries, one in each leg and are seated in the conical region of the base stent-graft. This assembly has several potential problems associated with it. Determining the appropriate length of the base stent-graft and each of the secondary stent-grafts cannot be accurately performed considering that all of the arteries involved can be very tortuous and difficult to estimate in length. The seal that is required at the junction of the main to the secondary stent-grafts may have a tendency for leakage due to the geometry of that junction. Glastra describes two cylindrically shaped secondary stent-grafts that are placed adjacent to each other and are required to expand out and seal against a larger cylindrical base stent-graft; this seal would be difficult to form and maintain. Glastra does not address specific means for attachment of the proximal end of the base stent-graft to the aorta.

[0011] Marcade describes in U.S. Pat. No. 5,683,449 a modular system for forming a bifurcated stent-graft for use in treating abdominal aortic aneurysm. The system includes a number of components that are delivered intraluminally to the site of the aneurysm and brought into contact with each other within the aneurysmal space. The primary graft member has a proximal stent at one end and has an decreasing diameter as the stent-graft extends towards its distal end. The base member has a Y-shaped structure with a proximal end that contacts the distal end of the primary graft member. The base member also forms two branches on its distal end, each branch being brought into contact with a tubular graft member that extends into an iliac artery. This modular system still requires that each individual component be sized for length and diameter in order to fit the vast differences found between abdominal aortic aneurysm patients. Each junction between individual components is also a site for potential leakage of blood into the space between the stent-graft and the native arterial conduit. Marcade shows approximately five barbs positioned on the proximal stent. Due to the geometry of the stent it is not possible to obtain precise positioning of the barbs into the aortic wall tissue to ensure long term anchoring that would prevent stent-graft migration and maintain an adequate leak tight seal.

[0012] Vorwerk describes in U.S. Pat. No. 5,562,724 describes a component bifurcated device for treating abdominal aortic aneurysm consisting of a main body and two tubular stent-grafts. The main body has an open proximal end and a distal bag-shaped end with two outlet openings formed in it. Two tubular stent-graft legs can be introduced through the iliac arteries of the patient and attached to the two outlet openings of the main body. Sizing the appropriate length of the main body in addition to the two stent-graft legs is difficult due to the tortuosity found in the blood flow pathway of the aorta and iliac arteries. Leakage at the attachment site of the stent-graft legs to the main body also is a major concern.

[0013] Palmaz describes in U.S. Pat. No. 5,683,453 and Marin in U.S. Pat. No. 5,507,769 two tubular stent-grafts that travel in parallel from the infrarenal aortic neck to each iliac artery. Each stent-graft has a stent positioned at each end of the tube to form a seal with the native artery. This system would also have difficulty in determining the appropriate length of the stent-graft due to vessel tortuosity. In addition, this system requires that the two proximal stents deform against each other and with the proximal neck of the aorta to form a leak tight seal; it is not likely that an appropriate seal or attachment to the proximal aortic neck would be made. Extending a plurality of stent tubular members further within the length of stent-graft create a stent-graft that is too stiff to pass through a tortuous iliac artery to reach the site of the abdominal aortic aneurysm.

[0014] Egoda describes in U.S. Pat. No. 5,591,228 a method of introducing a bifurcated stent-graft for abdominal aortic aneurysm treatment using three access points into the arterial vasculature. As with other intraluminal stent-graft procedures, two access sites involve the common femoral arteries. Egoda describes a third access site made in the left subclavian artery through which the stent-graft can be introduced. This method may allow better control over both ends of the stent-graft during implantation. The length of the stent-graft must still be determined prior to implant and estimation of the length of the blood flow pathway is difficult to determine using standard diagnostic equipment due to the tortuosity of the vessels involved in the aneurysmal dilation.

[0015] A one-piece endovascular graft is described by Piplani in U.S. Pat. No. 5,824,039 for treating a bifurcated abdominal aortic aneurysm lesion. This device has springs located at inlet and outlet ends to hold the graft in place. The springs also have barbs attached. The springs have a large zig zag appearance similar to other prior art attachment means and the barbs are not well protected from inappropriate snagging prior to deployment of the endovascular graft.

[0016] Modular intraluminal prosthesis are described by Lauterjung in U.S. Pat. No. 5,824,036 and by Fogarty in U.S. Pat. No. 5,824,037. Lauterjung describes a composite system using a magnetic tipped guidewire to assist in the assembly of the prosthesis and employs a stent at the ends of the prosthesis and elsewhere. Fogarty describes a self-expanding or resilient frame with a plastically deformable liner over the frame limiting the resilient expansion. Each of these two composite or modular systems shares similar problems to the composite systems described earlier, including the potential for leakage at the junction sites as well as leakage at the junction of the prosthesis with the vessel lumen.

SUMMARY OF THE INVENTION

[0017] The present vascular implant overcomes the disadvantages of prior art stent-grafts, attachment means, and vascular tubular members used for endoprosthetic aortic or arterial aneruysmal repair, or for arterial bypass or other arterial or venous reconstruction. The vascular tubular member of the present invention includes a vascular tubular member that can be intravascularly delivered to the site of vessel injury such as an aortic aneurysm where it is deployed in a manner that will exclude the vessel injury or aneurysm. This intravascular tubular member conveys blood flow from a proximal arterial region that is located proximal to an arterial lesion or aneurysm to one or more distal arterial vessels. One embodiment of the present invention is an intravascular tubular member having a folded tubular section that allows the length of the graft to be adjusted during the time of deployment of the intravascular tubular member. This intravascular tubular member allows the physician to deploy the exact correct length of tubular member for each individual patient and allows the intravascular tubular member to fit different patients that require intravascular tubular members of different lengths. The intravascular tubular member further can have a proximal attachment anchor positioned at its proximal end that allows the proximal end to be positioned accurately in the aortic wall tissue adjacent and distal to the renal arteries. The attachment anchor of the present invention is an attachment anchor that does not undergo significant length change during deployment thereby allowing the position of the attachment anchor within the aortic aneurysm to be accurately determined. The intravascular tubular member can also be anchored to the aorta proximal to the renal vessels for the condition that the aortic aneurysm is abruptly distended adjacent and distal to the renal arteries. The attachment anchor can include barbs to more firmly anchor the intravascular tubular member to the vessel wall. The intravascular tubular member can also include a distal attachment anchor to anchor the distal end of the intravascular tubular member to one or more distal vessels.

[0018] The structure of the vascular tubular member includes a woven structure formed from either multifilament polymeric strands or a composite of multifilament polymeric strands woven along with metal strands. This structure of the vascular tubular member wall is such that it can be supported in both the axial and circumferential directions with metal strands. The circumferentially oriented metal strands provide anti-kink and anti-crush characteristics to the vascular tubular member. The axially oriented metal strands can provide the vascular tubular member with axial compression resistance and ensure that the folded tubular section is maintained in a straight tubular form. These characteristics will provide the tubular sections of the present invention with a more stable pathway for the intravascular tubular member through the thrombus found within a typical abdominal aortic aneurysm. The one-piece construction of the intravascular tubular member of this invention does not allow for leakage at modular junctions such as that which can occur with prior art component or modular intravascular tubular member systems described earlier. One primary application for the intravascular tubular member of the present invention is in the treatment of abdominal aortic aneurysms. Although the description of the invention in this disclosure is directed toward treatment of abdominal aortic aneurysm, it is understood that the present invention is intended for treatment of other vascular lesions both arterial and venous including vessel bypass, traumatic injury, aneurysmal repair, and other lesions.

[0019] The intravascular tubular member of the present invention can be formed from a single straight tube having a proximal end and a distal end. As the intravascular tubular member is being inserted into the patient, it has a smaller nondeployed diameter and a shorter nondeployed length. After the intravascular tubular member is fully deployed, it has a larger deployed diameter and a longer deployed axial length. The straight intravascular folded tubular member is comprised of three sections, a proximal tubular section that includes a proximal tube with an open inlet end, a folded tubular section which includes a folded tube that is able to extend in axial length, and a distal tubular section that includes a distal tube with an open distal end. The proximal, folded, and distal sections are of a length that allows ease of insertion and implantation of the intravascular folded tubular member to vascular application. Alternately, the distal section can be very short and may only include the outlet end of the folded section. In the folded tubular section the folded tube is folded back and forth upon itself generating two circumferential fold lines and forming the folded tubular section of the intravascular folded tubular member. In the folded tubular section a portion of the outer surface of the intravascular folded tubular member is in direct contact with another portion of the outer surface, and a portion of the inner surface is in direct contact with another portion of the inner surface of the intravascular folded tubular member. The nondeployed axial length of the intravascular folded tubular member is shorter than the deployed axial length; the folded tubular section length will shorten as the deployed axial length of the

intravascular folded tubular member gets longer. The folded tubular section is positioned distal to the proximal tubular section which can have a proximal attachment anchor attached at the proximal end. Distal to the folded tubular section is a distal tubular section that can have a distal attachment anchor attached at or near the distal end.

[0020] The intravascular folded tubular member can be delivered intraluminally by compressing the intravascular folded tubular member radially to form a compressed conformation that can be delivered to the abdominal aorta or other vessel through a sheath or other delivery means placed in a common femoral artery. Upon delivery of the intravascular folded tubular member into the aorta, the intravascular folded tubular member expands to its deployed diameter. For a self-expanding intravascular folded tubular member the deployed diameter is between the nondeployed diameter and an equilibrium diameter that the intravascular folded tubular member would attain if fully deployed without a restricting force applied from the vessel with which it is in contact. The deployed diameter is generally approximately equal to the diameter of the native vessel that is being repaired. The intravascular folded tubular member can also be expanded by a catheter containing a mechanical expansion means such as a balloon. A proximal attachment anchor can be deployed to form an attachment that seals the proximal end of the intravascular folded tubular member to the aortic wall adjacent and distal to the renal vessels. The proximal attachment anchor does not undergo a significant axial length change during its deployment and as a result can be placed accurately in a position adjacent to the renal vessels for a more reliable attachment to the aortic wall. This reduces any chance for distal migration of the intravascular folded tubular member over time. Attachment of the intravascular folded tubular member to the attachment anchor of the present invention occurs at significantly more sites than is found with other prior art abdominal aortic aneurysm intravascular folded tubular members with zig-zag wire attachment means. The increased number of attachment sites provides a better seal of the attachment anchor and the intravascular folded tubular member to the aortic wall. Barbs can be located on the attachment anchor of the present invention such that they are folded inward during insertion of the device and extend outwards upon deployment of the intravascular folded tubular member.

[0021] The distal end of the intravascular folded tubular member is then positioned at an appropriate location within the abdominal aorta, typically at the site of the distal aortic neck if such a neck exists. It is common to position the distal end of the intravascular folded tubular member into an iliac or femoral artery. As the distal end of the intravascular folded tubular member is being positioned, a portion of the folded tubular section will be unfolded allowing intravascular folded tubular member material contained within the folded tubular section to unfold thereby allowing the intravascular folded tubular member to lengthen to an appropriate deployed axial length that is required to isolate an aneurysm, bypass an artery, or repair in some other way an artery for that individual patient. The length of the tortuous blood flow pathway through the thrombus in the aortic aneurysm can be accurately and appropriately sized in situ when using the intravascular folded tubular member of this invention.

[0022] The material of construction for the wall of the vascular tubular member with a folded tubular section as described previously can be any material that is used in vascular grafts or a combination of materials used in vascular grafts and endovascular stents. Typical vascular graft materials include expanded polytetrafluoroethylene, polyester, silicone, carbon, polyurethanes, biological tissues, silk, composite materials, and others. Some of these materials can be formed into a tube through processing methods that include paste extrusion, electrostatic spinning, spinning without electrostatics, salt leaching, and others. Additionally, the vascular tubular member of this invention which includes the intravascular folded tubular member can be formed from fibers of the materials listed above that have been woven, braided, knitted, or formed into a tubular member. The fibers can preferably be formed of many filaments of a very small diameter and which are wound to form a multifilament fiber or strand Such a multifilament fiber can offer an enhanced sealing capability at the crossover points of a woven or braided fabric vascular tubular member material. It is therefore preferred that a woven or braided tubular member be formed with multifilament yarn or multifilament fibers to reduce blood leakage at crossover points of polymer strand with polymer strand or polymer strand with metallic strand. Typical materials used in the construction of endovascular grafts and stents include Nitinol, stainless steel, tantalum, titanium, platinum, and other metals, metal alloys, and other suitable materials of large elastic modulus. Strands of these and other materials can be interwoven or interbraided with the polymeric materials used in vascular grafts to form a composite wall structure of the present invention.

[0023] A tubular double weaving method can be applied to the construction of the wall of the present vascular tubular member. A construction that involves weaving both polymeric fiber and metallic strands in both longitudinal and circumferential directions can encounter crossover points of one metal strand with another. At such crossover points, leakage or seepage of blood can occur from inside the vascular tubular member to the space outside the vascular tubular member. To reduce or eliminate small pores at the crossover points a tubular double weave is preferred when a metal strand is woven on both the axial and circumferential directions. With this technique a metal strand in one direction is brought out of the surface or the plane of the weave at the crossover point. The woven polymeric material without the metal strand forms a continuous plane of weave beneath the crossover point with good sealing due to the multifilament strands. Thus, leakage cannot occur at metallic strand to metallic strand crossover points due to the elimination of the pores or leakage sites due to the double weaving.

[0024] The attachment anchor that can be positioned at the proximal and distal ends of the intravascular tubular member can be of the self-expanding design or it can require an internal force application to force it outward, such as that provided by a balloon expandable means. The attachment anchor can be used with an intravascular tubular member that has a folded tubular section or it can be used with any other tubular member found in the prior art or that is being used for intravascular treatment of vessel injury. The metal strands that can be interwoven or interbraided into the wall structure of the intravascular tubular member can preferably be of a spring nature such that they self expand from the compressed state to form the deployed diameter; the metal wires can also undergo a plastic deformation as the intravascular tubular member undergoes expansion from its compressed conformation to its deployed diameter upon exposure to forces imposed by a balloon catheter placed within its lumen.

[0025] One preferred embodiment the intravascular folded tubular member of the present invention is a one-piece bifurcated tubular structure or means that is used in the treatment of abdominal aortic aneurysm. The intravascular folded tubular member has a proximal tubular section with a single open inlet end and a bifurcated main trunk that provides passage into two proximal leg tubes. Each proximal leg tube is joined to a folded tubular section, and each folded tubular section is joined to a distal section. The proximal tubular section has a deployed diameter approximately equal to the diameter of the aorta at the aortic proximal neck immediately adjacent and distal to the renal vessels. The two proximal leg tubes can have a diameter approximately equal to the diameter of the iliac artery or femoral artery into which they are to extend. The proximal end of the main trunk can have an attachment anchor attached to provide accurate attachment of the open proximal end within the proximal neck of the aorta. The attachment anchor can include barbs or hooks that provide a more definite attachment of the intravascular folded tubular member to the wall of the aorta to prevent migration, provide a leak-tight seal, and help support the aorta from further distension at that location. The folded tubular sections each have two circumferential fold lines and are folded back and forth in a manner similar to that described earlier for the straight intravascular folded tubular member. Each folded tubular section has a portion of the outer surface of the intravascular folded tubular member in direct contact with a another portion of the outer surface, and it has a portion of the inner surface of the intravascular folded tubular member in direct contact with another portion of the inner surface. The folded tubular sections allow the bifurcated folded tubular member to assume a shorter nondeployed axial length during the delivery of the intravascular folded tubular member than its deployed axial length. Each folded tubular section is attached to a distal tubular section with an open distal end. The open distal end of each distal tubular section can have an attachment anchor attached to form a precise and leak-free attachment to the iliac or femoral arteries.

[0026] A preferred bifurcated intravascular tubular structure or member of the present invention consists of a proximal tubular section or means with a proximal attachment anchor attached to its inlet end, two folded tubular sections attached to the proximal tubular section, two distal tubular sections attached to the two folded tubular sections, and two distal attachment anchor attached to each open distal end. The bifurcated intravascular tubular means is generally introduced into the aneurysmal abdominal aorta intraluminally through a surgical cut down or percutaneous access made into one common femoral artery. A sheath or other introducing means provides suitable access for the intravascular folded tubular member into the blood flow pathway of the aorta. Attachment of the proximal attachment anchor to the aorta is generally made adjacent and distal to the renal vessels. This attachment anchor can be a self-expanding attachment anchor or a balloon expandable attachment anchor. The attachment anchor is preferably short in axial length, has minimal length change upon deployment to allow more accurate placement, and can have barbs extending outward upon deployment to provide better attachment of the intravascular folded tubular member to the vessel wall. The two distal sections of the bifurcated tubular means are generally positioned in the right and left iliac arteries, respectively. The distal ends of the two distal section along with the two distal attachment anchor are positioned at an appropriate location within the iliac or femoral arteries so as to properly exclude the abdominal aortic aneurysm and any additional iliac or femoral aneurysm. As these distal ends are being positioned, the two folded tubular sections will unfold an appropriate amount to allow the deployed axial length of the bifurcated tubular means to be precisely sized to the individual patient. Variations between patients can be accommodated with the folded tubular sections as well as inaccuracies between angiographic length estimations of the aortic aneurysm and the actual length of the aneurysm.

[0027] Distal attachment anchor which are attached to the distal ends of the distal tubular sections can be deployed to form a secure and leak-tight attachment to each iliac artery or femoral artery. The wall structure of the bifurcated folded tubular member is similar to that described for the single straight tube. A woven or braided composite of a polymeric multifilament fiber interwoven or interbraided with a metal fiber can be formed into a one-piece Y-shaped tubular means of the present invention for treatment of abdominal aortic aneurysm with a bifurcated intravascular folded tubular member. Tubular double weaving can be used to reduce leakage sites at crossover points of the metal fibers or strands.

[0028] Another embodiment for the abdominal aortic aneurysm intravascular folded tubular member of the present invention has a proximal section with a bifurcated main trunk having an open inlet end and joined to two proximal leg tubes. In this embodiment only one proximal leg tube is joined to a folded section. The other proximal leg tube has an open distal end that is adapted to accommodate a cylindrically shaped intravascular folded tubular member that can be inserted into the open distal end and sealingly engaged with the proximal leg tube using an engagement means positioned on the cylindrically shaped intravascular folded tubular member. This sealing engagement on one side of the proximal section is similar to the modular systems shown for treatment of abdominal aortic aneurysm in the prior art. This embodiment allows one part of the bifurcated intravascular folded tubular member to be unfolded and extended in length in a manner similar to previous embodiments described in this invention, and the other part of the bifurcated intravascular folded tubular member to be extended by adding additional intravascular folded tubular member segments in a modular fashion as described in the prior art.

[0029] The folded tubular section for the straight or bifurcated intravascular folded tubular member of the present invention has three layers of intravascular folded tubular member wall that lie in direct contact with or in apposition with each other, an outer wall, a center wall, and an inner wall. These three layers extend from a proximal end to a distal end of the folded tubular section. The length of the folded tubular section becomes shorter as the intravascular folded tubular member becomes extended axially during the deployment of the intravascular folded tubular member. In the folded tubular section a portion of the outer surface of the tubular means is in direct contact with the outer surface of another portion of the tubular means, and a portion of the inner surface is in direct contact with another portion of the inner surface. As the folded tubular section becomes unfolded during the deployment it is desirable for the center wall to not wrinkle during the unfolding process. Such wrinkling can occur if the inner and outer wall slide with respect to the center wall rather than unfolding smoothly from the proximal or distal ends of the folded section. One way of significantly reducing or preventing this wrinkling from occurring is to apply a bonding agent or adhesive to the outside surfaces of the folded tubular sec-

tion. This adhesive is preferably one that resists the shearing motion that is associated with the relative sliding motion that can cause wrinkles to form. The adhesive should also be capable of undergoing fracture due to exposure to extensional or tension stresses that are generated during the desirable unfolding from the proximal or distal ends of the folded section.

[0030] Following deployment of the intravascular folded tubular member of the present invention, it may be desirable to ensure that further unfolding of the folded region does not occur. one or more securing pins or other securing means can be placed through all three walls of the folded tubular section to prevent any further unfolding that may occur after implantation.

[0031] The vascular implant of the present invention includes an attachment anchor that can be attached to the inlet or outlet ends of the intravascular tubular member of this invention, the intravascular folded tubular member of this invention, or of any other prior art tubular means used for intravascular implant. The attachment anchor is formed from a metal tube using machining methods that include mechanical, laser, chemical, electrochemical, or other machining methods to form a pattern of nodes and struts. The nodes and struts are intended to provide independent adjustment of expansion force provided by the attachment anchor uniformly outward against the vessel wall due to its expansion deformation and crush elastic force provided by the attachment anchor against external forces that tend to cause the attachment anchor to form an oval shape associated with crush deformation. The independent adjustment of expansion forces due to deformation in the cylindrical surface of the attachment anchor from the crush force which produces a deformation to a smaller radius of curvature in the radial direction of the attachment anchor such as forming an oval shape, allows the attachment anchor of the present invention to have a shorter axial length for a better focal line attachment to the vessel wall.

[0032] The nodes are formed of at least one hinge and two transition regions. The transition regions are each attached to a strut. A series of struts and nodes are positioned such that the struts are aligned adjacent to each other forming a single folded ring of struts and nodes with a generally cylindrical shape in a nondeployed state with a smaller nondeployed diameter. The attachment anchor of the present invention can be a balloon-expandable or a self-expanding attachment anchor. During expansion of the balloon-expandable attachment anchor, an expanding means such as a balloon dilitation catheter can be inserted along a central axis of the attachment anchor and expanded. The hinges undergo a plastic expansion deformation as the attachment anchor is expanded to a deployed state with a larger deployed diameter. In a deployed state the hinge exerts an outward expansion force through the struts which in turn push against the blood vessel to hold the vessel outwards and hold the intravascular tubular member against the vessel wall without leakage. A self-expandable attachment anchor is held, for example, within a deployment sheath at a smaller nondeployed diameter for delivery into the vasculature. The hinge is deformed elastically in its nondeployed state and exerts an outward force against the sheath. Upon release from the sheath the self-expandable attachment anchor expands outward until it comes into contact with the vessel wall or the intravascular tubular member. The hinge exerts an outward elastic expansion force through the struts which in turn push against the blood vessel to hold the vessel outwards and hold the intravascular tubular member against the vessel wall without leakage.

[0033] Hinges of the present invention have a larger radial dimension than the struts and a thinner width than the struts; the hinge length further having a major role in establishing the outward expansion forces generated by the hinges. The hinge length can be short to focus the expansion deformation of the hinge into a smaller area. For a balloon-expandable attachment anchor the smaller hinge length increases the percentage of metal in the hinge that undergoes a plastic deformation. The result is less rebound of the attachment anchor back towards its nondeployed state following balloon expansion. For a self-expandable attachment anchor the smaller hinge length will generate a greater expansion force for a smaller localized expansion deformation of the hinge. A longer hinge for a self-expandable attachment anchor provides a smaller drop-off of outward expansion force than a smaller hinge length for a specific deployment angle of the attachment anchor. The larger hinge length allows a similar outward force to be applied to the blood vessel wall for a wider range of vessel diameters for the same attachment anchor. For a balloon-expandable attachment anchor an increase in hinge width causes a greater amount of plastic deformation and provides a larger expansion force generated by the hinge than a smaller hinge width. For a self-expandable attachment anchor an increase in hinge width causes a larger outward expansion elastic force to be exerted against the vessel wall. A hinge radial dimension larger than the strut radial dimension produces a larger outward expansion force for both the balloon-expandable or self-expandable attachment anchor. The large hinge radial dimension does not allow the hinge to bend in a radial direction to form an oval such as would like to occur during exposure to a crush deformation.

[0034] The struts of the attachment anchor have a larger width than the hinge width such that the hinges can transfer their outward force through the struts to the vessel wall without allowing any bending of the struts in the cylindrical surface of the attachment anchor. The struts have a small radial dimension in comparison to the hinge radial dimension to allow the struts to deform elastically to a smaller radius of curvature in the radial direction of the attachment anchor upon exposure to a crush deformation. The strut width allows the struts to deform elastically at any prescribed crush force during exposure to a crush deformation. A longer strut length allows a greater percentage of the perimeter of the attachment anchor to be associated with the struts in comparison to the hinges or nodes. The longer struts provide the attachment anchor with an increased flexibility in the radial direction when exposed to a crush deformation. Conversely, a shorter strut provides the attachment anchor with a greater stiffness in the crush deformation mode with other attachment anchor dimensions remaining the same. The greater stiffness associated with an attachment anchor with such a shorter length strut allows the strut to be formed with a thinner radial dimension or smaller width and still have the same flexibility in crush deformation as a longer strut.

[0035] The attachment anchor of the present invention can be formed out of a higher modulus metal that other attachment devices. Other prior art attachment devices cannot be formed of the highest modulus metal because their expansion force cannot be changed without also affecting their crush force. With the present attachment anchor the outward expansion force can be designed independently from the crush force provided by the attachment anchor. The present attach-

ment anchor can be formed such that it is short in axial length in order to provide a more focused line of attachment to the vessel wall. Short stents formed with prior art designs can be designed to provide an appropriate outward expansion force, however this prior art stent would be too stiff or too flexible in a crush deformation and would be without the ability to adjust the crush deformation force with respect to the outward expansion force. The present attachment anchor can be designed to provide both an appropriate expansion force and an appropriate crush force. The hinge of the present attachment anchor can also provide more expansion force than other prior art attachment devices due to the use of higher modulus metal and due to the dimensions chosen for the hinge width, length, and radial dimension. The close efficient packing of the struts parallel to each other provides the present attachment anchor with a large expansion ratio. The short strut length allows the strut width to be minimized while still maintaining an appropriate flexibility in crush deformation further maximizing the expansion ratio provided by the present attachment anchor. The strong expansion force provided by the hinge allows an appropriate expansion force to be generated such that the attachment anchor of this invention with short axial length can provide adequate expansion forces to hold a large vessel such as the aorta outward and prevent leakage between the intravascular tubular member and the vessel wall.

[0036] The vascular tubular member tubular wall structure can be formed from a composite of polymeric and metallic strands that are either woven or braided to provide different characteristics in its axial and circumferential directions. In a weaving process for tubular structures one or more strands have substantially a circumferential direction and another group of strands have generally an axial direction. In a weaving process the substantially circumferential strands generally have a gradual helical wind that is approximately perpendicular to the longitudinal axis of the vascular tubular member but the strands are continuous and actually form a helix. A polymeric strand can be made up of substantially straight filaments to form a straight polymeric strand. This straight polymeric strand can be woven in a circumferential direction forming a straight circumferential polymeric strand, or woven in an axial direction forming a straight axial polymeric strand. The polymeric strand can also undergo a thermal, mechanical, or chemical forming process that can heat set, mechanically set, or chemically deform the polymer filaments or the strand to have local bends, helical spirals, or curves in it. The local bends can be spaced very close together with spacing approximately equal to the diameter of the filament. Alternately, the local bends can be spaced apart further than the diameter of a fiber that is made up of many filaments. This curved polymeric strand will have the characteristic that it can stretch or elongate in its axial direction. This curved polymeric strand can be woven in a circumferential direction forming a curved circumferential polymeric strand, or it can be woven in an axial direction forming a curved axial polymeric strand. The straight or curved polymeric strand could be made from filaments of expanded polytetrafluoroethylene, from filaments of Dacron polyester, polyurethane, or from other suitable polymeric filaments.

[0037] The metallic strands that could be interwoven between the polymeric strands could be formed from a straight metallic strands, fibers, or wire formed from a metal such as Nitinol, stainless steel, titanium, tantalum, or other suitable metal or alloy. The wire can be round in cross section or it can be flat wire with a more rectangular cross section. It is preferable for one embodiment that the wire or metallic strand be of an elastic nature that does not exceed its elastic limit during the deployment of the vascular tubular member of the present invention. The wire in another embodiment could undergo plastic deformation during the deployment of the vascular tubular member. This straight metallic strand can be woven in the circumferential direction forming a straight circumferential metallic strand, or it can be woven in the axial direction forming a straight axial metallic strand. The metallic strand can also undergo a thermal, mechanical, or chemical forming process that can heat set, mechanically set, or chemically set the metallic strand to have local bends, helices, or curves in it. This curved metallic strand will have the characteristic that it can either stretch or compress in its overall axial direction. This curved metallic strand can be woven in a circumferential direction forming a curved circumferential metallic strand, or it can be woven in an axial direction forming a curved axial metallic strand. When woven in an axial direction, the curved wire is held under tension and is therefore held in a straight conformation. Upon release of the metallic strand, it forms the curved shape that was formed into the metallic strand prior to weaving. Circumferentially weaving a curved metallic strand requires additional effort due to the tortuous pathway followed by the strand during the weave.

[0038] The vascular tubular member wall structure of the present invention can include a woven tubular structure consisting of curved and straight, polymeric and metallic strands in the circumferential and axial directions. In one structure straight circumferential polymeric strands and one or more straight circumferential metallic strands are interwoven circumferentially and straight axial polymeric strands are woven axially. This structure is easy to form and has good hoop strength that will resist kinking due to the metallic component. The folded tubular section has good approximation between the inner, center, and outer walls since only the polymeric strands are extending axially allowing the circumferential fold lines to have a very small radius of curvature.

[0039] In another vascular tubular member wall structure additional straight axial metallic strands are interwoven with the straight axial polymeric strands of the structure just presented above. The additional straight axial metallic strands provide the folded tubular section with the characteristic that resists wrinkling in the folded tubular section. A tubular double weave can be used whenever two metal strands form a crossover point. One of the metal strands can be brought out of the plane of the weave prior to the crossover point and reenter the plane of the weave after the crossover point. The weaving plane is thus continuous without one of the metal strands and leakage at that crossover point will not occur. The additional straight axial metallic strands offer axial strength against compressive deformation but can cause the vascular tubular member to become stiff and more difficult to negotiate the tortuous turns of the iliac and femoral arteries.

[0040] In still another vascular tubular member wall structure a curved axial metallic strand is interwoven with straight axial polymeric strands in the vascular tubular member wall structure just presented above instead of straight axial metallic strands. The curved axial metallic strands provide a benefit to the folded tubular section to resist wrinkling during the unfolding process. The curved axial metallic strands also provide the vascular tubular member with good axial support against compressive forces generated by the thrombus and

other physiological forces that can be placed upon the vascular tubular member. The curved axial metallic strands can compress elastically and thereby will not provide this vascular tubular member wall structure with good flexibility and will resist vascular tubular member kinking.

[0041] In yet another vascular tubular member wall structure straight circumferential polymeric strands are interwoven with one or more curved circumferential metallic strands in the circumferential direction and straight axial polymeric strands are interwoven with curved axial metallic strands in the axial direction. The curved circumferential metallic strands found in this structure allows the folded tubular section to unfold with greater ease due to their ability to elongate diametrically as, for example, one curved circumferential metallic strand located in an inner or outer wall passes adjacent to another curved circumferential metallic strand located in the center wall. The curves or bends in the curved circumferential metallic strands also allows the vascular tubular member to expand out uniformly to its deployed diameter which can be smaller than the equilibrium diameter of the vascular tubular member and provide uniform contact with the aortic wall.

[0042] In one more vascular tubular member wall structure curved circumferential polymeric strands are interwoven with one or more straight circumferential metallic strands in the circumferential direction and straight axial polymeric strands are interwoven with curved axial metallic strands in the axial direction. The curved circumferential polymeric strands provide an amount of circumferential stretch in the diametric direction. The other components of the weave restrict excessive circumferential stretch. This vascular tubular member structure can also be modified slightly to provide an additional characteristic. Near the proximal end of the tubular means the straight circumferential metallic strands can be eliminated thereby allowing the vascular tubular member to expand to a larger circumference. This circumferential expansion allows the vascular tubular member of the present invention to accommodate a reasonable tolerance in the estimated aortic neck diameter of a few millimeters. Similar circumferential accommodation also applies to the iliac artery.

[0043] Accommodation of the estimated aortic diameter with a vascular tubular member of a fixed non-flexible wall material with a maximum diameter can also be accomplished by ensuring that the vascular tubular member chosen can expand to a slightly larger diameter than the aortic diameter. Any embodiment of vascular tubular member wall structure of this disclosure can provide this characteristic. Any excess graft wall material will result in a wrinkle or fold if the perimeter of the tubular member is slightly larger than the perimeter of the aorta, for example. Provided that this wrinkle or fold is held tightly against the aortic wall by the proximal attachment anchor, leakage at the proximal site will not occur.

[0044] In yet one more vascular tubular member wall structure curved circumferential polymeric strands are interwoven with one or more curved circumferential metallic strands in one direction and the axial direction is the same as the vascular tubular member wall structure just described above. This structure offers the ability to stretch in the circumferential direction to a limited extent controlled by the amount of curvature provided to the circumferential strands. This vascular tubular member wall structure provides good anti-kink characteristics, good axial support against compression, good flexibility, and will accommodate a reasonable tolerance in the aortic neck diameter, and a tolerance on the iliac artery diameter.

[0045] In still one more vascular tubular member wall structure curved circumferential polymeric strands are interwoven with one or more curved circumferential metallic strands in one direction and the axial direction contains curved axial polymeric strands interwoven with curved axial metallic strands. This structure offers the ability to stretch in the circumferential and axial direction to a limited extent controlled by the amount of curvature provided to the circumferential and axial strands, respectively. This structure can extend in each direction throughout the entire tubular means. This vascular tubular member wall structure provides good anti-kink characteristics, good axial support against compression, good flexibility, and will accommodate a reasonable tolerance in the aortic neck diameter, and a tolerance on the iliac artery diameter.

[0046] All of the vascular tubular member wall structures presented in this disclosure can be formed with the axial metallic strands being directed with an augmented amount of helical turn. This is accomplished by taking metallic strand out of the weaving plane, stepping over to a new site that is displaced circumferentially, and inserting the metallic strand back into the plane of the weave. This stepping over process allows the axial metallic strand to assume a helical pathway along the axial direction of the vascular tubular member. This augmented amount of helical turn is in addition to the gradual helical turn naturally found in the axially oriented metallic strands due to their natural desire to orient perpendicular to the generally circumferential strands which also have a slight helical turn since they are wound in a continuous helix. The augmented helical turn of the metallic strands in the generally axial direction provides the vascular tubular member with an ability to bend without kinking even when straight metallic strands are used in the axial direction. Enhanced helical turn in the circumferential direction can also be accomplished by weaving two or more metallic strands into the circumferential weave. This can provide a steeper angel for the helical wind and provide additional axial flexibility without kinking.

[0047] In a preferred embodiment curved polymeric strands are wound in both the circumferential and axial direction to provide the vascular tubular member with a supple feel and good bending characteristics without kinking. For simplicity of manufacturing, one or more straight metallic strands are wound in the circumferential direction. Either curved metallic strands or straight metallic strands with the step over characteristic described above is used in the axial direction to provide the necessary compressive strength as well as provide good flexibility to the vascular tubular member. An entire straight or bifurcated vascular tubular member can be formed from a single contiguous woven material comprised of the polymeric and metallic strands described above. The vascular tubular member is woven without seam in its proximal, folded or distal section. For the bifurcated tubular member this is accomplished by splitting the number of strands that extend axially such that approximately half of those present in the main trunk extend down one proximal leg and half extend down the other proximal leg.

[0048] The vascular tubular member wall structure of the present invention can also be formed from a braiding process wherein straight polymeric and straight metallic strands are braided in a right hand spiral forming straight right spiral polymeric strands and straight right spiral metallic strands.

These strands can be made with localized bends or curves in them as described earlier, and these strands can be braided into a right hand spiral to form curved right spiral polymeric strands and curved right spiral metallic strands. Similarly the straight and curved, polymeric and metallic strands can be braided into a left hand spiral.

[0049] In one vascular tubular member wall braided structure a straight right spiral polymeric strand and a straight right spiral metallic strand are interbraided together in one direction and a straight left spiral polymeric strand and a straight left spiral metallic strand are interbraided in the opposite direction. The braiding process provides some ability for this wall structure to accommodate reasonable tolerances in the estimation of the proximal aortic neck diameter in order to provide a good diametric fit between the vascular tubular member and the proximal aortic neck. The presence of the straight and curved metallic strands provides good axial and circumferential strength and stability against compression in the radial or axial direction in comparison to other prior art materials of construction.

[0050] In other vascular tubular member embodiments the braided structure can involve either curved metallic strands or curved polymeric strands. These curved metallic or polymeric strands will provide the vascular tubular member with a greater flexibility due to the ability of these metallic strands to compress as the vascular tubular member is exposed to a tortuous pathway.

[0051] It is understood that the woven and braided vascular tubular member wall structures presented are not intended to be complete and that other combinations of straight and curved, polymeric and metallic strands can be used with weaving or braiding with the associated characteristics and advantages that have been described or taught in this disclosure.

[0052] The bifurcated tubular member used in the treatment of abdominal aortic aneurysm described in this invention can have a proximal attachment anchor attached at the proximal end of the bifurcated main trunk. This attachment anchor provides a circumferential expansion and attachment to the aorta without significant change in axial length. This small axial length change allows this attachment anchor to be placed very near to the renal arteries with precision and reduce the likelihood for distal migration of the vascular tubular member. A greater number of barbs can be placed on the attachment anchor due to the geometry of the attachment anchor which has a short axial length and involves a hinge to supply the outward forces of the attachment anchor. The increased number of barbs will better hold the vascular tubular member to the aorta around the entire circumference.

[0053] The bifurcated folded tubular member of the present invention can also have a proximal attachment anchor that is displaced proximally from the proximal end of the main trunk. The displaced attachment anchor can be joined to the bifurcated main trunk by the metal strands that are woven axially or helically into the vascular tubular member or by the metal strands that are braided into the vascular tubular member. The displaced proximal attachment anchor is intended in one embodiment to provide attachment proximal to the renal arteries in a region of the aorta that is significantly proximal to the aneurysmal region of the aorta. Since many abdominal aortic aneurysms occur adjacent to the renal vessels and generally distal to the renal vessels, it is sometimes necessary to find a proximal attachment site that is proximal to the renal arteries. The displaced proximal attachment anchor will provide this attachment capability and prevent any distal migration of the intravascular tubular member. The small metallic strands that connect the displaced attachment anchor to the main trunk of the intravascular tubular member can cross over a renal artery without causing a significant thrombotic or occlusive effect. The metallic strands are positioned around the circumference to provide the main trunk with support from the attachment anchor along its entire circumference. Only a minimal number of metallic strands extend to the displaced attachment anchor in order to reduce the chances for thrombus formation at the entrances to the renal arteries. The number of strands can range from two to approximately sixteen. An additional proximal attachment anchor may be attached to the open proximal end of the main trunk in addition to the displaced attachment anchor to provide a tight leak-free seal with the aorta. The displaced attachment anchor can have barbs to enhance attachment to the aorta or it can be an attachment anchor without barbs as described earlier. The metallic strands can be attached to selected securing sites of the attachment anchor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0054] Other objects of the present invention and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, in which like reference numerals designate like parts throughout the figures thereof and wherein:

[0055] FIG. **1**A is a sectional view of a vascular tubular member implanted within an abdominal aortic aneurysm;

[0056] FIG. **1**B is a sectional view of an intravascular tubular member implanted in a bifurcated abdominal aortic aneurysm;

[0057] FIG. **2**A is a sectional view of a straight intravascular folded tubular member in a partially deployed state;

[0058] FIG. **2**B is a sectional view of a straight intravascular folded tubular member in a fully deployed state;

[0059] FIG. **2**C is a cross sectional view of a straight intravascular folded tubular member near the inlet end in a nondeployed state;

[0060] FIG. **2**D is a cross sectional view of a straight intravascular folded tubular member near the outlet end in a nondeployed state;

[0061] FIG. **2**E is a sectional view of a straight intravascular folded tubular member in an unfolded state;

[0062] FIG. **3** is an isometric view of a straight intravascular folded tubular member in a nondeployed state with an attachment means at inlet and outlet ends;

[0063] FIG. **4**A is a sectional view of a bifurcated intravascular folded tubular member in a partially deployed state;

[0064] FIG. **4**B is a sectional view of a bifurcated intravascular folded tubular member in a fully deployed state;

[0065] FIG. **4**C is a sectional view of a bifurcated intravascular folded tubular member in a nondeployed state within a delivery sheath near the inlet end;

[0066] FIG. **4**D is a sectional view of a bifurcated intravascular folded tubular member in a nondeployed state within a delivery sheath near the outlet ends;

[0067] FIG. **4**E is a sectional view of a bifurcated intravascular folded tubular member in a nondeployed state on a balloon dilitation catheter near the inlet end;

[0068] FIG. **4**F is a sectional view of a bifurcated folded tubular member in an unfolded state;

[0069] FIG. **5** is a partially sectioned view of a bifurcated folded tubular member in a nondeployed state with attachment means at the inlet and outlet ends;

[0070] FIG. **6** shows a sectional view of a folded tubular section in a nondeployed state with a bonding agent applied;

[0071] FIG. **7**A is a schematic sectional view of the folded tubular section in a nondeployed state;

[0072] FIG. **7**B is a schematic sectional view of the folded tubular section unfolded from the circle to the point-down triangle;

[0073] FIG. **7**C is a schematic sectional view of the folded tubular section unfolded from the square to the point-up triangle;

[0074] FIG. **7**D is a schematic sectional view of the folded tubular section unfolded evenly;

[0075] FIG. **7**E is a schematic sectional view of the folded tubular section with wrinkling;

[0076] FIG. **8** is a sectional view of a folded tubular section with holding pins;

[0077] FIG. **9**A is an isometric view of an attachment anchor with one hinge per node in a nondeployed state;

[0078] FIG. **9**B is an isometric view of an attachment anchor with one hinge per node in a deployed state;

[0079] FIG. **9**C is an enlarged detailed isometric view of a node of an attachment anchor with one hinge;

[0080] FIG. **9**D is a perspective view of an attachment anchor with an oval attachment anchor surface;

[0081] FIG. **10**A is an isometric view of an attachment anchor with two hinges per node in a nondeployed state;

[0082] FIG. **10**B is an isometric view of an attachment anchor with two hinges per node in a deployed state;

[0083] FIG. **10**C is an enlarged detailed isometric view of a node of an attachment anchor with two hinges;

[0084] FIG. **10**D is a perspective view of an attachment anchor with nodes and struts in a closed configuration in a nondeployed state;

[0085] FIG. **10**E is a perspective view of an attachment anchor with nodes and struts in a closed configuration in a deployed state;

[0086] FIG. **11**A is an isometric view of an attachment anchor with barbs in a nondeployed state;

[0087] FIG. **11**B is an enlarged view of a portion of an attachment anchor with barbs in a nondeployed state;

[0088] FIG. **11**C is an isometric view of an attachment anchor with barbs in a deployed state;

[0089] FIG. **11**D is an enlarged view of a portion of an attachment anchor with barbs in a deployed state;

[0090] FIG. **12**A is an isometric view of attachment anchors positioned at an inlet end and an outlet end of an intravascular tubular member;

[0091] FIG. **12**B is an isometric view of attachment anchors positioned at an inlet end and an outlet end of a straight intravascular folded tubular member;

[0092] FIG. **12**C is a partially sectioned view of attachment anchors positioned an inlet and outlet ends of a bifurcated intravascular folded tubular member;

[0093] FIG. **13**A is a perspective view of a woven vascular tubular member;

[0094] FIG. **13**B is a perspective view of a woven multifilament strand wall structure for a vascular tubular member;

[0095] FIG. **13**C is a perspective view of a woven monofilament strand wall structure;

[0096] FIG. **13**D is a perspective view of a multifilament strand formed of filaments;

[0097] FIG. **13**E is a perspective view of an expanded polytetrafluoroethylene filament;

[0098] FIG. **13**F is a perspective view of a straight multifilament strand formed of straight filaments;

[0099] FIG. **13**G is a perspective view of a curved multifilament strand formed of curved filaments;

[0100] FIG. **13**H is a perspective view of a curved expanded polytetrafluoroethylene filament formed of microfilaments;

[0101] FIG. **13**I is a perspective view of a vascular tubular member formed of expanded polytetrafluoroethylene strands;

[0102] FIG. **13**J is a perspective view of a wall structure formed of metallic strands woven along with polymeric multifilament strands;

[0103] FIG. **13**K is a perspective view of a straight monofilament strand;

[0104] FIG. **13**L is a perspective view of a curved monofilament strand;

[0105] FIG. **13**M is a perspective view of a woven wall structure of flattened metallic strands;

[0106] FIG. **14** is a representation of a vascular tubular member with a woven wall structure having straight axial metallic, straight axial polymeric, straight circumferential metallic, and straight circumferential polymeric strands;

[0107] FIG. **15** is a perspective view of double weaving at a metal to metal crossover point;

[0108] FIG. **16**A is a representation of a vascular tubular member with a woven wall structure having straight axial polymeric, straight circumferential polymeric, and straight circumferential metallic strands;

[0109] FIG. **16**B is a representation of a vascular tubular member with a woven wall structure having straight axial polymeric, curved axial metallic, straight circumferential polymeric, and straight circumferential metallic strands;

[0110] FIG. **16**C is a representation of a vascular tubular member with a woven wall structure having straight axial polymeric, curved axial metallic, straight circumferential polymeric, and curved circumferential metallic strands;

[0111] FIG. **17**A is a representation of a vascular tubular member with a woven wall structure having straight axial polymeric, curved axial metallic, curved circumferential polymeric, and straight circumferential metallic strands;

[0112] FIG. **17**B is a representation of a vascular tubular member with a woven wall structure having straight axial polymeric, curved axial metallic, curved circumferential polymeric, and curved circumferential metallic strands;

[0113] FIG. **17**C is a representation of a vascular tubular member with a woven wall structure having curved axial polymeric, curved axial metallic, curved circumferential polymeric, and curved circumferential metallic strands;

[0114] FIG. **18**A is a representation of a vascular tubular member with a woven wall structure having curved circumferential polymeric, straight circumferential metallic, curved axial polymeric, and straight axial metallic strands having a circumferential step-over;

[0115] FIG. **18**B is a representation of a vascular tubular member with a woven wall structure having curved circumferential polymeric, curved axial polymeric, straight circumferential metallic, and curved axial metallic strands with augmented helical turn;

[0116] FIG. **19** is a representation of a vascular tubular member with a braided wall structure having left and right spirals of multifilament polymeric and monofilament metallic strands;

[0117] FIG. **20** is a partially sectioned view of an intravascular tubular member formed of a woven wall structure with multifilament polymeric strands and axially directed metallic strands interwoven and a displaced attachment anchor;

[0118] FIG. **21** is an intravascular folded tubular member formed with a woven wall structure of multifilament polymeric strands interwoven along with monofilament metallic strands;

[0119] FIG. **22** is an intravascular folded tubular member formed with a woven wall structure formed entirely of multifilament polymeric strands;

[0120] FIG. **23** is a bifurcated intravascular folded tubular member formed of a woven wall structure of multifilament polymeric strands interwoven along with monofilament metallic strands and having attachment anchors at the inlet and outlet ends.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0121] The present invention is a vascular implant intended for use to repair injured arteries or veins of the body. Such injuries can include aneurysms, stenoses, diffuse atherosclerosis, traumatic injury, or other injury that requires vascular repair or bypassing of the vessel. The vascular implant includes a vascular tubular member that conveys blood flow from a region of the repaired blood vessel proximal to the vessel injury to a region distal to the vessel injury. The vascular tubular member is primarily intended to be an intravascular tubular member for intravascular use using percutaneous access to the interior of the vessel or a minimal surgical cutdown to access a blood vessel either proximal or distal to the injured vessel that is to be repaired. The intravascular tubular member is entered into the proximal or distal blood vessel in a smaller diameter nondeployed conformation and is delivered to the site of the vessel injury where it enlarges to a larger diameter providing a passage for blood flow. An embodiment of the present invention is an intravascular folded tubular member that also enlarges in length following delivery to the site of vessel injury. One intravascular repair application that is in particular need of improvement is the repair of aortic aneurysms and most common the repair is one involving the abdominal aorta. The present invention is well suited to provide improvements in treating abdominal aortic aneurysms although it can also be used effectively in the repair of vessels throughout the body. The intravascular tubular member can include an attachment means attached to the proximal end or distal end of the intravascular tubular member to hold the intravascular tubular member firmly into contact with the wall of the injured blood vessel, prevent blood leakage at the proximal end or distal end, and prevent distal migration of the intravascular tubular member. The vascular implant of the present invention includes an attachment means that can be used with other prior art intravascular devices in addition to the intravascular tubular member of the present invention. The vascular tubular member includes not only the intravascular tubular member but also includes a surgical vascular graft that can be implanted surgically for repair of vascular injury. A vascular tubular member can include other tubular members that can have a generally tubular shape and have application in the repair of blood vessels. A woven and braided wall structure is presented that has application to both surgical vascular grafts as well as intravascular tubular members. It is understood that the present invention is not limited to the embodiments presented in this disclosure. The present invention can also be applied to other tubular organs of the body besides blood vessels. Such tubular organs include but are not limited to the intestines, esophagus, trachea, bile ducts, or other ducts of the body.

[0122] FIGS. **1**A and **1**B show a side and frontal view of abdominal aortic aneurysms **5**. The abdominal aortic aneurysm **5** can be used as an example of an arterial injury that can be treated with one or more embodiments of the present invention. Distension of the abdominal aorta **10** often extends from distal to the left renal vein **15** to the common iliac artery **20**, external iliac artery **25**, common femoral artery **30** or to more than one artery. The left renal vein **15** follows a path anterior to the aorta from the left kidney **35** to the inferior vena cava **40**. The left renal vein **15** can provide some support to assist the abdominal aorta **10** from further distension proximal to the left renal artery **45** and right renal artery **50**. A blood flow native lumen **53** extends from the suprarenal aorta **55** through the distended abdominal aorta **10**, through the aorto-iliac bifurcation **57**, and into each common iliac artery **20**, each external iliac artery **25**, and each common femoral artery **30**. Thrombus **60** fills the cavity that exists between the blood flow native lumen **53** and the abdominal aortic wall **70**. Lumbar arteries **75** located on the posterior side of the aorta and other arteries of the region can be occluded due to the presence of thrombus **60** or may remain patent depending upon the severity of the aneurysm. Each internal iliac artery **80** is often patent and should be allowed to remain patent when repairing an abdominal aortic aneurysm **5** if possible. An embodiment of the vascular implant **82** of the present invention is shown in FIG. **1**A. The vascular implant **82** can include a vascular tubular member **83** that can be placed surgically within the native lumen or the vascular implant **82** can be an intravascular tubular member **85** that could have a bifurcation and could be placed percutaneously or with minimal surgical cutdown through a distal or other connecting vessel to reach the site of vessel injury as shown in FIG. **1**B. In FIG. **1**B the intravascular tubular member could have been inserted by a sheath placed in one of the common femoral arteries **30** and delivered to the abdominal aorta **10**. The intravascular tubular member **85** can have an attachment means **87** attached to it to help provide a seal between the intravascular tubular member **85** and the native lumen **53** and help reduce migration of the intravascular tubular member **85**. The vascular implant **82** can include the attachment means **87** which can be used with the intravascular tubular member **85** of the present invention or it can be used with other stent-graft devices. The intravascular tubular member **85** can be bifurcated with a bifurcation that extends from a proximal aortic neck **90** to each common iliac artery **20**, common femoral artery **30**, or other distal artery. The intravascular tubular member **85** can also have other configurations and embodiments which will be explained further in this disclosure.

Folded Tubular Members

[0123] A first embodiment of the present invention (see FIGS. **2**A-**2**D) is a straight intravascular folded tubular member **95** for repairing an arterial lesion, an aneurysm, or other vascular injury found in a blood vessel. The straight intravascular folded tubular member **95** is intended to provide a blood flow passage **100** from a region of the blood vessel proximal to the vascular injury to a region of blood vessel distal to the vascular injury. The preferred method of deploying the straight intravascular folded tubular member **95** is to insert it through a percutaneous access through a sheath as is well

known in the industry or with a small surgical cutdown to provide direct access to a blood vessel located either proximal or distal to the vascular injury.

[0124] FIG. **2**A shows the straight intravascular folded tubular member **95** in a radially deployed state with a radially deployed inlet end diameter **105**, a radially deployed outlet end diameter **110**, and a straight nondeployed tubular member length **115**. The straight intravascular folded tubular member **95** has a straight proximal tubular section **120**, a folded tubular section **125**, a distal tubular section **130**, an inner surface **135** and an outer surface **140**. The inner surface **135** and outer surface **140**, and intravascular tubular member wall **143** each extend continuously from an inlet end **145** through the straight proximal tubular section **120**, through the folded tubular section **125**, and through the distal tubular section **130** to an outlet end **148** of the folded tubular section **125**. The continuous intravascular tubular member wall **143** can have attachments between the straight proximal tubular section **120** and the folded tubular section **125** and between the folded tubular section **125** and the distal tubular section **130** although it is preferred to form the intravascular tubular member wall **143** with each of these sections joined contiguously from the same material without attachments between sections. The inner surface **135** of the straight proximal tubular section **120** and the distal tubular section **130** is a blood flow surface in contact with blood flow. A portion of the inner surface of the folded tubular section **125** is a blood flow surface in contact with blood flow. The straight proximal tubular section **120** has inlet end **145** that provides passage for blood flow into the straight proximal tubular section **120** and into the straight intravascular folded tubular member **95**. The straight proximal tubular section **120** has a straight nondeployed proximal tubular section length **150**. The straight proximal tubular section **120** is joined either contiguously or with an attachment to the folded tubular section **125**. The folded tubular section **125** is formed from a continuous tube that is folded back and forth upon itself to form three separate walls, a folded tubular section outer wall **155**, a folded tubular section center wall **160**, and a folded tubular section inner wall **165**. The folded tubular section inner wall **165** is joined either contiguously or with attachment to a straight proximal tubular section wall **170** to form a continuous wall. The folded tubular section **125** has a proximal circumferential fold line **175** and a distal circumferential fold line **180** and has a nondeployed folded tubular section length **185** extending from the proximal circumferential fold line **175** to the distal circumferential fold line **180**. The portion of the intravascular tubular member wall **143** that forms the folded tubular section **125** has an upstream end **187** and a folded tubular section downstream end **188**. The straight proximal tubular section wall **170** is joined to the folded tubular section upstream end **187** and the distal tubular section wall **190** is joined to the folded tubular section downstream end **188**. In the folded tubular section **125**, a portion of the inner surface **135** of the straight intravascular folded tubular member **95** is in apposition with another adjoining portion of the inner surface **135**. Similarly, in the folded tubular section **125** a portion of the outer surface **140** is in apposition with another adjoining portion of the outer surface **140**. The folded tubular section outer wall **155** is joined either contiguously or with an attachment to a distal tubular section wall **190** of the distal tubular section **130** to form a continuous wall. The distal tubular section **130** has an outlet end **148** to provide passage of blood flow out of the distal tubular section **130** and out of the straight intravascular folded tubular member **95**. The distal tubular section **130** has a nondeployed distal tubular section length **200** extending from the folded tubular section **125** to the outlet end **148**. The straight intravascular folded tubular member **95** has a straight nondeployed tubular member length **115** that extends from the inlet end **145** to the outlet end **148**. The straight intravascular folded tubular member **95** has a blood flow passage **100** which provides passage of blood flow from the inlet end **145** to the outlet end **148**. The distal circumferential fold line **180** is in contact with the blood flow passage **100** such that shear forces acting by the blood onto the inner surface **135** will not act to generate separation between the three walls of the folded tubular section **125**. The distal tubular section **130** has a nondeployed distal tubular section length **200** that can provide significant length in accordance with the length requirements for a specific vascular application. Alternately, it is understood that the nondeployed distal tubular section length **200** can be very short such that it includes essentially only the outlet end **148** without any significant length.

[0125] FIG. **2**B shows the straight intravascular folded tubular member **95** in a fully deployed state or in an implanted state with a radially deployed inlet end diameter **105**, a radially deployed outlet end diameter **110**, and a straight deployed tubular member length **205**. The inlet end **145** and outlet end **148** have been extended in axial position with respect to each other. To accomplish the longer straight deployed tubular member length **205** the folded tubular section **125** has unfolded such that its deployed folded tubular section length **210** is shorter in the fully deployed state or implanted state (see FIG. **2**B) than the nondeployed folded tubular section length **185** in the non-axially deployed state shown in FIG. **2**A. The straight deployed proximal tubular section length **215** and the deployed distal tubular section length **220** are longer in the deployed state as shown in FIG. **2**B than the straight nondeployed proximal tubular section length **150** and the nondeployed distal tubular section length **200**, respectively in the non-axially deployed state. It is possible for the deployed distal tubular section length **220** to have increased more in length than the straight deployed proximal tubular section length **215** as the straight intravascular folded tubular member **95** goes from a partially deployed state to a fully deployed state. Alternately, both the straight deployed proximal tubular section length **215** and deployed distal tubular section length **220** could have increased the same amount as the straight deployed tubular member length has extended from a partially deployed state to a fully deployed state as will be explained further later. All reference numerals correspond to those elements previously or otherwise described.

[0126] FIGS. **2**C and **2**D show cross sectional views of the straight intravascular folded tubular member **95** in a nondeployed state, a non-radially deployed state, or insertion state. The length of the straight intravascular folded tubular member in FIGS. **2**C and **2**D is the same as in FIG. **2**A. In one embodiment for delivering or inserting a self-expanding straight intravascular folded tubular member **95**, for example, an outer delivery sheath **225** holds the straight intravascular folded tubular member **95** with a smaller insertion diameter or nondeployed inlet end diameter **230** and with a smaller insertion diameter or nondeployed outlet end diameter **235**. To deliver the straight intravascular folded tubular member **95** to the site of the vascular injury, the delivery sheath **225** containing the straight intravascular folded tubular member **95** is entered into a vessel either proximal or distal to the vascular

lesion. Upon removal from the delivery sheath **225**, the straight intravascular folded tubular member **95** expands from the nondeployed state to form the partially deployed state with a larger radially deployed inlet end diameter **105** and radially deployed outlet end diameter **110** as shown in FIG. **2**A. Following delivery of the straight intravascular folded tubular member **95** to the site of the lesion, the straight intravascular folded tubular member **95** is extended from a straight nondeployed tubular member length **115** to an appropriate straight deployed tubular member length **205** representative of an implanted state. Mechanical dilitation of the tubular member can be further employed if needed such as with a balloon dilitation catheter to expand the straight intravascular folded tubular member **95** to its radially deployed inlet end diameter **105** and radially deployed outlet end diameter **110** to ensure that the straight intravascular folded tubular member has attained a larger deployed diameter **237** (see FIGS. **2**A and **2**B). The delivery sheath **225**, in addition to a balloon dilitation catheter, or other delivery system means can be used to deliver the straight intravascular folded tubular member **95** to the site of vascular injury and deploy it from a nondeployed state or insertion state with a smaller insertion diameter or nondeployed diameter to a deployed state or implanted state with a larger deployed diameter **237** or implanted diameter. The straight intravascular folded tubular member can also be a balloon-expandable device. In this case the straight intravascular folded tubular member, either with or without an attachment means can be mounted in a nondeployed state onto the balloon of a balloon dilitation catheter. Upon delivery to the site of the lesion, the balloon can be expanded to cause the straight intravascular folded tubular member to assume its radially deployed state.

[0127] FIG. **2**E shows a straight intravascular folded tubular member **95** in an unfolded state with a straight unfolded tubular member length **240** prior to forming the folded tubular section **125** shown in FIGS. **2**A and **2**B. The straight intravascular folded tubular member **95** can be formed out of any material used in vascular grafts, in stent-grafts, or implanted vascular conduits such as tubular expanded polytetrafluoroethylene (ePTFE), woven expanded polytetrafluoroethylene fibers, woven or knitted polyester, polyurethane, silicone, or other materials such as composite woven or braided materials presented later in this disclosure.

[0128] The straight intravascular folded tubular member **95** can have but is not required to have an attachment means **87** at the inlet and outlet end **148** as shown in FIG. **3**. This attachment means can be a prior art stent used for vascular implant. Such an attachment means **87** if present generally serves to hold the straight intravascular folded tubular member **95** in place and ensure a leak free fit with the native vessel proximal or distal to the vessel injury. The straight intravascular folded tubular member **95** can be placed within a blood vessel and with the inlet end **145** and outlet end **148** being attached to the native vessel using a separate prior art stent or attachment means of any type that is placed near the inlet end **145** and outlet end **148** to form an attachment with the native vessel. If appropriate, a surgical cutdown could be conducted and sutures used to hold the inlet end **145** and outlet end **148** of the straight intravascular folded tubular member **95** in place with a leak free seal. The straight intravascular folded tubular member **95** could also be formed from a material that maintained a tubular or cylindrical shape with an outward extending force and did not require an attachment means. Existing vascular graft materials including polyurethane, silicone, and others are capable of providing this characteristic and may not require an additional attachment means in some implant situations. Such implant situations include repair of blood vessels with luminal injury that would benefit by a vascular graft but with adequate vessel integrity and anatomy such that graft migration and sealing are not of acute concern.

[0129] It is often times preferable to include an attachment means **87** to ensure a tight seal between the straight intravascular folded tubular member **95** and the vessel wall and to prevent migration of the straight intravascular folded tubular member **95**. An attachment anchor **245** which is included in the present invention and is discussed in more detail later in this disclosure is shown attached to the inlet end **145** and outlet end **148** of the straight folded tubular member **95**. FIG. **3** shows the straight intravascular folded tubular member **95** in a deployed state with the attachment anchor **245** containing barbs **250** attached to the straight proximal tubular section **120** near the inlet end **145** with securing fibers **255** or other securing means. Almost any attachment means such as a stent found in the prior art can be used as the attachment means for the inlet end **145** and outlet end **148** of the straight intravascular folded tubular member **95**. The attachment anchor **245** of the present invention shown in FIG. **3** can provide more enhanced anchoring properties than found with other prior art attachment means and will be discussed later in this disclosure. The attachment anchor **245** with barbs **250** is positioned on the inner surface **135** of the straight intravascular folded tubular member **95** such that it forcibly holds the straight intravascular folded tubular member **95** outward against the vessel wall after the attachment anchor **245** has been deployed to a larger diameter. The attachment anchor **245** has barbs **250** that extend outward to provide enhanced anchoring of the straight intravascular folded tubular member **95** to the vessel wall. This anchoring helps to prevent migration of the straight intravascular folded tubular member **95** and in the case of abdominal aortic aneurysm repair can help to support the aortic wall from further aneurysmal dilitation. The attachment anchor **245** without barbs **250** is shown attached to the distal tubular section **130** at or near the outlet end **148** with securing fibers **255**. The attachment anchor **245** is positioned on the inside of the straight intravascular folded tubular member **95** such that it forcibly holds the straight intravascular folded tubular member **95** outward against the vessel wall. For ease of description, the straight intravascular folded tubular member **95** is shown with an attachment anchor **245** with barbs **250** attached to the straight proximal tubular section **120** and an attachment anchor **245** without barbs **250** attached to the distal tubular section **130**. Either the straight proximal tubular section **120** or the distal tubular section **130** could have the attachment anchor **245** with or without barbs **250** attached and still be within the teachings of the present disclosure.

[0130] Another embodiment of the present invention is a bifurcated intravascular folded tubular member **260** shown in FIGS. **4**A-**4**D and described collectively below. This embodiment is intended for vascular repair of a blood vessel trunk that has a bifurcation wherein one or both native vessel legs bifurcating off of the vessel trunk are also in need of repair. Blood flow from the common blood vessel trunk of the vessel proximal to the site of vessel injury into the bifurcated intravascular folded tubular member **260**. The bifurcated intravascular folded tubular member **260** has an inlet end **145** that provides passage for blood flow into the bifurcated intravascular folded tubular member **260** (see FIG. **4**B). The bifur-

cated intravascular folded tubular member **260** has two outlet ends **148** that provide passage for blood flow out of the bifurcated intravascular folded tubular member **260** into two distal vessels located distal to the vessel lesion. One common application for this embodiment is in the repair of abdominal aortic aneurysms where one or both common iliac, external iliac, or femoral arteries are involved in the aneurysmal dilation of the vessel wall. The bifurcated intravascular folded tubular member **260** has a bifurcated proximal tubular section **265** with an inlet end **145**, a bifurcated main trunk **270** joined either contiguously or with an attachment to two proximal leg tubes **275**. The bifurcated intravascular folded tubular member **260** has an inner surface **135** and an outer surface **140**. Each of the proximal leg tubes **275** are joined either contiguously or with an attachment to a folded tubular section **125**. Each folded tubular section **125** is joined either contiguously or with an attachment to a distal tubular section **130**. Each distal tubular section **130** has an outlet end **148** that provides passage for blood flow out of each distal tubular section **130** and out of the bifurcated intravascular folded tubular member **260**.

[0131] The bifurcated intravascular folded tubular member **260** is shown in a partially deployed state in FIG. **4**A. The inlet end **145** has a larger radially deployed inlet end diameter **105** and each outlet end **148** has a larger radially deployed outlet end diameter **110**. A continuous intravascular tubular member wall **143** extends from the inlet end **145** to each outlet end **148**. The continuous intravascular tubular member wall **143** can have attachments between the bifurcated proximal tubular section **265**, the folded tubular section **125**, and the distal tubular section **130** of the intravascular tubular member wall **143** or the intravascular tubular member wall **143** can be contiguous without attachments. The radially deployed bifurcated intravascular folded tubular member **260** has a shorter bifurcated nondeployed tubular member length **280** than the bifurcated deployed tubular member length **290**. The bifurcated intravascular folded tubular member **260** shown in this embodiment is similar to the straight intravascular folded tubular member **95** shown in FIGS. **2**A-**2**D except that the present embodiment has a bifurcated proximal tubular section **265** that is bifurcated and it has two folded tubular sections **125** joined to the bifurcated proximal tubular section **265** instead of one, each folded tubular section **125** being joined to a distal tubular section **130**. The structure of each folded tubular section **125** of the bifurcated intravascular folded tubular member **260** is the same as the structure of the folded tubular section **125** of the straight intravascular folded tubular member **95** shown in FIGS. **2**A-**2**E. Each folded tubular section **125** has a continuous tubular wall that is folded back and forth upon itself to form a folded tubular section inner wall **165**, a folded tubular section center wall **160**, and a folded tubular section outer wall **155**. In the folded tubular section **125** a portion of the inner surface **135** is in apposition with another portion of the inner surface **135**. In the folded tubular section **125** a portion of the outer surface **140** is in apposition with another portion of the outer surface **140**. Each folded tubular section **125** has a proximal circumferential fold line **175** to a distal circumferential fold line **180** and has a nondeployed folded tubular section length **185** extending between the proximal **175** and distal **180** fold lines. Each folded tubular section **125** has a wall with an upstream end **187** and a downstream end **188**. The wall of the bifurcated proximal tubular section **265** is joined to folded tubular section upstream end **187**, and the distal tubular section wall **190** is joined to the folded tubular section downstream end **188**. The bifurcated proximal tubular section **265** has a bifurcated nondeployed proximal tubular section length **285** and the distal tubular section **130** has a nondeployed distal tubular section length **200**. The nondeployed distal tubular section length **200** can have significant length to accommodate a variety of vascular applications with varying lengths of vascular injury. Alternately, the nondeployed distal tubular section **130** can have negligible length and the distal tubular section **130** can consist of the outlet end **148**. All reference numerals correspond to those elements previously or otherwise described.

[0132] FIG. **4**B shows the bifurcated intravascular folded tubular member **260** in a fully deployed state or implanted state, being deployed to both a larger radially deployed inlet end diameter **105**, a larger radially deployed outlet end diameter **110**, and a longer bifurcated deployed tubular member length **290**. During full deployment to a bifurcated deployed tubular member length **290**, the bifurcated proximal tubular section **265** extends in length to a bifurcated deployed proximal tubular section length **295**, the distal tubular section **130** extends in length to a deployed distal tubular section length **220**, and the folded tubular section **125** reduces in length to a deployed folded tubular section length **210**. This extension in length from a shorter bifurcated nondeployed tubular member length **280** to a longer bifurcated deployed tubular member length **290** is accomplished as the folded tubular section **125** unfolds an appropriate amount to achieve an appropriate bifurcated deployed tubular member length **290** for the bifurcated intravascular folded tubular member **260**. During the unfolding process it is possible for either the bifurcated nondeployed proximal tubular section length **285** or the nondeployed distal tubular section length **200** to extend more than the other tubular section length extends in forming the bifurcated deployed tubular member length **290**.

[0133] The bifurcated intravascular folded tubular member **260** is generally intended to be delivered to the site of a lesion such as an aortic aneurysm in a nondeployed or insertion state as shown in cross section in FIGS. **4**C and **4**D. FIG. **4**C shows a cross sectional view of the bifurcated intravascular folded tubular member **260** near the inlet end **145** in a nondeployed state; FIG. **4**D shows a cross sectional view of the bifurcated intravascular folded tubular member **260** near the outlet end **148** in a nondeployed state. A guidewire **298** is shown extending through one distal tubular section **130** of FIG. **4**D and through the center of the bifurcated proximal tubular section **265** in FIG. **4**C. The bifurcated intravascular folded tubular member **260** can also be mounted on a balloon dilitation catheter **300** (see FIG. **4**E) and delivery system capable of expanding the bifurcated intravascular folded tubular member **260** from a nondeployed state or insertion state to a larger deployed diameter **237** representative of the radially deployed state of FIG. **4**A or fully deployed state of FIG. **4**B. As an intravascular tubular member **85** of the present invention the straight intravascular folded tubular member **95** and the bifurcated intravascular folded tubular member **260** are intended to be delivered to the site of vascular injury with a smaller nondeployed diameter **305** that can easily fit within a small surgical access or percutaneous access in a blood vessel either proximal or distal to the vascular injury. Once the intravascular tubular member is delivered to the site of vessel injury it will expand out to larger deployed diameter **237** that is approximately equal to the diameter of the native vessel that is to be repaired. In one embodiment the bifurcated intravas-

cular folded tubular member **260** can be held with a smaller nondeployed inlet end diameter **230** and nondeployed outlet end diameter **235** by a delivery sheath **225**. For treatment of abdominal aortic aneurysm **5** the delivery sheath **225** containing the bifurcated intravascular folded tubular member **260** is generally introduced into one common femoral artery **30** and advanced proximally through the native lumen **53** of the common iliac artery **20** and abdominal aorta **10** to the proximal aortic neck **90** generally located just distal to the renal arteries **45** & **50** (see FIGS. **1**A and **1**B). The bifurcated intravascular folded tubular member **260** is released from the delivery sheath **225** such that the inlet end **145** is positioned distal to the renal arteries **45** & **50** and the bifurcated intravascular folded tubular member **260** expands to the radially deployed inlet end diameter **105**. This can be accomplished, for example, for a bifurcated intravascular folded tubular member that is self-expandable or has an attachment means attached to the inlet or outlet ends that is self-expandable. The delivery sheath **225** is removed delivering the bifurcated intravascular folded tubular member **260** to the abdominal aorta **10** in a partially deployed state as shown in FIG. **4**A. Alternately, the present invention can be made to expand from a nondeployed state of smaller nondeployed inlet end diameter **230** or nondeployed outlet end diameter **235** to a deployed state of larger radially deployed inlet end diameter **105** or radially deployed outlet end diameter **110** using a mechanical expansion device such as a balloon dilitation catheter **300**. In this case the bifurcated intravascular folded tubular member or the attachment means which can be attached thereto can be balloon-expandable. Each outlet end **148** of the two distal tubular sections is positioned at the appropriate location within the common iliac artery **20**, external iliac artery **25**, or common femoral artery **30**. This positioning causes each of the folded tubular sections to unfold to provide the appropriate lengths for each of the two deployed folded tubular section lengths **210**. The bifurcated intravascular folded tubular member **260** is then fully deployed and extends from a region of the abdominal aorta proximal to the vessel injury or aneurysm to two distal iliac or femoral arteries. The inlet end **145** of the bifurcated intravascular folded tubular member **260** provides passage for blood flow from the abdominal aorta proximal to the vessel injury into the blood flow passage **100** and each outlet end **148** providing passage for blood flow to each of two distal arteries located distal to the vessel injury. FIG. **4**F shows the bifurcated intravascular folded tubular member **260** in an unfolded state with a bifurcated unfolded tubular member length **315** as it might appear prior to forming each folded tubular section **125** found in FIGS. **4**A and **4**B. All reference numerals correspond to those elements previously or otherwise discussed.

[0134] An additional preferred embodiment of a bifurcated intravascular folded tubular member **260** is shown in FIG. **5** with an attachment anchor **245** or other attachment means **87** at the inlet end **145** and at each outlet end **148**. The attachment means **87** can be any barbed or non-barbed attachment means found in the prior art or device that can be used to anchor the ends of an intravascular tubular member. The attachment means **87** serves to hold the bifurcated intravascular folded tubular member **260** firmly against the vessel wall at its inlet end **145** and outlet end **148** to prevent migration, and reduce leakage between the bifurcated intravascular folded tubular member **260** and the native lumen **53** (see FIGS. **1**A and **1**B). The bifurcated intravascular folded tubular member **260** is not required to have an attachment means. A separate stent such as found in the prior art placed on the inner surface **135** at the inlet end **145** and outlet end **148** of the bifurcated intravascular folded tubular member **260** can be used to prevent migration and leakage. At the inlet end **145** an attachment anchor **245** of the present invention with barbs **250** similar to that shown in FIG. **3** can be attached. This attachment anchor **245** will be described in detail later in this disclosure. Securing fibers **255** or other securing means attach the attachment anchor **245** to the inner surface **135** of the bifurcated proximal tubular section **265** near the inlet end **145**. The attachment anchor **245** with barbs **250** can be short to allow it to be placed more accurately near the renal arteries without extending distally beyond the aortic neck into the aneurysmal space. The attachment anchor **245** shown allows an increased number of barbs **250** to be positioned along the circumference of the attachment anchor **245**. This increased number of barbs **250** allows the bifurcated intravascular folded tubular member **260** to be anchored well to the aortic wall to prevent leakage of blood, prevent migration, and may also provide some additional support to prevent further dilation of the abdominal aorta. An attachment anchor **245** without barbs **250** is attached to the inner surface **135** of each distal tubular section **130** at each outlet end **148** using securing fibers **255**. Each attachment anchor **245** either with or without barbs **250** can be constructed out of an elastic metal such as Nitinol, stainless steel, or other metal or metal alloy that provides the attachment anchor **245** with a self expanding characteristic. Alternately, the attachment anchor **245** can be formed out of a metal such as stainless steel, titanium, tantalum, platinum, or other metal or metal alloy that undergoes plastic deformation to attain a deployed attachment anchor diameter **320**.

Unfolding of Folded Tubular Section

[0135] It can be desirable for the folded tubular section **125** to unfold evenly or in a controlled manner without wrinkling as it moves from a nondeployed folded tubular section length **185** to a deployed folded tubular section length **210**. Furthermore it is desirable for the folded tubular section **125** (see FIG. **4**B) to remain at a constant deployed folded tubular section length **210** with the straight or bifurcated intravascular folded tubular member **95** & **260** in a fully deployed state. FIG. **6** shows the nondeployed state of the folded tubular section **125** including its junction to the straight proximal tubular section **120** and its junction to the distal tubular section **130**. This discussion applies equally well for the folded tubular section **125** joined to the bifurcated proximal tubular section **265** (see FIGS. **4**A and **4**B). As shown in FIG. **6** a bonding agent **325** can be applied to the portion of the outer surface **140** of the folded tubular section **125** that is in apposition with another portion of the outer surface **140** of the folded tubular section **125**. The bonding agent **325** can be an adhesive such as cyanoacrylate, epoxy, polyurethane, or other adhesive that would allow the bonded region to peel at the proximal circumferential fold line **175** preferential to the distal circumferential fold line **180** and allow expansion of the straight intravascular folded tubular member **95** from a straight nondeployed tubular member length **115** to a straight deployed tubular member length **205** as described earlier in FIGS. **2**A and **2**B. The adhesive would resist wrinkling of the folded tubular section center wall **160** due to relative movement or slippage of the folded tubular section center wall **160** with respect to the folded tubular section inner wall **165** or folded tubular section outer wall **155**. Placement of the bond-

ing agent **325** on the portions of the outer surface **140** of the folded tubular section **125** which are in apposition would not significantly affect thrombosis of the straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260** (see FIGS. **4**A and **4**B) since the outer surface **140** is not in contact with blood flow. Placement of the bonding agent **325** on the outer surface **140** of the folded tubular section **125** that is in apposition can allow the distal tubular section **130** to elongate preferentially to, or with a greater length change than, the straight proximal tubular section **120** or bifurcated proximal tubular section **265** (see FIGS. **4**A and **4**B) for the case of the bifurcated intravascular folded tubular member **260**. A bonding agent **325** that would not create thrombosis could also be applied to the portions of the inner surface **135** of the folded tubular section **125** that were in apposition. This would further reduce wrinkling of the folded tubular section center wall **160** and allow the folded tubular section **125** to unfold in a controlled manner, with unfolding providing for more even extension of the straight proximal tubular section **120** with respect to the distal tubular section **130**.

[0136] The unfolding of the folded tubular section inner wall **165**, folded tubular section center wall **160**, and folded tubular section outer wall **155** (see FIGS. **2**A and **4**A) can be seen more clearly in the schematic sectional drawings of FIGS. **7**A-**7**E which show folded tubular section walls **330** along with their junction to the straight proximal tubular section wall **170** and the distal tubular section wall **190**. It is understood that this teaching of unfolding applies equally well to each folded tubular section **125** found in the bifurcated intravascular folded tubular member **260** of FIGS. **4**A and **4**B. FIG. **7**A shows the folded tubular section **125** having the folded tubular section walls **330** with the outer surface **140** of the folded tubular section inner wall **165** in apposition with the outer surface **140** of the folded tubular section center wall **160**. The inner surface **135** of the folded tubular section center wall **160** is in apposition with the inner surface **135** of the folded tubular section outer wall **155**. Markers in the form of a circle **335**, square **340**, point-up triangle **345** and point-down triangle **350**, and rectangle **355** mark positions on the folded tubular section **125** of FIG. **7**A with a nondeployed folded tubular section length **185** for reference purposes. In FIG. **7**B the deployed folded tubular section length **210** has been reduced as the folded tubular section center wall **160** from the circle **335** to the rectangle **355** has unfolded to become the folded tubular section inner wall **165**. The straight deployed proximal tubular section length **215** has lengthened from the straight nondeployed proximal tubular section length **150** more than the deployed distal tubular section length **220** has increased from the nondeployed distal tubular section length **200**. This form of unfolding can generally occur when bonding agent **325** is placed only on portions of the inside surface of the folded tubular section **125** in apposition with another portion of inside surface. In FIG. **7**C the deployed folded tubular section length **210** has been reduced from FIG. **7**A as the folded tubular section center wall **160** from the rectangle **355** to the square **340** has unfolded to become the folded tubular section outer wall **155**. The deployed distal tubular section length **220** has lengthened more than the straight deployed proximal tubular section length **215** has lengthened. This form of unfolding can be generated by placement of a bonding agent **325** on portions or the outer surface **140** of the folded tubular section **125** in apposition with another portion of outside surface as described in FIG. **6**. In FIG. **7**D the deployed folded tubular section length **210** has been reduced from the nondeployed folded tubular section length **185** shown in FIG. **7**A as a portion of the folded tubular section center wall **160** has unfolded to become a portion of both the folded tubular section inner wall **165** and the folded tubular section outer wall **155**. The straight deployed proximal tubular section length **215** and the deployed distal tubular section length **220** have both increased. This form of unfolding can occur if the folded tubular section inner wall **165** and folded tubular section outer wall **155** unfold evenly. Placing an effectively similar bonding agent **325** on both the inner surface **135** and outer surface **140** can result in this even unfolding pattern. Similar results can occur with no bonding agent placed on the folded tubular section **125**. In FIG. **7**E the deployed folded wall section length has been reduced from FIG. **7**A. The folded tubular section center wall **160** has not unfolded but has rather wrinkled to allow the straight deployed proximal tubular section length **215** and the deployed distal tubular section length **220** to increase. The use of a bonding agent **325** as explained in FIG. **6** can enhance the ability of the straight intravascular folded tubular member **95** and bifurcated intravascular folded tubular member **260** of the present invention to unfold in a manner similar to the methods described in FIGS. **7**A-**7**D and not wrinkle in an uncontrolled manner as shown in FIG. **7**E.

[0137] FIG. **8** shows a folded tubular section **125** with holding pins **360** extending through the folded tubular section inner wall **165**, folded tubular section center wall **160**, and folded tubular section outer wall **155**. Following full deployment of the straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260** such holding pins **360** or other form of holding means can be placed to ensure that further elongation of the intravascular tubular member cannot occur. The holding pins **360** can be the same as the barbs **250** located on the attachment anchor **245** of the present invention.

Attachment Anchor

[0138] FIG. **9**A is an isometric view of an embodiment of the attachment anchor **245** of the present invention without barbs in a nondeployed state. FIGS. **9**A-**9**C will be discussed collectively. This attachment anchor **245** is similar to the attachment anchor shown in FIG. **5** except that the barbs **250** are not present. The attachment anchor **245** of the present invention is comprised entirely out of nodes **365** and struts **370** arranged in a ring structure. The attachment anchor **245** of the present embodiment is comprised of a series of nodes **365** and struts **370** arranged in a generally cylindrical shape. The axially oriented struts **370** are separated by interstrut openings **375**. Each of the nodes **365** include at least one hinge **380** and have an intranodal opening **385** that connects with one of the interstrut openings **375**. This attachment anchor **245** can be machined from a metal cylinder using machining techniques including mechanical machining, laser machining, chemical machining, electrochemical etching, electric discharge machining, and other machining methods. The metal used in the formation of the attachment anchor **245** can include stainless steel, Nitinol, tantalum, titanium, platinum, gold, or other metals or metal alloys. Nitinol, some stainless steel compositions, or other metals with elastic properties are suited to an attachment anchor **245** that is self-expandable; other stainless steel compositions, titanium, and other metals or metal alloys with plastic deformation properties can be suited to an attachment anchor **245** that is balloon-

expandable. The metal can be chosen to provide a high yield strength or have a high elastic modulus or Young's modulus that can provide the attachment anchor **245** with a high expansion force while maintaining a lower profile and a more supple feel in a crushing deformation. A crushing deformation tends to deform the generally cylindrically shaped attachment anchor **245** into an oval shape. The design of the nodes **365** and the struts **370** can be chosen to provide appropriate outward expansion forces by the attachment anchor **245** for a particular application. Typically a larger diameter and thicker walled blood vessel would require an attachment anchor **245** with greater expansion forces outward against the blood vessel wall than a smaller diameter, thinner walled blood vessel. The attachment anchor **245** must provide adequate outward expansion force to hold the intravascular tubular member of the present invention outward against the blood vessel wall without leakage, it must resist any compression forces offered by the blood vessel, and it must prevent migration of the intravascular tubular member. The attachment anchor **245** is a radially expandable vascular implant that can be a self-expandable attachment anchor **245** or a balloon-expandable attachment anchor **245**. The design of the node **365** can be altered to provide for a completely elastic deformation of the metal in the hinge **380** or to provide for plastic deformation of the metal in the hinge **380**. The intranodal openings **385** provide sites for attachment of securing fibers **255** (see FIGS. **3** and **5**) to the attachment anchor **245** in order to hold the attachment anchor **245** to a straight intravascular folded tubular member **95**, or to a bifurcated intravascular folded tubular member **260** as described in FIGS. **3** and **5**, or to any other tubular member or tubular means that is used as an intravascular graft or intravascular tubular member. The attachment anchor **245** of the present invention can be used with other prior art stent-graft devices to anchor such devices to a blood vessel. In a nondeployed state, the struts **370** are adjacent and parallel to each other and in direct apposition to each other to provide the closest position of struts **370** with respect to each other. This provides the attachment anchor **245** with an ability to attain the largest expansion ratio of attachment anchor diameters from a deployed state to a nondeployed state. The attachment anchor has a hinge width radius of curvature **386** (FIG. **9**B) which describes the radius of curvature with the direction of the radius of curvature aligned with the direction of the hinge width **420** (FIG. **9**C). The attachment anchor **245** has a nondeployed attachment anchor diameter **387**.

[0139] FIG. **9**A shows an isometric view of the attachment anchor **245** in a nondeployed state with a smaller nondeployed diameter **387** or insertion diameter and FIG. **9**B shows the attachment anchor **245** in a deployed state with a larger deployed attachment anchor diameter **380**. The strut length **390** remains constant from the nondeployed or insertion state to the deployed or implanted state. A deployed attachment anchor length **395** in an axial direction **398** is shorter than the nondeployed attachment anchor length **400** but the amount of length change is minimal due in part to the increased number of deformation sites or nodes **365** found in the present attachment anchor **245** in comparison to other prior art attachment devices. Additionally, the greater number of deformation sites or nodes allows each deformation site to undergo a smaller deformation with less attachment anchor length change. The interstrut openings **375** between the struts **370** in a circumferential direction **403** in a nondeployed state can be negligible and the struts **370** can be in direct contact with each other. The generally cylindrical shape of the attachment anchor has a generally cylindrical uniformly curved attachment anchor surface **404** formed by the struts **370** and nodes **365**. In addition, the attachment anchor can be deployed to a small deployment angle **405** of less than 60 degrees which further reduces the amount of attachment anchor length change in going from a nondeployed state to a deployed state. The deployment of the attachment anchor **245** to a smaller deployed angle **405** in comparison to other prior art attachment devices can be accomplished due to the greater number of nodes **365** found on the present attachment anchor **245**. Alternately, the attachment anchor **245** of the present invention can be deployed to a larger deployment angle **405** than other prior art attachment means formed with round wires due to the greater force that can be generated by the hinge **380** of the present invention in comparison to a round wire. This greater force can be generated due to the hinge design and due to the higher modulus material that can be used for the hinge. The larger deployment angle **405** can provide the present attachment anchor **245** with a greater expansion ratio of deployed attachment anchor diameter **320** to nondeployed attachment anchor diameter **387**. The attachment anchor **245** is deployed from a smaller insertion diameter or nondeployed attachment anchor diameter **387** in its nondeployed or insertion state to a larger deployed attachment anchor diameter **320** or insertion diameter in its deployed or implanted diameter. The ratio of deployed attachment anchor diameter **320** to nondeployed attachment anchor diameter **387** is maximized by positioning the struts **370** parallel and in apposition to each other in the nondeployed state.

[0140] FIG. **9**C is an enlarged isometric view of a portion of the attachment anchor **245** shown in FIG. **9**A. Each of the nodes **365** comprises the hinge **380** and two transition regions **410**. The hinge **380** has a hinge length **415**, a hinge width **420**, and a hinge radial dimension **425**. The strut **370** has a strut width **430**, a strut radial dimension **435**, and a strut length **390** as shown in FIG. **9**A. The hinge **380** has a greater hinge radial dimension **425** than the strut radial dimension **435** and the hinge **380** has a smaller hinge width **420** than the strut width **430**. Each of the transition regions **410** extends from the hinge **380** to the strut **370**. It has a transition width **440** that varies from the smaller hinge width **420** to the larger strut width **430** and a transition radial dimension **445** that varies from the larger hinge radial dimension **425** to the smaller strut radial dimension **435**. The transition regions **410** provides a smooth uniform transition of metal strength and conformation from each hinge **380** to each of the struts **370**. The struts **370** have a strut cross sectional area **447** that can be different from and varied independently from a hinge cross sectional area **448**. As shown in FIGS. **9**A and **9**B the attachment anchor **245** has a nondeployed attachment anchor perimeter **449** and a deployed attachment anchor perimeter **451**. The transition regions **410** have an abrupt transition region length **452** that is as short as possible without causing a discontinuity in cross sectional area in order to maximize the hinge length **415** and strut length **390**. The cross sectional areas of the transition regions are maintained to be larger than either the strut cross sectional area **447** or the hinge cross sectional area **448**.

[0141] An embodiment of the attachment anchor **245** is a self-expandable vascular implant that can be used with the straight intravascular folded tubular member **95**, bifurcated intravascular folded tubular member **260** of the present invention, or with any other intravascular tubular means that is used for intravascular repair of blood vessels. The hinge length **415**

can be long, extending approximately from one of the transition regions **410** to another as shown in FIG. **9**C and having a hinge length **415** equal to or greater than approximately twice the strut width **430**. For a self-expandable attachment anchor **245** with a long hinge length **415** several advantages are obtained over prior art attachment devices such as those formed from zig zag shaped wire. The long hinge length **415** provides a smaller drop-off of the expansion elastic force exerted outward against the vessel wall by the attachment anchor **245** as the attachment anchor **245** extends from a nondeployed state to a deployed state with an elastic deformation. This smaller drop-off of outward expansion force provides a similar outward force over a variety of diameters for which the same attachment anchor can be used. The attachment anchor **245** of the present invention can therefore exert a greater outward force in a fully deployed state as shown in FIG. **9**C than one with a shorter hinge length **415** and similar hinge width **420** and hinge radial dimension **425** and the same outward expansion force in a nondeployed state. In addition, the hinge **380** of the present attachment anchor **245** is responsible for generating the outward force, and the hinge **380** is positioned with significant circumferential direction **403**. The strut **370** does not significantly contribute to generating the outward expansion force generated by the attachment anchor **245**. The deployed or nondeployed attachment anchor length **395** & **400**, in substantially an axial direction **398**, can be smaller than other prior art or zig zag wire type attachment devices that provide similar outward expansion forces. This allows the attachment anchor **245** to form a more focused line attachment to the vessel wall consisting of a ring of small axial length in the axial direction **398** for contact between the attachment anchor **245** and the vessel wall or a focused attachment between the attachment anchor **245** and the vascular tubular member **85** that resides between the attachment anchor **245** and the blood vessel wall. Prior art zig zag wire attachment devices have a portion of the wire bent in a hair-pin turn and another portion that is not bent as significantly forming a wire strut. Prior art zig zag wire attachment devices generate a majority of their elastic outward force from the portion that is significantly bent. These prior art devices rely in part on the bending of the wire that is not significantly bent to generate the elastic force that is exerted outward against the vessel wall. These bending wires from zig zag wire attachment devices extend in significantly an axial direction **398** with a greater axial length than the struts of an embodiment of the present invention. The attachment anchor **245** of the present invention can be constructed with a smaller deployed attachment anchor length **395** than prior art devices and can be positioned closer to the renal vessels of the aorta with less chance of distal migration.

[0142] Alternately, the attachment anchor **245** of the present invention can be used with a mechanical expanding means such as the dilitation balloon of a balloon expansion catheter. The attachment anchor **245** can be forced to expand due to the dilitation balloon causing the metal located in the hinge **380** to deform plastically and hold the intravascular tubular member of the present invention or other intravascular stent-graft out against the aortic wall. The struts **370** for the balloon-expandable attachment anchor **245** do not contribute significantly to the outward expansion force generated by the hinge **380** of the attachment anchor **245**. The struts **370** transfer the outward expansion force generated by the hinge **380** from one node to another to the vessel wall to hold the vessel wall outward, provide a seal, and help prevent migration of the intravascular tubular member. The hinge **380** of the attachment anchor **245** can be adjusted in hinge length **415**, hinge width **420**, or in hinge radial dimension **425** to provide the necessary outward forces to hold the intravascular tubular member **85** of the present invention or other prior art intravascular stent-graft outwards against the aorta.

[0143] The attachment anchor **245** of this embodiment, whether a balloon-expandable attachment anchor or a self-expandable attachment anchor, has a single ring structure formed of nodes **356** and struts **370** with the struts **370** folded back and forth adjacent to each other in the nondeployed state. The hinge length **415**, width **420**, and radial dimension **425** provide an expansion deformation in the uniformly curved attachment anchor surface **404** that produces an outward expansion force exerted against the vessel wall or the intravascular tubular member wall **143** in its expanded state. The struts **370** transfer the forces generated by the hinges **380** to the vessel or intravascular tubular member wall **143**. The struts **370** do not deform within the uniformly curved attachment anchor surface **404** due to the larger strut width **430** in comparison to the hinge width **420**. If the attachment anchor **245** is subjected to a crush deformation such that it forms an oval attachment anchor surface **453**, the struts **370** will bend in a radial direction due to the relatively small strut radial dimension **435** with an elastic deformation. The strut length, width, and radial dimension all provide the strut with an ability to flex elastically during the crush deformation. The hinge will not deform in the radial direction upon exposure to a crush deformation due to the large hinge radial dimension **425** in comparison to the strut radial dimension **435**. A longer strut length **390** along with a fewer number of nodes will allow the attachment anchor **245** to have a greater percentage of the attachment anchor associated with the struts **370** in comparison to the hinges **380** and hence provide the attachment anchor with a greater flexibility in bending due to a crush deformation.

[0144] Other prior art attachment means including those with zig zag designs have a long axial length to reduce the number of zig zags that are used around their circumference and hence reduce the amount of volume occupied by the attachment means per axial length times the deployed diameter. Most zig zag designs in a nondeployed state consist of a series of hair pin turns connected by straight wire segments that are generally not parallel to each other. The hair pin turns have a radius of curvature that limits the number of hair pin turns that can be used or that will fit along a circumference of an attachment means. The attachment anchor **245** of the present invention has struts **370** that are generally parallel to each other and can be in direct apposition or contact with each other in a nondeployed state (see FIG. **9**A) and each hinge **380** is machined such that it is smaller in hinge length **415** than a curvature diameter for the hair pin turn for the attachment means of the prior art. The hinge length **415** can have a length of approximately twice the strut width **430**. The hinge conformation allows it to generate a larger outward force than that generated by prior art wire hair-pin turns formed with a similar curvature diameter. Therefore, many more nodes **365** of the present invention each with a hinge **380** can be placed around the circumference of the nondeployed attachment anchor **245**. This greater number of nodes **365** and accompanying struts **370** allows each of the struts **370** to be shorter in length than other prior art attachment means in order to achieve a specific expansion ratio of deployed diameter **237** to nondeployed diameter **238** and a specific outward force. The

presence of the hinge **380** allows the outward expansion force provided by the attachment anchor **245** within the uniformly curved attachment anchor surface **404** to be controlled by setting the hinge radial dimension **425**, hinge length **415**, and hinge width **420**. The expansion deformation occurs with the hinges deforming within the uniformly curved attachment anchor surface **404**. A higher strength metal can be used with the present hinge **380** allowing a greater outward expansion force to be exerted with a thinner hinge width **420** or with less metal volume per nondeployed hinge length **415** being used in the attachment anchor **245**. This provides a smaller attachment anchor diameter in the nondeployed state which can fit into a smaller diameter sheath. This outward expansion force is controlled independently from the crush force which is controlled by the strut dimensions.

[0145] A thin strut radial dimension **435** can provide the attachment anchor **245** with a flexibility to form an oval attachment anchor surface **453** when exposed to a crush deformation by allowing the thin struts **370** to bend in the radial direction in forming an oval shape as shown in FIG. **9**D. The oval attachment anchor surface **453** of FIG. **9**D that is found when the attachment anchor **245** is exposed to crush deformation is not found in the uniformly curved attachment anchor surface **404** which is maintained in a cylindrical shape during normal expansion deformation of the attachment anchor **245**. The result is that the attachment anchor **245** can fit into a small diameter delivery sheath **225** in its nondeployed or nonexpanded state yet has high expansion force and is flexible in crush deformation. This combination of properties is not possible with the round wire zig zag or other attachment means described in the prior art in which the expansion force and crush force of the attachment device are tied together. Alternately, it is further understood that the strut radial dimension **435** can be formed large enough such that the struts **370** will not flex easily if exposed to a crush deformation. In this case the attachment anchor will retain a substantially cylindrical shape with a uniformly curved attachment anchor surface **404** and will be resistant to forming an oval shape characteristic of crush deformation. The strut deformation due to crush is always an elastic deformation and is more easily deformed than the hinge in a radial direction.

[0146] The short attachment anchor length with a greater number of nodes **365**, and struts **370** allows the attachment anchor **245** to be placed such that it is more firmly anchored into healthy blood vessel with a more focal line of attachment to the vessel. For the example of the abdominal aortic aneurysm **5**, the attachment anchor **245** can be placed closer to the aortic neck and nearest to the renal arteries **45** & **50** in order to get a more firm anchoring into the aortic wall **70** and not into the thrombus **60** that lines the native lumen **53** for most of the lumen of the abdominal aorta **10** (see FIGS. **1**A and **1**B). The shorter length also provides an advantage for forming a better seal of the intravascular tubular member with the vessel wall. The shorter length and increased number of nodes **365** further allows more barbs **250** to be placed along the circumference of the attachment anchor **245**. This increase in number of barbs **250** (see FIGS. **3** and **5**) provides better attachment at an increased number of sites. The result is an increased ability to form a leak free seal between the native blood vessel and the inlet end **145** or outlet end **148** of any intravascular tubular member or other stent-graft device. Furthermore, the attachment anchor **245** with short length and with the increase number of barbs **250** is more likely to provide an intravascular tubular member or other stent-graft device of any type a greater resistance to distal migration.

[0147] For a self-expandable attachment anchor **245** an increase in hinge width **420** or hinge radial dimension **425** will increase the amount of outward force provided by the attachment anchor **245** for the same deployment angle **405** or amount of expansion deformation. Increasing the hinge length **415** will result in a smaller drop-off in outward force provided by the attachment anchor **245** as it expands from a nondeployed state to a deployed state. Therefore, by changing the dimensions of the hinge **380**, the outward force delivery characteristics of the attachment anchor **245** can be adjusted to provide the desired outward elastic expansion force. The strut width **430** and strut radial dimension **435** can be adjusted to provide struts **370** that will remain elastic during the expansion of the attachment anchor **245** or during crush deformation with greater flexibility due to bending to an arc with the radius of curvature in the direction of the smaller strut radial dimension **435** and more rigidity in the direction of bending of the larger strut width **430**. The small strut radial dimension **435** allows the attachment anchor **245** to be soft and pliable in a crushing type of deformation while maintaining a large expansion force in the circumferential direction **403** needed to hold the blood vessel outward with appropriate force and without leakage between the intravascular tubular member **85** and the vessel wall.

[0148] For a balloon-expandable attachment anchor **245** the dimensions of the hinge **380** can affect its ability to yield under the expansion force of the dilitation balloon and its ability not to yield under the forces applied to it by the aorta. Increasing the hinge width **420** and hinge radial dimension **425** will increase the amount of yield force that is required to expand the attachment anchor **245** from a nondeployed state to a deployed state; it will also increase the amount of yield force that must be exceeded for the aorta to collapse the attachment anchor **245**. Increasing the hinge width will reduce the amount of deployment angle **405** that is required before plastic deformation will occur and the hinge **380** will no longer return to its original position or equilibrium position with all external forces removed. Reducing the hinge length **415** will cause the metal in the hinge **380** to deform a greater extent during the expansion from the nondeployed state to the deployed state. The hinge **380** with a smaller hinge length **415** will have a greater tendency to undergo a plastic deformation for a smaller expansion deformation. The struts **370** for the balloon-expandable attachment anchor **245** also remain elastic during the expansion deformation as well as during crush deformation.

[0149] An increase in strut length **390** also increases the flexibility of the attachment anchor **245** in undergoing a crush deformation to an oval shape. Since the struts **370** are smaller in the radial dimension **435** than the hinge **425** or the transition region **445**, the struts bend more easily in the radial direction. Increasing the length **390** of the struts **370** provides a greater percentage of the attachment anchor **245** that is associated with the struts **370** in comparison with hinges **380** or transition regions **410** and therefore provides a greater flexibility in the radial direction during crush deformation.

[0150] An alternate embodiment for the attachment anchor **245** is shown in FIGS. **10**A and **10**B. FIG. **10**A shows the attachment anchor **245** in a nondeployed state with the attachment anchor **245** not expanded. FIG. **10**B shows the attachment anchor **245** after it has been expanded to a deployed state. The main difference between this embodiment and the

one presented in FIG. **9**A-**9**C is the shape of the nodes **365** and the presence of two hinges **455** on each of the nodes **365**. The nodes **365** and struts **370** are aligned in series in the same way as the embodiment shown in FIGS. **9**A-**9**C. Each node **365** of this embodiment is joined to two struts **370** and each strut **370** is joined to two nodes **365** in a manner similar to that shown for the embodiment of FIGS. **9**A-**9**C. All reference numerals correspond to those elements previously or otherwise described. A detailed isometric view of one of the nodes **365** plus a portion of two struts **370** is shown in FIG. **10**C. Each of the nodes **365** is comprised of a hub **457**, two hinges **455**, and two transition regions **410**. The hub **457** provides a less flexible portion of each node **365** to which the two more flexible hinges **455** can be joined. Deformation is substantially less or absent from the hub **457**. The transition regions **410** are similar in design and function to the transition regions **410** described in FIG. **9**C. The two hinges **455** perform a similar function as the single hinge **380** described in FIG. **9**C. Each of the hinges **455** has a smaller hinge width **420** and a longer hinge radial dimension **425** in comparison to the larger strut width **430** and shorter strut radial dimension **435**, respectively. The length of the transition region **410** is abrupt or short to conserve length that can be used as length for the struts **370** or the hinge **380**.

[0151] For a self-expandable attachment anchor **245** each of the hinges **455** is designed to deform elastically during the expansion of the attachment anchor **245** from a nondeployed state to a deployed state. A metal of very high yield strength and high elastic modulus can be used for the attachment anchor **245** of the present invention. A higher strength metal provides the attachment anchor **245** of the present invention with an ability to have all components or elements have a smaller radial dimension than other prior art attachment devices. Increasing the hinge radial dimension **425** and the hinge width **420** will provide an increase in the outward elastic expansion force provided by the attachment anchor **245** in holding the intravascular tubular member **85** of the present invention or other intravascular stent-graft against the aorta. Reducing the hinge length **415** will provide a larger outward force of the attachment anchor **245** against the vessel wall in the deployed state with a specific deployment angle **405** and provided that the hinge radial dimension **425** and hinge width **420** remain constant for comparison purposes. The hinge length **415** defines the region of the nodes **365** wherein the majority of the expansion deformation occurs. The hinge length **415** includes the region of each node **365** having a smaller hinge width **420** than the strut width **430** and that remains approximately constant in strut width **430** for a distance. The hinge length **415** can include a region of a minimum hinge width **420**. The hinge length **415** can be long such as the case shown in FIG. **9**C or it can be very short as the case shown in FIG. **10**C. With two hinges **455** associated with each of the nodes **365** it is possible to provide each of the hinges **455** of each of the nodes **365** with different dimensions and different expansion characteristics. The hub **457** can provide a site for forming a contiguous junction to a barb **250**. The two hinges **455** shown in FIG. **10**C can be easier to machine than a single hinge **380** as shown in FIG. **9**C.

[0152] For a balloon-expandable attachment anchor **245** an increase in the hinge radial dimension **425** will cause an increase in the yield force needed by a dilitation balloon to cause the attachment anchor **245** to expand and will increase the yield force necessary to cause collapse of the attachment anchor **245** due to compressive forces applied by the abdominal aorta or other treated artery on the deployed attachment anchor **245**. An increase in the hinge width **420** will cause the expansion deformation from a nondeployed state to a deployed state to cause more plastic deformation of the metal hinges **455** for a specific deployment angle **405** and will require a larger expansion deformation force. Increasing the hinge length **415** will reduce the amount of plastic deformation and reduce the rate of change in force for a particular expansion deformation or deployment angle **405**. Adjusting the hinge length **415**, hinge width **420**, and hinge radial dimension **425** allows the balloon-expandable attachment anchor **245** to be specifically designed to provide appropriate yield forces for a specific vascular application. This is not able to be accomplished with the wire zig zag or other attachment devices described by the prior art.

Stress Versus Strain

[0153] The stress versus strain relationship for a metal bar or beam such as a strut **370** or a hinge **380** & **455** can in general be estimated by Hooke's law which states that stress applied to the metal bar is equal to an elastic modulus times the strain or deformation to which the bar will deform. This elastic modulus or Young's modulus is a material property characteristic of the particular metal being used for the bar. The deformation can be a bending deformation that is characteristic of the expansion deformation encountered by the strut **370** or the hinge **380** & **455**. A bar in an unstressed state that is exposed to an applied stress below its elastic limit or yield stress will undergo an elastic flexure or elastic deformation which is reversible and the bar will return to its unstressed state upon removal of the applied stress. If the bar is exposed to an applied stress that is larger than its yield stress or if it is deformed to an inelastic flexure that is greater than its elastic limit or proportional limit, or if it is deformed beyond its yield point, plastic deformation will occur and the bar will not return to its original unstressed state with the original conformation or shape of the bar. The bar will generally return part way back to its initial unstressed state due to the elastic portion of the deformation.

[0154] Exposing a bar to a torque or moment can result in bending the bar from a straight shape to a bent conformation with a radius of curvature. The relationship between the applied moment and the radius of curvature can be estimated by the equation that states that moment is equal to Young's modulus times moment of inertia divided by radius of curvature. The moment of inertia is different for different cross sectional shapes of the bar that is being bent. For a bar having a circular cross section and having a diameter, the moment of inertia is given by Pi times the diameter to the fourth power divided by 64. For a rectangular bar cross section with one side of magnitude B and another side of magnitude H, where B is the magnitude of the side in the radial direction of the radius of curvature and H is the magnitude of the side perpendicular to B, the moment of inertia is given by B to the third power times H divided by 12. Similarly, the bar can be bent from one radius of curvature to a second radius of curvature with a similar type of analysis as described above by examining a change in radius of curvature that is comparable to that of starting from a flat surface as just described.

[0155] The hinge cross sectional area **448** is equal to the multiplication product of the hinge width **420** and the hinge radial dimension **425**. Each hinge **380** & **455** has a large hinge radial dimension **425** that does not allow for significant bending deformation along a radius of curvature with a radius

aligned along the hinge radial dimension. Bending deformation for each hinge **380** & **455** occurs to form a radius of curvature with the radius aligned with the hinge width **420**, and this radius of curvature is referred to as the hinge width radius of curvature **386**. The hinge can undergo an expansion deformation with bending occurring in the uniformly curved attachment anchor surface **404**. The moment of inertia for the hinge **380** & **455** can be estimated by using the hinge width **420** to correspond with the magnitude B and the hinge radial dimension **425** to correspond with the magnitude H. The strut cross sectional area **447** is equal to the multiplication product of the strut width **430** and the strut radial dimension **435**. The moment of inertia for each of the struts **370** can be estimated using the strut radial dimension **435** to correspond with the magnitude B and the strut width **430** to correspond with the magnitude H. In the attachment anchor **245** of the present invention the hinge cross sectional area **448** can be varied independently of the strut cross sectional area **447** to provide the attachment anchor **245** with a variety of expansion force characteristics and other properties. For example, the hinge width **420** and hinge radial dimension **425** can be equal to the diameter of a round wire and produce a moment that is 1.67 times larger than the round wire based on the equation for moment stated earlier. Thus for a similar magnitude of hinge width in comparison to the diameter of a round wire, the attachment anchor **245** in a nondeployed state can provide a greater outward extension force by the hinge **380** & **455** to the struts **370** than a circular cross sectional or round wire. The hinge radial dimension **425** can also be increased in magnitude to provide an even greater moment of inertia to the hinge **380** & **455** such that even larger moment is generated to produce larger extensional forces by the attachment anchor **245**. Increasing the hinge radial dimension **425** such that it is significantly larger than the hinge width **420** will also have a profound effect on increasing the moment of inertia for bending to a radius of curvature with the radius in the radial direction. Hence the hinges **380** will not allow bending to occur in the radial direction such as found in the struts **370** in forming an oval shape during crush deformation.

[0156] As another embodiment for the design of the attachment anchor **245**, the hinge radial dimension **425** can be formed such that it is approximately equal to the diameter of a prior art zig zag wire that is used as an attachment means and the hinge width **420** can be smaller that the diameter of the zig zag wire. In this embodiment the hinge **380** & **455** would undergo a smaller amount of localized deformation associated with a bend to a specific radius of curvature than the zig zag wire. The attachment anchor **245** could be formed out of a metal with a higher elastic modulus than the prior art zig zag wire attachment means without undergoing plastic deformation. The hinge **380** & **455** of the present attachment anchor **245** can thus produce an equal or greater moment than a round wire with a diameter larger than the hinge width **420** and remain elastic. This embodiment is particularly useful for a self expanding attachment anchor **245**.

[0157] For a balloon-expandable attachment anchor **245** the hinge length **415** can be shortened such that the bending deformation of the hinge **380** & **455** associated with expansion from the nondeployed state to the deployed state exceeds the yield point of the metal used to form the attachment anchor **245**. For a bending deformation of the hinge **380** & **455** from one hinge width radius of curvature **386** to another hinge width radius of curvature **386**, an increase in the hinge width **420** will also serve to increase the amount of hinge **380** & **455** material exposed to deformation beyond the yield point of the metal. Hence both hinge length **415** and hinge width **420** can be adjusted to provide inelastic flexure of the metal and plastic deformation. The hinge radial dimension **425** can be further adjusted to control the amount of force that is required to expand the attachment anchor **245** to a particular amount of deformation during deployment of the attachment anchor **245** and to control the amount of force exerted by the attachment anchor **245** against the vessel wall in its deployed attachment anchor diameter **320**.

[0158] The strut cross sectional area **447** can be different than the hinge cross sectional area **448** and can be varied independently from it. The strut width **430** is designed to be large enough such that during expansion of the attachment anchor **245** the struts **370** do not bend or flex significantly within the uniformly curved attachment anchor surface **404** of the attachment anchor **245** with a radius of curvature in a radial direction aligned with the strut width **430**. The hinge **380** & **455** can therefore transfer its moment to the strut **370** which then exerts an outward force upon the vessel wall to hold it outwards. Since the strut width **430** and strut radial dimension **435** provide a rectangular cross sectional shape for the strut **370** the strut width **430** can be smaller than the diameter of a round wire and provide a greater moment in resisting bending deformation to a radius of curvature with a radius in the direction of the strut width **430**. The struts **370** will not bend in within the uniformly curved attachment anchor surface **404** such as in the direction of their strut width **430**.

[0159] The strut radial dimension **435** is formed to be thinner than the hinge radial dimension **425** such that it can flex to form a radius of curvature with a radius aligned with the strut radial dimension **435**; this bending deformation is similar to a crush deformation that would cause the attachment anchor **245** to form an oval attachment anchor surface **453** rather than the cylindrical uniformly curved attachment anchor surface **404** that it normally has. The struts **370** would remain elastic due to its thin wall, due to a choice of metal such that the struts **370** do not exceed the elastic limit of the metal, and due to a longer strut length that distributes the bending along a longer length. The metal chosen for forming the attachment anchor **245** could be chosen from a high modulus material and still remain flexible to allow this bending deformation to form an oval shape due to the thin radial dimension. The prior art attachment means formed of a round wire or other prior art structures of high modulus could not provide a combination of a large outward extension force and a low or soft crushing force since the properties of the round wire or other prior art structures affect both the extension force and the crush force. With this embodiment of the present invention, an attachment anchor **245** could be formed entirely out of a high modulus metal with the hinge **380** & **455** providing a large moment for expansion deformation in the uniformly curved attachment anchor surface **404** and the strut **370** allowing the attachment anchor **245** to be bent to an oval shape to accommodate variations in the shape of the aorta or other blood vessel. The hinge **380** & **455** does not allow bending in the radial direction due to crush deformation forces and the strut **370** does not bend in the uniformly curved attachment anchor surface **404**.

[0160] The struts **370** can be increased in their radial dimension **435** to provide additional resistance to bending in crush deformation. The strut radial dimension is still maintained smaller than the hinge radial dimension **425** and smaller than the strut width **430**. The strut radial dimension

435 is not as large as the hinge radial dimension **425** such that the strut always flexes preferentially to the hinge in a crush deformation and the strut **370** is designed to flex elastically. The strut cross sectional area **447** has been altered independently of the hinge cross sectional area **448**. An increase in strut radial dimension **435** will provide the strut **370** with a resistance to additional bending to a radius of curvature with a radius aligned with the direction of the strut radial dimension **435**. This embodiment of the attachment anchor **245** will be resistant to crush deformation that would cause the attachment anchor **245** to form an oval shape. The strut radial dimension **435** is still less than the hinge radial dimension **425** and the strut remains elastic when exposed to crush deformation.

[0161] The strut length **390** for the attachment anchor **245** of the present invention can be small and thereby require a greater number of struts **370** with smaller strut length **390** in order to extend and provide contact with the vessel wall with an adequate outward expansion force. The increased number of struts **370** and shorter strut length **390** provides a more focused line of attachment of the attachment anchor **245** to the blood vessel wall. In the case of abdominal aortic aneurysm repair, the attachment anchor **245** can be placed closer to the renal arteries with a better attachment to the vessel wall proximal to the thrombus lining. In an expanded state of the attachment anchor **245**, the moment exerted by each hinge **380** & **455** is transmitted to a torque exerted by the strut **370** outward against the vessel wall. This outward torque can be resolved into a product of the outward force against the vessel wall and the strut length **390**. The hinge **380** & **455** can therefore transfer its moment to the strut **370** which then exerts an outward force upon the vessel wall to hold it outwards.

[0162] The present attachment anchor **245** can be optimally suited to provide a smaller strut length **390** and a greater number of struts **370** and nodes **365** in order to apply a specific outward force against the vessel or tubular member wall for a nondeployed attachment anchor perimeter **449** and a deployed attachment anchor perimeter **451**. Strut length has an effect upon the flexibility characteristics of the attachment anchor in a crush deformation mode. A longer strut length provides the attachment anchor with a greater percentage of the perimeter of the attachment anchor in a deployed state that is associated with the struts in comparison to the nodes. Since the struts are more flexible in a crush deformation than the nodes, longer strut length provides a greater flexibility in forming an oval shape. To provide an attachment anchor having longer strut length with the same crush flexibility as a shorter strut, the strut radial dimension would be increased to provide the appropriate bending moment in the radial direction. The strut width can be reduced to provide the appropriate resistance to bending in the attachment anchor surface during expansion deformation. The attachment anchor **245** has nodes with hinges **380** & **455** that are machined into the metal rather than having a wire formed into a loop such as found in prior art attachment means. Each hinge **380** & **455** can be machined with a smaller hinge width radius of curvature **386** than can be formed from a round wire of diameter similar in magnitude to the hinge width **420**. Furthermore the hinge **380** & **455** of the present invention can generate a greater moment than can be generated by a round wire as found in prior art attachment means. The struts **370** are similarly formed by machining to form struts **370** of approximately similar or smaller strut width **430** than the diameter of a round wire of similar strength or moment of inertia allowing the struts **370** to be aligned adjacent to each other or touching each other and parallel to each other in a close packed conformation in a nondeployed state. In a deployed state the present attachment anchor **245** can provide a greater outward force against the vessel wall due to the greater moment generated by each hinge **380** & **455**. The present attachment anchor **245** can be formed with a nondeployed attachment anchor length **400** that is less than approximately 0.20 to 0.30 inches for abdominal aortic aneurysm repair of an aorta with a deployed diameter **237** of approximately 25 millimeters and less than approximately 0.10 to 0.20 inches for an attachment anchor length **400** in vessels that are less than approximately 6 millimeters in diameter. The number of struts **370** along the deployed attachment anchor perimeter **451** of the attachment anchor **245** can be at least approximately 26 to 32 for abdominal aortic aneurysm repair of an aorta with a 25 millimeter diameter and at least approximately 14 to 20 for use in a vessel of approximately 6 millimeter diameter.

[0163] Alternately, the attachment anchor **245** of the present invention can be formed of large strut length **390** greater than approximately 0.3 inches, a thinner strut width **430**, and a larger strut radial dimension **435** and having a lesser number of struts **370** than the approximately 14 struts stated for the previous embodiment. The attachment anchor **245** of the present invention can be formed with any number of struts **370** and with any strut length **390** that is suited to a particular application. The hinge **380** & **455** of the present invention can provide a greater moment than the moment provided by prior art round wire zig zag attachment means and other prior art attachment means. Therefore the hinge **380** & **455** of the present invention can transfer a large torque to a strut **370** of larger strut length **390** than the length of other prior art round wire struts and provide a greater outward force against the blood vessel to hold it outward than a round wire attachment means. The attachment anchor **245** of the present invention can therefore be used to provide a short or a long strut length **390** with varying strut radial dimensions and strut widths. The number of struts **370** can similarly be varied such that an attachment anchor **245** with longer struts **370** can be formed with less struts **370** than other prior art attachment means.

[0164] The deployment angle **405** of the present attachment anchor **245** is generally intended to be small enough such that the change in nondeployed attachment anchor length **400** in a nondeployed state to a deployed attachment anchor length **395** in a deployed state does not affect the positioning of the attachment anchor **245** within the blood vessel prior to deploying it to a deployed state. A total deployment angle **405** of less than 60 degrees results in a change in the attachment anchor length from the nondeployed state to the deployed state of approximately 15 percent. The present attachment anchor **245** can be designed such that the hinge **380** & **455** will provide any deployment angle **405** from 1 to 80 degrees. To maintain a small change in attachment anchor length from a nondeployed state to a deployed state a deployed angle of less than 45 degrees can be attained by the present attachment anchor **245**. Alternately, in order to provide the attachment anchor **245** with the least number of nodes **365** and struts **370** while still providing for the greatest expanded deployed attachment anchor diameter **320**, it is desirable to provide a deployment angle **405** that is greater than 45 degrees. The hinge **380** & **455** of the present invention can be formed from a metal of large Young's modulus as stated earlier. The hinge

380 & 455 can be formed of a thin hinge width 420 and a long hinge length 415 such that the moment maintained by the hinge 380 & 455 will still be adequate even at a large bending deformation angle or deployment angle 405. Thus the hinge 380 & 455 of the present invention can supply adequate outward force at a deployment angle 405 greater than 45 degrees and up to 180 degrees.

[0165] The attachment anchor 245 of the present invention can have one or two hinges 455 positioned on each node 365. For the embodiment with two hinges 455, the hinges 455 can be equivalent to each other in dimension and perform similarly to having one larger hinge such as a single hinge 380 of another embodiment. Alternately, each hinge 455 on a particular node can be formed with a different hinge length 415 or hinge width 420 than the other. The moment that is generated by each hinge 455 after exposure to a similar bending deformation would therefore be different. The struts 370 joined via transition regions to each of the hinges 455 can be adjusted such that the strut lengths 390 are different. This embodiment of an attachment anchor 245 with struts 370 of different strut length 390 connected to the same node can apply a uniform force outward against the blood vessel wall although the longer strut could undergo a greater amount of bending deformation in a crush mode.

[0166] An alternate embodiment for the attachment anchor 245 of the present invention is shown in a nondeployed state in FIG. 10D and in a deployed state in FIG. 10E. The attachment anchor 245 is formed entirely out of nodes 365 and struts 370 arranged to form a ring with a cylindrical shape. The attachment anchor 245 of this embodiment has a uniformly curved attachment anchor surface 404 in its deployed state shown in FIG. 10D. The attachment anchor 245 of this embodiment has the same description and function for the hinges 455, hubs 457, and struts 370 as were described and shown in FIGS. 10A-10C. The hinges 455 have hinge dimensions that allow the hinges to undergo expansion deformation within the uniformly curved attachment anchor surface 404 but will not deform in a radial direction due to a crush deformation. The struts 370 have strut dimensions that allow them to bend elastically as the attachment anchor 245 bends to an oval shape during crush deformation but the struts 370 will not bend in the uniformly curved attachment anchor surface 404. Barbs 250 can be a component of any of the nodes 365 in a manner described for the embodiment shown in FIGS. 10A-10C. This embodiment can be a balloon-expandable or a self-expandable attachment anchor 245. The metal used to form the attachment anchor 245 along with the dimensions used for the hinge 455 determine whether a plastic deformation or an elastic deformation of the hinge 455 will occur during the expansion deformation from a nondeployed state to a deployed state as described earlier for the embodiment shown in FIGS. 10A-10C. This embodiment (see FIGS. 10D and 10E) of the attachment anchor 245 provides an improved stability in maintaining a cylindrical shape over the embodiment shown in FIG. 10A-10C due to the closed diamond shaped structure or closed configuration formed by the nodes 365 and struts 370 of the present embodiment in comparison to the series alignment of nodes and struts shown in the embodiment of FIGS. 10A-10C. All reference numerals correspond to those elements previously or otherwise described.

Attachment Anchor with Barbs

[0167] FIGS. 11A-11D shows another embodiment for the attachment anchor 245 of the present invention with barbs 250 joined to nodes 365 along an attachment anchor outside end 458. The node 365 of this embodiment as shown in FIGS. 11B and 11D include the hinge 380, the transition regions 410, and the barb 250. The barbs 250 can be contiguously joined to any portion of a node 365 including a hub 457 or a hinge 380 & 455. FIG. 11A shows the attachment anchor 245 of this embodiment in a nondeployed state or an insertion state. An isometric view of a portion of the attachment anchor 245 shown in FIG. 11A in a nondeployed state is shown in FIG. 11B. The barb 250 has been folded over into the intranodal opening 385 and is being held in a protected conformation by the struts 370 and the transition regions 410. FIG. 11C shows the attachment anchor 245 in a deployed or implanted state with barbs 250 extending outward to the side. An isometric view of a portion of the attachment anchor 245 shown in FIG. 11C is shown in FIG. 11D. As the struts 370 expanded during the deployment of the attachment anchor 245, they released the barb 250 allowing the barb 250 to extend outwards in its fully extended state. The barbs 250 of the present attachment anchor 245 are folded and protected when the attachment anchor 245 is in a nondeployed state. As the attachment anchor is expanded, the barbs 250 are completely released by the struts 370 such that they extend outward to their fullest extent. This is in contrast to the barbs of other prior art attachment means that are deployed an increasing amount as the attachment means is extended to a greater amount. The barbs 250 of the present invention are designed to deploy fully and extend outward once the attachment anchor 245 has been extended enough such that the struts 370 allow the barbs 250 to be released from its folded position as shown in FIG. 11B. When the attachment anchor 245 is expanded by either allowing it to self-expand or through expansion with a dilitation balloon, each of the barbs 250 is released by the struts 370 and transition regions 410 and the intranodal opening 385 and allowed to extend outwards. The barbs 250 provide anchoring of the attachment anchor 245 and the intravascular tubular member 85 of the present invention or other intravascular stent-graft to the aortic vessel wall or other arterial wall. Such anchoring can help to prevent migration of the intravascular tubular member and help to prevent further aneurysmal dilitation of the aorta. In a nondeployed state the barbs 250 are folded up such that they cannot catch or snag on the intravascular tubular member 85 or other intravascular stent-graft device or tissue components. The barbs 250 can be machined using mechanical, laser, electrochemical, or other machining techniques as described for machining the attachment anchor into the same metal tube that forms the attachment anchor 245. The barbs 250 can be machined such that they are continuous and contiguous with each node 365 without the need for an attachment of the barbs 250 to the nodes 365. The barbs 250 can be contiguous with the hinges 380 or with the hubs 454 if such hubs are present on the node. Each barb 250 is considered to be a component of the node 365. The strength of the barbs 250 is therefore increased and their resistance to stress cracking or fracture will be reduced. Attachment wires or barbs used in other prior art attachment devices have been attached by welding, brazing, or other techniques and have suffered problems with metal failure and fracture of the attachment wires. The present attachment anchor 245 does not have such welds, brazes, or other forms of attachment of the barbs 250 to the attachment anchor 245.

[0168] FIG. 12A shows the attachment anchor 245 attached near the inlet end 145 and near the outlet end 148 of an

intravascular tubular member **85**. The intravascular tubular member can be any surgical vascular graft, intravascular tubular member, other intravascular stent-graft, or other vascular tubular member that is in need of an attachment anchor **245** to hold either the inlet end **145** or the outlet end **148** of the vascular tubular member into contact with a native artery or vein. The intravascular tubular member **85** can be formed from ePTFE, knitted or woven polyester, polyurethane, silicone or any other material use in surgical vascular grafts, intravascular grafts, intravascular stent-grafts, or vascular conduits. The intravascular tubular member **85** can be a straight or bifurcated vascular graft, intravascular graft, or intravascular stent-graft. The attachment anchor **245** holds the intravascular tubular member outward against the native vessel wall, prevents leakage of blood between the vascular tubular member and the native lumen, and prevents distal migration of the vascular tubular member. The attachment anchor **245** can be attached to the intravascular tubular member with securing fibers **255**. Such securing fibers **255** can include sutures, polyester fiber, polytetrafluoroethylene fiber, metal wire, staples, biocompatible and biostable fiber, or other securing means. The securing fibers **255** can extend through and attach to any or all of the intranodal openings **385** found in the nodes **365** of the attachment anchor **245**. The attachment anchor **245** positioned at the inlet end **145** can have barbs **250** attached or the attachment anchor **245** can be one without barbs **250** as shown on the outlet end **148**. If the attachment anchor **245** has barbs **250**, the wall of the intravascular tubular member **85** or other prior art intravascular stent-graft can be attached to the attachment anchor **245** such that the barbs **250** can extend outward without snagging the intravascular tubular member, or other device component such as the delivery sheath **225** (see FIGS. **2**C, **2**D, **4**C, and **4**D). If the attachment anchor **245** does not have barbs **250** such as the attachment anchor **245** positioned, for example, at the outlet end **148**, the attachment anchor **245** can be attached to the wall of the intravascular tubular member such that it does not protrude beyond the outlet end **148**. The securing fibers **255** can extend through the intranodal openings **385** of the attachment anchor **245** without pinching or cutting the securing fibers **255**.

[0169] FIG. **12**B shows the attachment anchor **245** attached near the inlet end **145** and near the outlet end **148** of the straight intravascular folded tubular member **95**. The straight intravascular folded tubular member **95** can be the intravascular tubular member **85** shown in FIGS. **2**A-**2**D that can be in need of an attachment anchor **245** to hold either the inlet end **145** or the outlet end **148** of the straight folded intravascular tubular member **85** into contact with a native artery such as the abdominal aorta or with a vein. The attachment anchor **245** is held to the straight intravascular folded tubular member **95** with securing fibers **255** as described in FIG. **12**A. The attachment anchor **245** positioned at the inlet end **145** can have barbs **250** attached or the attachment anchor **245** can be one without barbs **250**. If the attachment anchor **245** has barbs **250**, the straight proximal tubular section wall **170** can be attached to the attachment anchor **245** such that the attachment anchor **245** extends beyond the inlet end **145** of the straight intravascular folded tubular member **95** and the barbs **250** can extend outward without snagging the straight intravascular folded tubular member **95**. If the attachment anchor **245** does not have barbs **250** such as the attachment anchor **245** positioned at the outlet end **148**, the attachment anchor **245** can be attached to the distal tubular section wall **190** of the straight intravascular folded tubular member **95** such that it does not protrude beyond the outlet end **148**. The securing fibers **255** can extend through the intranodal opening **385** of the attachment anchor **245** without pinching or cutting the securing fiber **255**.

[0170] FIG. **12**C shows the attachment anchor **245** attached near the inlet end **145** and near each outlet end **148** of the bifurcated intravascular folded tubular member **260**. The bifurcated intravascular folded tubular member **260** can be the bifurcated intravascular folded tubular member **260** shown in FIG. **5** that is in need of an attachment anchor **245** to hold either the inlet end **145** or the outlet end **148** of the bifurcated intravascular folded tubular member **260** into contact with a native artery such as the abdominal aorta. The attachment anchor **245** is held to the bifurcated intravascular folded tubular member **260** with securing fibers **255** as described in FIG. **12**A. It is preferred that the attachment anchor **245** positioned at the inlet end **145** may have barbs **250** attached although the attachment anchor **245** can be one without barbs **250**. If the attachment anchor **245** has barbs **250**, the wall of the bifurcated intravascular folded tubular member **260** can be attached to the attachment anchor **245** such that the attachment anchor **245** extends beyond the inlet end **145** of the bifurcated intravascular folded tubular member **260** and the barbs **250** can extend outward without snagging the bifurcated intravascular folded tubular member **260**. If the attachment anchor **245** does not have barbs **250** such as shown for each attachment anchor **245** that is positioned at each outlet end **148**, the attachment anchor **245** can be attached to the distal tubular section wall **190** of the bifurcated intravascular folded tubular member **260** such that it does not protrude beyond the outlet end **148**. The securing fibers **255** can extend through the intranodal opening **385** of the attachment anchor **245** without pinching or cutting the securing fibers **255**.

[0171] The straight intravascular folded tubular member **95** and bifurcated intravascular folded tubular member **260** with the attachment anchor **245** shown in FIGS. **12**B and **12**C have specific advantages that provide these embodiments with distinct advantages when used together. The straight intravascular folded tubular member **95** and bifurcated intravascular folded tubular member **260** can be in need of an attachment means **87** that is attached to the intravascular folded tubular member and provides for better attachment than that provided by other prior art attachment means. The straight intravascular folded tubular member **95** and bifurcated intravascular folded tubular member **260** with the attachment anchor **245** of the present invention provides the inlet end **145** and outlet end **148** with a more firm anchoring to the native vessel than with other prior art attachment means. The short nondeployed attachment anchor length **400** allows the attachment anchor **245** to be placed precisely where it is needed. For example, in the treatment of abdominal aortic aneurysm **5** it can be important to place the attachment anchor **245** as close as possible to the left renal artery **45** and right renal artery **50** where the abdominal aortic wall **70** is not distended (see FIGS. **1**A and **1**B). Other prior art attachment means with a longer length often can extend into the thrombotic lining of the aorta where it is not possible to provide a firm attachment to the vessel wall. The short deployed attachment anchor length **395** (see FIG. **9**C) allows the attachment anchor **245** of the present invention to have a greater number of nodes **365** positioned around the circumference to allow for a better attachment to the native vessel. The increased number of nodes **365** offers

the opportunity of the present attachment anchor **245** to have a greater number of barbs **250** attached. In a nondeployed state, the barbs **250** are protected such that snagging of the barb **250** on the intravascular folded tubular member or delivery sheath **225** (see FIGS. **2**C, **2**D, **4**C, and **4**D) is not possible. Upon deployment the increased number of barbs **250** provides an improved attachment to the vessel wall that can further reduce the chances for further aneurysm dilation and can reduce the chances for distal migration of the intravascular folded tubular member. Once the inlet end **145** of the straight intravascular folded tubular member **95** (see FIG. **12**B) or bifurcated intravascular folded tubular member **260** is attached to the native vessel proximal to the vessel injury using the attachment anchor **245** it is more likely to remain attached without migration as the outlet end **148** of each distal tubular section **130** is placed into appropriate location at a site distal to the vessel injury. Placement of the outlet end **148** causes each folded tubular section **125** to unfold and can place a force on the attachment anchor **245** at the inlet end **145** to move distally. Therefore the attachment anchor **245** of the present invention provides the necessary advantages to specifically improve the function of the straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260**. Furthermore, since the straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260** is a one-piece construction and not a modular system such as many prior art devices, blood leakage cannot occur except at an inlet end **145** or outlet end **148**. Placing the attachment anchor **245** at the inlet end **145** and at each outlet end **148** will provide a better seal of the intravascular folded tubular member with the native lumen of the blood vessel. This is due to the increased number of struts **370** (see FIG. **9**A) and nodes **365** that provide a more uniform force along the circumference of the intravascular folded tubular member. The resulting straight intravascular folded tubular member **95** and bifurcated intravascular folded tubular member **260** will provide a leak free one-piece intravascular folded tubular member that can isolate an aneurysm better than a multi-tubular modular system. Other prior art one-piece systems that cannot provide a positive length determination in situ as with the present intravascular folded tubular member. These prior art one-piece systems require an estimation of their length in comparison to the actual vessel lesion length prior to implant. This often results in placing the inlet end **245** or outlet end **148** in a vessel location that is either thrombus **60** laden, blocks a side branch vessel such as an internal iliac artery **80** in the case of abdominal aortic aneurysm repair (see FIGS. **1**A and **1**B), or is of inappropriate vessel diameter to match the diameter of the prior art device. The present straight intravascular folded tubular member **95** (see FIG. **12**B) or bifurcated intravascular folded tubular member **260** (see FIG. **12**C) can have its inlet end **145** and each outlet end **148** placed precisely after the intravascular folded tubular member has been delivered within the blood vessel. The inlet end **145** and outlet end **148** of the present intravascular folded tubular member can therefore be placed in a vessel location that is better able to form a leak free seal if it is combined with the improved attachment anchor **245** of the present invention.

Wall Structure

[0172] The wall structure for a surgical vascular graft, an intravascular tubular member, an intravascular folded tubular member, or other vascular tubular member, can be formed by weaving fibers or strands of polymeric material, metallic material, or other material to form a woven vascular tubular member **460** as shown in FIGS. **13**A-**13**M. The description of these figures and reference to individual components and their reference numerals will proceed together. The woven vascular tubular member **460** can have a tight tubular weave that will not leak blood serum or blood cellular elements after implant. Generally one or more circumferential fibers or circumferential strands **465** are woven with a gradual helical wind in a generally circumferential direction **470** and a plurality of axial fibers or axial strands **475** are woven in a generally axial direction **398** and interface or cross over the circumferential strands **465** as shown in FIG. **13**A. The axial strands **475** or circumferential strands **465** can be formed of a single filament or can be formed of many filaments **483** as shown in FIG. **13**B. Following the formation of the woven vascular tubular member **460** the axial strands **475** tend to reorient slightly to become perpendicular to the generally circumferential strands **465** and will have a small helical wind to them. In the weave of the strands the points where the generally circumferential strands **465** cross over the generally axial strands **475** will be referred to as crossover points **485** (see FIG. **13**A). The woven vascular tubular member **460** can be used as a surgical vascular graft for surgical implant or can be used as an intravascular tubular member **85** that can be delivered and implanted percutaneously or delivered through a delivery sheath **225** (see FIG. **4**D) placed in a blood vessel that was accessed through a small cutdown procedure to access the blood vessel.

[0173] Polymeric strands used to weave a woven vascular tubular member **460** can be formed of a single monofilament strand **490** and are referred to as polymeric monofilament strands **490** or monofilament fibers as shown in the woven monofilament wall structure of FIG. **13**C. A woven vascular tubular member **460** formed from polymeric monofilament strands **490** will have small gaps or leakage sites **495** for blood leakage at or near the monofilament strand crossover points **498**. The size of the leakage sites **495** is dependent upon the monofilament strand diameter **500** as well as how tightly they are packed. The size of the gaps or leakage sites **495** can be approximately as large as the monofilament strand diameter **500**. To prevent blood cellular elements from passing through the leakage sites **495**, the gaps cannot be significantly larger than the cellular elements found in the blood. With small leakage sites **495**, red blood cells and platelets can become trapped and create thrombosis that will prevent leakage from that gap or leakage site. Red blood cells are typically 8 micrometers in the larger diameter of the red blood cell. Monofilament strands **490** with a monofilament strand diameter **500** of only 8 micrometers would be too small, too weak, and impractical to weave or braid into a vascular graft, intravascular tubular member **460**, or woven vascular tubular member **460**. Fibers or strands formed from many smaller filaments **483** can form a multifilament strand **510** that will provide the necessary sealing at multifilament crossover points **513** of a multifilament strands **510** in generally the axial direction **398** with multifilament strands **510** in generally the circumferential direction **470**; these multifilament strands form a woven multifilament strand wall structure shown in FIG. **13**B.

[0174] A multifilament strand formed from approximately 3 to 100 filaments **483** will deform in the crossover points **485** and will seal the gaps or leakage sites **495** at or near crossover points **485** in a weave of the multifilament strands **510** as

shown in FIG. **13**B. A filament diameter **515** can range from approximately 1 to 200 micrometers and the multifilament strand diameter **520** or fiber diameter can range from approximately 0.001 to 0.040 inches (see FIG. **13**D). The multifilament strand **510** or fiber will have significant flexibility due to the small filament diameter **515** and the multifilament strand will have strength due to the presence of many filaments **483**. At the crossover points **485** the multifilament strands **510** will spread the filaments **483** out to form a more flattened cross section for the strand and this spreading out of the filaments **483** will reduce the size of the gap or leakage site **495** such that leakage of blood will not occur as shown in FIG. **13**B.

[0175] Polymeric strands can be formed from filaments **483** of expanded polytetrafluoroethylene (ePTFE), polyester, polyethylene terephthalate, polyurethane, silicone, or copolymers or block copolymers involving these polymers or filaments **483** formed from other polymeric materials that are suitable for implant within the body from the standpoint of biocompatibility, biostability, strength, flexibility, and other properties. An expanded polytetrafluoroethylene filament **525** (ePTFE filament **525**) as shown in FIG. **13**E is formed from paste extrusion and can be stretched under high temperature, and sintered at very high sintering temperature to increase the axial strength thereby forming an ePTFE filament **525** that is well suited to forming an ePTFE multifilament strand **510** that can be woven into the wall structure of the present invention. The wall structure for a vascular tubular member **83** includes the general material of construction, such as polymeric or metallic, and physical description of the wall such as woven or braided. Each ePTFE filament **525** can include one or more expanded polytetrafluoroethylene microfilaments **530** (ePTFE microfilaments **530**) within a cross section; such microfilaments tend to contain significant polymeric molecule orientation along its length which contributes to its excellent axial strength. An ePTFE filament **525** can contain nodal regions **535** of polytetrafluoroethylene which can provide sites of junction between ePTFE microfilaments **530** such that ePTFE microfilaments **530** are connected together with polytetrafluoroethylene to form a single ePTFE filament **525** that cannot be easily divided into individual ePTFE microfilaments **530** throughout the length of the ePTFE filament **525**. The expanded polytetrafluoroethylene multifilament strand **510** (ePTFE multifilament strand **510**) for use in weaving surgical vascular grafts, intravascular tubular members **85**, or other vascular tubular members **83** can have a multifilament strand diameter **520** (see FIG. **13**D) that ranges from approximately 0.001 to 0.040 inches, an expanded polytetrafluoroethylene filament diameter **540** (ePTFE filament diameter **540**) that ranges from approximately 1-200 micrometers, and an expanded polytetrafluoroethylene microfilament diameter **545** (ePTFE microfilament diameter **545**) that ranges from approximately 0.01 to 200 micrometers. The ePTFE multifilament strand **510** used in larger diameter surgical vascular grafts, intravascular tubular members, or vascular tubular members ranging in diameter from approximately 8 to 30 millimeters such as those used in abdominal aortic aneurysm repair has a preferred multifilament strand diameter **520** that ranges from approximately 0.003 to 0.040 inches, a preferred ePTFE filament diameter **540** that ranges from approximately 2.5 to 200 micrometers, and a preferred expanded polytetrafluoroethylene microfilament diameter **545** (ePTFE microfilament diameter **545**) that ranges from approximately 0.01 to 200 micrometers. In weaving a surgical vascular graft, intravascular tubular member, or vascular tubular member for coronary or other small diameter vascular applications with a smaller vascular tubular member diameter ranging from approximately a 3 to 6 millimeter diameter, for example, an ePTFE multifilament strand **510** can have a preferred multifilament strand diameter **520** that ranges from 0.001 to 0.020 inches, a preferred ePTFE filament diameter **540** that ranges from approximately 1 to 200 micrometers, and a preferred ePTFE microfilament diameter **545** that ranges from approximately 0.01 to 200 micrometers. An ePTFE multifilament strand **510** of the preferred embodiments contains at least three ePTFE filaments **525** or at least three ePTFE microfilaments **530** in order to provide adequate sealing at multifilament strand crossover points **513** and each filament is comprised of one or more microfilaments.

[0176] A surgical vascular graft or vascular implant **82**, intravascular tubular member **85**, or vascular tubular member **83** formed from weaving multifilament strands **510** of polyester or other polymeric material could have a wall structure for the vascular tubular member **83** of the present invention formed from multifilament strands **510** and filaments **483** with diameters having a similar range to that discussed above for the polytetrafluoroethylene multifilament strands **510** and ePTFE filaments **525**.

[0177] Polymeric multifilament strands **510** used in forming the woven wall structure of some embodiments of the present invention can extend along their linear axis **550** with a generally linear or straight shape forming straight multifilament strands **555** (see FIG. **13**F). The strands can be formed of straight filaments **560** that also have a linear or straight shape along their linear axis **550**. Polymeric multifilament strands **510** formed from such straight filaments **560** that are straight will not in general have significant stretch characteristics in the direction of their linear axis **550**. Alternately, polymeric multifilament strands **510** can be formed from curved filaments **570** that have a zig zag shape, a sinusoidal shape, helical shape, or some other form of curved shape extending in the direction of their linear axis **550** forming a curved multifilament strand **573** as shown in FIG. **13**G. A curved multifilament strand **573** formed from such curved filaments **570** will exhibit extension or stretch characteristics in the linear axis **550** direction of the fiber (see FIG. **13**G). The amount of zig zag or curved shape that can be formed into the curved filaments **570** is such that it can provide the curved multifilament fiber or curved multifilament strand **573** with a stretch amount ranging from approximately one to fifty percent of its length along its linear axis **550**. Such curved filaments **570** can be formed by thermal, chemical, or mechanical treatment of the filaments **483** of the strand to form a set shape found in the curved filaments **570** with at least some temporary memory of the set shape under normal conditions of use for the vascular or intravascular graft. A straight expanded polytetrafluoroethylene filament **575** (see FIG. **13**E) containing straight expanded polytetrafluoroethylene microfilaments **580** can be exposed to high temperature while fixing or holding a specific length along its axis **550** to generate a curved shape for the microfilaments as shown in FIG. **13**H. This specific length is shorter than its elongated length when exposed to axial stress. This high temperature is lower than the very high temperature used during the sintering step mentioned earlier. This process results in a curved expanded polytetrafluoroethylene filament **585** with curved expanded polytetrafluoroethylene microfilaments **590**. The curved shape for the curved ePTFE microfilaments **590** and curved

ePTFE filament **585** will not easily return to a straight shape unless exposed to high temperature while held under stress. Expanded polytetrafluoroethylene multifilament strands **510** formed from curved ePTFE filaments **585** that have curved ePTFE microfilaments **590** will provide significant axial stretch. Thermal treatment can also be applied to polyester multifilament strands **510** or to other polymeric multifilament strands **510** to form a curved filaments **570** and curved multifilament strands **573** using techniques known in the textile industry.

[0178] A surgical vascular graft, an intravascular tubular member **85**, or other vascular tubular member can be formed by weaving ePTFE multifilament strands **510** or other polymeric multifilament strands **510** into a tubular form. The multifilament strands **510** can either have straight ePTFE filaments **575** or curved ePTFE filaments **585** and weaving a vascular tubular member **83** out of curved multifilament strands **573** will give stretch characteristics in the direction or their linear axis **550** as they are woven in the axial direction **398**, circumferential direction **470**, or both directions (see FIGS. **13**B and **13**G). An embodiment of a vascular tubular member formed from ePTFE multifilament strands **510** of curved ePTFE filaments **585** is shown in FIG. **13**I. Curved multifilament strands **573** formed from curved ePTFE filaments **585** could be woven in the circumferential direction **470** (see FIG. **13**A) with straight multifilament strands **555** in the axial direction. Such a structure approximates the radial compliance found in native blood vessels and can provide improved healing at the junction sites of the vascular tubular member with the native vessel. Expanded polytetrafluoroethylene curved multifilament strands **573** can be woven in the axial direction **398** with straight multifilament strands **555** in the circumferential direction **470**. Such a wall structure can provide improved flexibility with excellent kink resistance. Curved multifilament strands **573** formed from curved ePTFE filaments **585** can be woven in each direction to provide a woven vascular tubular member **460** with stretch characteristics in both directions (see FIG. **13**I). Such a wall structure can have both radial and axial compliance and be resistant to kinking. Such a woven vascular tubular member **460** could be used for standard surgical arterial reconstruction, as a component of a stent-graft, or a the wall structure for and intravascular tubular member for treatment of vascular injury such as abdominal aortic aneurysm repair. A similar vascular tubular member can be woven from straight or curved polymeric multifilament strands **510** of polyester or other polymer to form a vascular tubular member similar to FIG. **13**I.

[0179] Circumferential strands **465** and axial strands **475** formed of metal material can be woven along with the multifilament polymeric strands **595** formed of filaments **483** of polymeric material in the generally circumferential direction **470**, the generally axial direction **398**, or both directions as shown in FIG. **13**J to form the woven vascular tubular member **460** shown in FIG. **13**A. Metallic strands **600** woven along with the polymeric strands **595** can be a metallic monofilament strand **490** of a circular cross section or metallic multifilament strands **510** formed from a plurality of smaller diameter metal filaments **483**. The metallic strands **600** can be formed out of stainless steel, Nitinol, tantalum, titanium, an alloy of these metals, other metal used in the formation of implanted stents, or other metal capable of being implanted and having adequate strength to support the stresses found in a surgical vascular graft, intravascular graft, or vascular tubular member. The metallic strands **600** can have a generally linear or straight shape in the direction of their linear axis **550** forming metallic straight monofilament strands **605** or metallic straight multifilament strands **555** (see FIGS. **13**K and **13**F). In a preferred embodiment the metallic strands **600** are metallic monofilament strands **490** and are woven along with the multifilament polymeric strands **595** to form a wall structure for the woven vascular tubular member **460** as shown in FIG. **13**J. At the metal to metal crossover points **610**, leakage sites **495** can be created that could allow blood leakage out of the woven vascular tubular member **460** formed of the wall structure of this embodiment.

[0180] Alternately, the metallic strands **600** can be bent or formed by mechanical, chemical, or thermal methods into a zig zag, sinusoidal, helical, or other curved shape forming a metallic curved monofilament strand **615** or a metallic curved multifilament strand **570** as shown in FIGS. **13**L and **13**G. The metallic curved monofilament strand **615** has a direction of its linear axis **550** determined by the overall direction of the curved monofilament strand **615** along its length. The metallic curved monofilament strand **615** is able to extend in a generally linear axis **550** direction by an amount that ranges from one to fifty percent of its generally axial length. The metallic monofilament strand diameter **500** or multifilament strand diameter **520** can range from 0.001 to 0.020 inches. The metallic monofilament strand **490** can provide an outward expansion force to the wall structure of the woven vascular tubular member **460** and provide resistance to axial compressive forces generated by the native tissue surrounding the woven vascular tubular member **460**.

[0181] The wall structure as shown in FIG. **13**J for a surgical vascular graft, intravascular graft, an intravascular folded tubular member, or a vascular tubular member **83** used in the treatment of abdominal aortic aneurysm or the treatment of other large diameter vessels with a diameter of 8 to 30 millimeters, the metallic monofilament strand diameter **500** (see FIG. **13**C) is preferably approximately 0.003 to 0.020 inches. For a vascular graft or intravascular graft for treatment or coronary vessels or vessels less than 6 millimeters, the preferred metallic monofilament strand diameter **500** or metallic multifilament strand diameter **520** is approximately 0.001 to 0.016 inches. The presence of metallic strands **600** in the circumferential direction **470** (see FIG. **13**J) provides the surgical vascular graft, intravascular tubular member **85**, or vascular tubular member **83** made from this wall structure with the property of exerting an outward force against the native vessel, holding the native vessel outward in an open and patent conformation, and resisting against vessel contraction due to tissue scarring and healing. Due to the circumferential direction **470** of some of the metallic strands **600**, the amount of outward extensional force generated by a metallic strand **600** of smaller diameter is greater than that provided by a larger diameter but more zig zag or bent metallic strands such as those disclosed in prior art stent-graft devices. The metallic strands **600** in the axial direction **398** provide the surgical vascular graft, or intravascular graft formed from this wall structure with resistance to compressive length changes. The intravascular tubular member **85** or vascular tubular member **83** as shown in FIGS. **2**A, **2**B, **4**A, **4**B, and in other embodiments can have a woven wall structure as described in the embodiments of FIGS. **13**A-**13**M and can undergo a change in diameter from a smaller or nondeployed diameter **305** in its nondeployed state as it is being inserted into the vascular system to a larger or deployed diameter **237** in its

deployed state after it is implanted in the appropriate location. The woven vascular tubular member **460** (see FIG. **13**A) of the present invention can be formed entirely out of woven metallic strands **600**.

[0182] In a preferred embodiment, metallic strands **600** formed of straight **605** and curved **615** monofilaments of metallic material are woven along with the multifilament polymeric strands **595** in either the axial direction **398**, the circumferential direction **470**, or both directions as shown in FIG. **13**J. When metallic strands **600** are woven along with the multifilament polymeric strands in the circumferential direction **470** as shown in FIG. **13**J, the number of metallic strands per length of woven vascular tubular member **460** can range from one metallic strand **600** approximately every 0.060 inches to one metallic strand **600** every 1.5 inches. It is preferred to place a metallic strand **600** in the circumferential direction **470** approximately every 0.10 to 0.90 inches along the length of the woven vascular tubular member **460**. For the metallic strands **600** in the axial direction **398**, the spacing range between metallic strands **600** in the circumferential direction **470** is the same as the spacing range along the axial direction **398** of the woven vascular tubular member **460** with a wall structure as shown in FIG. **13**J. This spacing for metallic strands applies to the wall structures which are shown in FIGS. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, and **18**B.

[0183] The metallic strands **600** can be formed of a metal with a high yield strength that will remain elastic during the deployment of the intravascular tubular member from the nondeployed state to the deployed state. The high yield strength metallic strands **600** will provide the intravascular graft with a self-expandable property. Such an intravascular tubular member can be contained completely within a delivery sheath **225** (see FIGS. **2**C, **2**D, **4**C, and **4**D) during the delivery of the intravascular tubular member **85** to the site of the vessel lesion that is to be treated by the intravascular tubular member. Upon release of the self-expandable intravascular tubular member **85** from the delivery sheath **225**, it expands outward to its vascular tubular member deployed diameter **237** and the woven wall structure of the present invention is placed into contact with the native vessel or thrombus.

[0184] Alternately, the metallic strands **600** shown in FIG. **13**J can be formed from a metal with a yield strength that will allow plastic deformation to occur during the deployment of the woven intravascular tubular member **460**. This embodiment of the woven intravascular tubular member **460** formed of this wall structure can be expanded internally by a mechanical expanding means such as a balloon of a balloon dilitation catheter to force the intravascular tubular member **85** to expand from its smaller vascular tubular member nondeployed diameter **238** to a larger vascular tubular member deployed diameter **237**. The metallic strands of this embodiment undergo a plastic deformation during the deployment from the vascular tubular member nondeployed diameter **238** to the vascular tubular member deployed diameter **237** as shown in FIGS. **2**B, **2**C, **4**B, and **4**D.

[0185] The metallic strands **600** used in the wall structure of the present invention as shown in FIG. **13**J can be flattened metallic strands **620** with approximately a rectangular cross sectional shape (see FIG. **13**M). The advantages of this form of metallic strand is that it provides a closer packing with another flattened metallic strands **620** at a flattened crossover point **623** in a weave that contains flattened metallic strands **620** with a smaller gap and smaller leakage site **495**. The flattened metallic strands **620** can be woven along with multifilament polymeric strands **595** as shown in FIG. **13**J such that minimal blood leakage will occur at crossover points. Flattened metallic strands **620** can be more difficult to weave than round strands due to required orientation of the flattened strands during weaving.

Woven Wall Structure

[0186] The woven wall structures shown in the embodiments shown in the following figures, FIGS. **14**, **15**, **16**A-C, **17**A-C, **18**A and **18**B apply to a vascular tubular member **83** that can be implanted as a surgical vascular graft, as an intravascular tubular member **85** without a folded tubular section **125**, as an intravascular folded tubular member including a folded tubular section **125**, or as any other vascular tubular member. The intravascular tubular member can be a straight intravascular folded tubular member **95**, a bifurcated intravascular folded tubular member **260**, or a straight intravascular tubular member, without a folded tubular section **125** or a bifurcated intravascular tubular member without a folded tubular section **125**. The woven tubular structures of the present invention are intended to be formed without a seam and are therefore seamless. It is further understood that a woven material of the wall structure described in this invention could be formed of a flat woven wall structure that is then formed into a straight or bifurcated tube with a wall structure as described. These figures are intended to represent various combinations of multifilament strands **510** and monofilament strands **500** of metallic material or polymeric material with a straight or curved conformation used to form the wall structure of the present vascular tubular member **83**. The actual woven structures showing woven strands of various types is shown in FIGS. **13**A-**13**M. It is further noted that the circumferentially oriented strands actually are woven with a helical wind as discussed earlier. This helical wind can be gradual so that it appears as a generally circumferentially wound strand as shown in these figures. It is understood that the circumferential strands **465** or circumferentially oriented strands can have a significant helical wind to them. This significant helical wind is accomplished by winding more than one strand or several strands in the circumferential direction **470** at the same time. An even greater helical wind can be accomplished in the circumferential direction by generating a double helical wind with each helix involving several strands. A double helix can be formed, for example by introducing circumferential strands into the tubular weave from two positions located 180 degrees apart. Axial strands tend to orient themselves such that they are perpendicular to the circumferentially oriented strands giving the axial strands a helical wind or turn to them.

[0187] The present invention for a vascular tubular member **83** includes the wall structure for the vascular tubular member. The woven wall structures shown in FIGS. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, **18**B, **20**A-**20**D, **21**, **22**A, **22**B, and **23** are included in the preferred embodiments of this invention. The strands that are of a polymeric material used to form these wall structures are woven with only multifilament strands **510** of polymer material. Polymer material can be any of the polymers indicated including ePTFE, polyester, or other suitable polymer material. The multifilament strands **510** can be woven in either a generally axial direction **398** or a generally circumferential direction **470**. These multifilament strands of polymeric material can be formed of filaments **483** that are either curved filaments or straight filaments; and hence the multifilament strands **510** of polymeric material will be

referred to as curved axial polymeric strands **625**, curved circumferential polymeric strands **630**, straight axial polymeric strands **635**, and straight circumferential polymeric strands **640**. The present invention for a vascular tubular member **83** includes a wall structure that can be formed from woven metallic strands **600**. The metallic strands **600** can be metallic monofilament strands **490** or metallic multifilament strands **510**. In the preferred embodiments of the above indicated figures, FIGS. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, **18**B, **19**, **20**A-**20**D, **21**, **22**A, **22**B, and **23**, the metallic strands are metallic monofilament strands **490** woven along with the multifilament strands **510** of polymeric material in either the axial direction **398**, circumferential direction **470**, or both directions forming monofilament strands **490** of metallic material. The monofilament strands **490** of metallic material can be formed of straight monofilament strands **605** or curved monofilament strands **615** and hence the monofilament strands **490** of metallic material will be referred to as curved axial metallic strands **645**, curved circumferential metallic strands **650**, straight axial metallic strands **655**, and straight circumferential metallic strands **660**.

[0188] The wall structures described in FIGS. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, **18**B, and **19** can all be applied as a vascular tubular member **83** that is suitable for vascular surgery, as an intravascular tubular member **85** that is suitable for intravascular implant either with percutaneous access or with a small surgical cutdown in an adjoining vessel either proximal or distal to the site of vascular injury. As an intravascular tubular member **85**, it can be used without an attachment means as shown in these drawings, or it can be used with any attachment means found in the prior art, or with the attachment anchor **245** disclosed earlier in this disclosure as a part of this invention. The wall structures can be formed into a straight intravascular folded tubular member **95**, or a bifurcated intravascular folded tubular member **260** as shown in FIGS. **2**A, **2**B, **4**A, and **4**B. Each vascular tubular member presented has an inlet end **145**, an outlet end **148**, an inner surface **135**, an outer surface **140**, a vascular tubular member wall **662**, and a wall thickness **663**.

[0189] FIG. **14** shows an embodiment for the wall structure for the surgical vascular graft, the intravascular tubular member **85**, or the vascular tubular member **83** of this invention. All reference numerals correspond to those elements previously or otherwise described. This structure has straight axial metallic strand **655** and straight circumferential metallic strands **660** woven along with straight axial polymeric strands **635** and straight circumferential polymeric strands **640**. The straight axial polymeric strands **635** or straight circumferential polymeric strands **640** tend to seal polymer to polymer crossover points **665** between these strands and can effectively seal polymer to metal crossover points **670** such as between a straight axial polymeric strand **635** with a straight circumferential metallic strand **660**. The straight circumferential metallic strands **660** provide outward force of this tubular member against the aortic wall in it deployed state. The straight circumferential metallic strands **660** help to resist kinking by helping to maintain a round cross section. The straight axial metallic strands **655** provide the tubular member with strength in the axial direction **398** to overcome compressive forces that may act to reduce its axial length. The straight axial metallic strands **655** enhance the ability of the folded tubular section **125** of a straight **95** or bifurcated **260** intravascular folded tubular member to unfold easily without wrinkling of the folded tubular section center wall **160**. The presence of the straight axial metallic strands **655** generates axial stiffness in the tubular member causing it to be less flexible in negotiating tortuous turns found in the iliac, femoral, and other arteries of the body.

[0190] FIGS. **14** and **13**J show a metal to metal crossover point **610** of a straight circumferential metallic strand **660** with a straight axial metallic strand **655**. FIGS. **14** and **13**J will be used as an example to describe the process of forming a double weave. It is understood that the double weave can be equally well applied to any wall structure that involves a metallic strand **600** crossing over another metallic strand **600**. To prevent leakage from occurring at gaps or leakage sites **495** of such metal to metal crossover points **610** a tubular double weave is created as shown in FIG. **15**. For example, in the axial direction **398** both the straight axial polymeric strands **635** and the straight axial metallic strands **655** are woven together in the weave plane **675** to the left of the metal to metal crossover point **610**. Near the metal to metal crossover point **610** the straight axial metallic strands **655** are brought out of the weave plane **675** and above the straight circumferential metallic strand **660** and back into the weave plane **675** to the right of the metal to metal crossover point **610**. Underneath the straight axial metallic strands **655** at the crossover point the straight axial polymeric strands **635** are woven with the straight circumferential polymeric strands **640** and the straight circumferential metallic strand **660** such that a continuous woven layer **680** is located beneath the straight axial metallic strand **655** that was brought out of the weave plane **675**. The result is a leak free wall structure with metallic strands being woven in two directions, axial direction **398** and circumferential direction **470**.

[0191] FIG. **16**A shows another embodiment for the wall structure of the present invention. In this embodiment straight circumferential polymeric strands **640** and straight circumferential metallic strands **660** are woven circumferentially and only straight axial polymeric strands **635** are woven axially. This embodiment does not have the axial compressive force capability described in the embodiment of FIG. **14** but it has excellent kink resistance due to the straight circumferential metallic strands **660** and has excellent flexibility through tortuous turns since only the flexible polymeric strands are positioned axially.

[0192] FIG. **16**B shows still another vascular tubular member wall structure with a curved axial metallic strand **645** woven along with a straight axial polymeric strand **635** in the axial direction **398** instead of the straight axial metallic strand **655** as shown in FIG. **14**. The curved axial metallic strand **645** also provides the vascular graft, the intravascular graft, or the tubular member with good axial support against compressive forces generated by the thrombus **60** and other physiological forces that can be placed upon the tubular member. The curved axial metallic strand **645** can compress elastically and thereby will provide this tubular member wall structure with good axial flexibility to extend around tortuous turns in a blood vessel. The curved axial metallic strand **645** provides a benefit to the folded tubular section **125** of a straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260** by resisting wrinkling during the unfolding process. The curved axial metallic strand **645** can prevent the center wall of the folded tubular section **125** from forming wrinkles (see FIG. **7**E) and can help the intravascular folded tubular section **125** to unfold evenly during the deployment of the folded tubular member.

[0193] FIG. **16**C shows yet another wall structure for the surgical vascular graft, intravascular tubular member **85**, or vascular tubular member **83** having a similar structure to that of FIG. **16**B only with a curved circumferential metallic strand **650** in the circumferential direction instead of the straight circumferential metallic strand **660**. The axial strands **475** have remained the same as in FIG. **16**B. The curved circumferential metallic strand **650** found in this structure allows the folded tubular section **125** of a straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260** to unfold with greater ease due to their ability to elongate diametrically as one curved circumferential metallic strand **650** located in an folded tubular section inner wall **165** or folded tubular section outer wall **155** passes adjacent to another curved circumferential metallic strand **650** located in the folded tubular section center wall **160**. The curves or bends in the curved circumferential metallic strands **650** also allows the intravascular folded tubular member to expand out uniformly to its deployed diameter **237** and provide uniform contact with the wall or the native vessel or aortic wall in the case of abdominal aortic aneurysm. The deployed diameter **237** of the vascular tubular member **83** used as an intravascular tubular member **85** (see FIG. **1**B) of the present invention can be smaller than the equilibrium diameter that the intravascular tubular member could attain if not constrained by the native vessel in the deployed state.

[0194] FIG. **17**A shows one more vascular tubular member **83** wall structure with a curved circumferential polymeric strand **630** woven along with a straight circumferential metallic strand **660** in the circumferential direction and a straight axial polymeric strand **635** is woven along with a curved axial metallic strand **645** in the axial direction **398**. The curved circumferential polymeric strand **630** provides an amount of circumferential stretch in the diametric direction. The straight circumferential metallic strands **660** and curved axial metallic strands **645** restrict excessive circumferential stretch of the curved circumferential polymeric strands **630**. This wall structure can also be modified slightly to provide an additional characteristic. Near the inlet portion **685** of the tubular means the straight circumferential metallic strand **660** can be eliminated thereby allowing the vascular tubular member to expand to a larger circumference. This circumferential expansion allows the vascular tubular member of the present invention to accommodate a reasonable tolerance in the estimated diameter of the artery such as an estimation of the diameter of the aortic neck. The inlet end **145** of the vascular tubular member **83** can accommodate a tolerance in the estimation of the aortic neck diameter and provide a leak free seal of the vascular tubular member with the vessel wall without overlap of excess material at the inlet end **145** or outlet end **148** due to an oversized diameter of the vascular tubular member **83**. Similar circumferential accommodation also applies to accommodating the estimated diameter of an artery or blood vessel such as the iliac or femoral artery with the outlet end **148** of the vascular tubular member **83**.

[0195] Accommodation of the estimated aortic diameter or other blood vessel diameter with a vascular tubular member **83** of a fixed non-flexible wall material in the circumferential direction **470** with a maximum diameter can also be accomplished by ensuring that the vascular tubular member chosen can expand to a larger maximum deployed diameter **237** than the arterial diameter in which the device is to be placed. For the abdominal aortic aneurysm application this is accomplished by choosing a vascular tubular member **83** with an equilibrium diameter or maximum dimension of the deployed diameter **237** that is larger than the aortic diameter plus any tolerance in diameter estimation associated with measuring technique errors. Any excess intravascular tubular member wall material due to a slight oversized tubular member diameter will result in an overlap of excess wall material. Provided that this overlap material is held tightly against the aortic wall by the proximal attachment means **87**, leakage at the proximal site will not occur.

[0196] FIG. **17**B shows yet one more vascular tubular member wall structure which is the same as that of FIG. **17**A except that a curved circumferential metallic strand **650** has replaced the straight circumferential metallic strand **660**. This structure offers the ability to stretch in the circumferential direction **470** to a limited extent controlled by the amount of curvature provided to the curved circumferential metallic strands **650** and curved circumferential polymeric strands **630**. This vascular tubular member **83** wall structure provides good anti-kink characteristics, good axial support against compression, good flexibility, and will accommodate a reasonable tolerance in the diameter of the proximal aortic neck, and a tolerance on the iliac artery diameter.

[0197] FIG. **17**C shows still one more vascular tubular member wall structure with a curved circumferential polymeric strand **630**, a curved circumferential metallic strand **650**, a curved axial polymeric strand **625** interwoven, and a curved axial metallic strand **645**. This structure offers the ability to stretch in the circumferential direction **470** and axial direction **398** to a limited extent controlled by the amount of curvature provided to the strands. This structure can extend throughout the entire tubular means. This vascular tubular member wall structure provides good anti-kink characteristics, good axial support against compression, good flexibility, and will accommodate a reasonable tolerance in the aortic neck diameter, and a tolerance on the iliac artery diameter.

[0198] FIGS. **18**A and **18**B show further embodiments of the wall structure that can be applied to the vascular tubular member **83** of the present invention. The vascular tubular member wall structures presented in FIGS. **14**, **16**A-**16**C, **17**A-**17**C that contain curved axial metallic strands **645** or straight axial metallic strands **655** which can be directed with an augmented amount of helical turn. This augmented helical turn is accomplished by taking the straight axial metallic strands **655** out of the weave plane **675**, creating a step-over **690** by stepping the straight axial metallic strands **655** over to a new site that is displaced circumferentially, and inserting the strands **655** back into the plane of the weave **675** as shown in FIG. **18**A. This stepping over process allows the axial metallic strand **655** to assume a helical pathway along the axial direction **398** of the vascular tubular member **83**. This augmented amount of helical turn is in addition to the gradual helical turn naturally found in the axially oriented metallic strands **600** due to their natural desire to orient perpendicular to the generally circumferential strands **465** such as the straight circumferential metallic strands **660** and curved circumferential polymeric strands **630** which also have a slight helical turn since they are wound in a continuous helix as shown in FIG. **18**A. The augmented helical turn of the metallic strand in the generally axial direction **398** provides the stent-graft with an ability to bend without kinking even when straight metallic strands are used in the axial direction **398**. In FIG. **18**B two straight circumferential metallic strands **660** are wound in a double helix with a greater angle with respect

to the circumference. This induces the curved axial metallic strands **645** to orient at an angle with respect to the axial direction **480**.

[0199] In the embodiments of the wall structure of the present invention shown in FIGS. **18**A and **18**B curved circumferential polymeric strands **630** and curved axial polymeric strands **625** are wound in the circumferential **470** and axial direction **398** to provide the vascular tubular member **83** with a supple feel and good bending characteristics without kinking. For simplicity of manufacturing, a straight circumferential metallic strand **660** is wound in the circumferential direction **470**. Either a curved axial metallic strand **645** (see FIG. **18**B) or a straight axial metallic strand **655** (see FIG. **18**A) with the step over characteristic described above is used in the axial direction **398** to provide the necessary compressive strength as well as provide good flexibility to the vascular tubular member **83**.

[0200] An entire straight vascular tubular member or bifurcated vascular tubular member can be formed from a single contiguous woven material comprised of the polymeric multifilament strands **510** or the combined polymeric multifilament strands **510** and metallic monofilament strands **490** described in FIGS. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, and **18**B. The bifurcated intravascular folded tubular member **260** can be woven without seam in its proximal tubular section, folded tubular section **125**, or distal tubular section **130**. This is accomplished by weaving the main trunk **270** with approximately twice the number of polymeric multifilament strands **510** and metallic monofilament strands **490** in the axial **398** and circumferential **470** directions as will be used in each proximal leg tube **275**, folded tubular section **125**, or distal tubular section **130** (see FIGS. **13**J and **14**). The weaving of two proximal leg tubes **275** from the main trunk **270** can proceed continuously without seam as approximately half of the strands in the axial direction **398** and circumferential direction **470** are directed from the main trunk **270** to each proximal leg tube. The weave plane **675** for each proximal leg tube **275** (see FIG. **4**A) is continued to form the weave plane **675** for the wall structure for the folded tubular section **125** and the distal tubular section **130**. The wall thickness **663** of the woven vascular tubular member **460** (see FIG. **13**A) can be formed to minimal wall thickness **663** while maintaining strength of the vascular tubular member wall **662**.

Braided Wall Structure

[0201] FIG. **19** shows a wall structure of the braided vascular tubular member **705** of the present invention formed from a braiding process with similar nomenclature being used as used for the woven vascular tubular member **460**. The braided vascular tubular member **705** has straight polymeric and straight metallic strands braided in a right hand spiral forming a straight right spiral polymeric strand **710** and a straight right spiral metallic strand **715**, and in a left hand spiral forming a straight left spiral polymeric strand **720** and a straight left spiral metallic strand **725**. The braiding process provides some ability for this wall structure to accommodate reasonable tolerances in the estimation of the proximal aortic neck diameter in order to provide a good diametric fit between the braided vascular tubular member **705** and the proximal aortic neck. The strands **710**, **715**, **720**, and **725** can be made with localized bends or curves in them as described earlier, and these strands can be braided as described for the embodiments of FIGS. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, and **18**B, and these stands can be braided as described in FIG. **19**. The presence of the straight or curved metallic monofilament strands **605** and **615** (see FIGS. **13**L and **13**K) provides good axial and circumferential strength and stability against compression in the radial or axial direction **398**. The metallic curved monofilament strands **615** or curved polymeric multifilament strands **573** can provide the vascular tubular member with a greater flexibility due to the ability of these strands to compress or extend as the braided vascular tubular member **705** is exposed to a tortuous pathway. The spacing between the right spiral metallic strands **715** or the left spiral metallic strands **725** braided in either the right or left spiral to form a braided vascular tubular member **705** is similar to the spacing ranges stated for the woven vascular tubular member **460**.

Applications of Wall Structure

[0202] The wall structure described in FIGS. **13**A-**13**M, **14**, **15**, **16**A-**16**C, **17**A-**17**C, **18**A, **18**B, and **19** can be applied to a surgical vascular graft, an intravascular tubular member **85**, or other vascular tubular member **83**. As a surgical vascular graft with a woven or braided wall structure, the metallic straight **605** and curved **615** monofilament strands offer improved kink resistance and can provide crush resistance to the vascular graft when placing the graft across a knee joint or other vascular space that is exposed to compressive forces. For the woven vascular tubular member **460** the curved circumferential polymeric strands **630** and curved circumferential metallic strands **650** offer enhanced diametric flexibility or diametric compliance which can lead to improved healing at anastomoses of the vascular tubular member with the native vessel. The curved axial metallic strands **645** or straight axial metallic strands **655** of the woven tubular member offer resistance to axial compressive forces which can also lead to kinking and allow the vascular graft to be pulled through tunnels during implantation without concern for damage to the vascular graft due to excessive axial stretching. As an intravascular tubular member the woven and braided wall structures offer the benefit of a built-in stent. For the woven vascular tubular member **460** the straight circumferential metallic strands **660** and curved circumferential metallic strands **650** offer a thin wall structure with excellent expansion elastic forces acting outward against the native vessel wall or native lumen. Since the straight **660** and curved **650** circumferential metallic strands can be positioned regularly within the wall structure throughout the weave, there can be more of them and their diameter can be smaller than stent wires for most prior art stents. For the woven vascular tubular members **460** the straight **660** and curved **650** circumferential metallic strands are nearly circumferential; they exert a greater outward force for a thinner strand diameter than a zig zag shaped stent or as stent with large bends that require their struts **370** to extend in a non-circumferential direction. The straight **655** and curved **645** axial metallic strands of the woven vascular tubular members **460** also provide a built-in structure onto which any attachment means can be attached firmly to either the inlet **145** or outlet end **148**. The woven wall structures with curved circumferential metallic strands **650** and curved circumferential polymeric strands **630** are able to stretch circumferentially and accommodate errors in estimated diameter of the native blood vessel. The woven wall structures with curved circumferential polymeric strands **630** along with straight or curved circumferential metallic strands **650** can also accommodate errors in the estimation of native vessel diameter by removing the straight **660** or curved **650** circumferential metallic strands near the inlet end **145** or the

outlet end **148** of the intravascular tubular member. The curved circumferential polymeric strands **630** of the woven wall structure will allow the intravascular tubular member **85** to stretch and accommodate errors in the diameter estimation such that any attachment means **87** placed at the inlet end **145** or outlet end **148** can form a leak tight seal with the artery either proximal or distal to the vessel injury. The woven **460** or braided **705** vascular tubular member formed from polymeric multifilament strands **510** can also be used as an intravascular tubular member **85** and offers the strongest and safest wall structure for the thinnest wall thickness **663**. The safety associated with weaving or braiding multifilament strands **510** of ePTFE relates to its ability to avoid a catastrophic tear in the wall structure. Standard tubular ePTFE vascular grafts can form an axial or circumferential tear that can lead to significant complications or possibly patient death. The woven vascular tubular member **460** formed from multifilament strands **510** of ePTFE would not allow a local defect found in the wall structure to extend in an axial direction **398** or circumferential direction **470**. The multifilament strands allows the woven vascular tubular member **460** formed from the strands containing ePTFE filaments **525** to seal against blood leakage at crossover points **485** of the ePTFE strands.

[0203] The wall structure described in FIGS. **13**A-**13**E, **14**, **15**, **16**A-**16**C, **17**A-**17**C, **18**A, and **18**B are well suited to the straight intravascular folded tubular member **95** and bifurcated intravascular folded tubular member **260** with associated advantages. The woven wall structure, woven from polymeric multifilament strands **510** in one embodiment and in other embodiments with metallic straight **605** or curved **615** monofilament strands also woven along with the polymeric multifilament strands **510**, offers the greatest strength with one of the thinnest wall thicknesses **663**. Since the folded tubular section **125** of the straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260** has three folded tubular section walls **330**, it is important that each wall be of a minimum wall thickness **663**. Also of importance is ensuring that the straight or bifurcated proximal tubular section wall **170**, folded tubular section walls **330**, and distal tubular section wall **190** cannot be easily torn which can lead to a life threatening sequalae for the patient. These safety and performance characteristics can be obtained by weaving multifilament strands **510** of ePTFE or multifilament strands **510** of polyester as described in FIGS. **13**A-**13**M. The folded tubular section **125** requires that the folded tubular section inner wall **165**, folded tubular section outer wall **155**, and folded tubular section center wall **160** can slide with respect to each other as the straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260** is deployed from a partially deployed state of smaller length to a fully deployed state of greater length. The woven wall structures with straight circumferential metallic strands **660** or curved circumferential metallic strands **650** provide a substantially smooth wall structure without significant protrusions that can provide ease of unfolding in the folded tubular section **125**. The weaving of metallic straight **605** or curved **615** monofilament strands in the circumferential direction **470** into the wall structure provides an optimum way of providing a built-in metallic stent to provide outward expansion forces while minimizing the thickness of the three folded tubular section walls **330**. Since the metallic straight **605** or curved **615** monofilament strands are acting in a nearly circumferential direction **470**, their strength to provide the outward expansion forces is greatest for the least metallic strand **600** diameter.

[0204] FIG. **20** shows the inlet end **145** and outlet end **148** of an intravascular tubular member **85** with a wall structure similar to an embodiment shown in FIG. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, or **18**B. The woven wall structure can be formed of any combination of weave involving either straight multifilament strands, straight monofilament strands, curved multifilament strands, or curved monofilament strands used to weave generally circumferential polymeric strands **740**, generally circumferential metallic strands **745**, generally axial polymeric strands **750**, and generally axial metallic strands **755** as described in the previous embodiments or otherwise intended. Thus for example, a generally circumferential polymeric strand **740** is understood to mean a straight **640** or curved **630** circumferential polymeric strand, a generally circumferential metallic strand **745** means a straight **660** or curved **650** circumferential metallic strand, a generally axial polymeric strand **750** means a straight **635** or a curved **625** axial polymeric strand, and a generally axial metallic strand **755** means a straight **655** or a curved **645** axial metallic strand. This definition shall also be applicable to FIGS. **21**-**23**. Attached to the inlet end **145** is an attachment means **87**. The attachment means can be the attachment anchor **245** described in FIGS. **9**A, **9**B, **10**A-**10**C, and **11**A-**11**D. A displaced attachment anchor **760** is located at a position displaced away from the inlet end **145** in a proximal direction and not in contact with the woven wall structure. The displaced attachment anchor **760** is the attachment anchor **245** that is located away from the inlet end **145**. The distance that the displaced attachment anchor is located from the inlet end **145** can range from approximately 5 millimeters to 40 millimeters. For an abdominal aortic aneurysm application the displaced attachment anchor **760** can be displaced approximately 10 to 25 millimeters away from the inlet end **145**. The displaced anchor is attached to the intravascular tubular member with axially oriented attachment strands **765**. The attachment strands **765** can be attached to the displaced attachment anchor **760** through selected intranodal openings **385** (see FIG. **9**A) of the displaced attachment anchor **760**. The attachment strands **765** can be extensions of the generally axial metallic strands **755** or generally axial polymeric strands **750**. Preferably the attachment strands **765** are generally axial metallic strands **755** which are continuous with the generally axial metallic strands **755** found in the weave of the intravascular tubular member **85**. Thus, the woven wall structure of the intravascular tubular member **85** with generally axial metallic strands **755** has the structure inherent in the woven intravascular tubular member to simply extend some or all of the generally axial metallic strands **755** proximally beyond the inlet end **145** and use them to attach to the displaced attachment anchor **760**. The displaced attachment anchor **760** provides a proximal anchoring site that is positioned farther away proximally from the vessel injury than the inlet end **145**. Vessel side branches such as the left renal artery **45** and right renal artery **50** in the case of abdominal aortic aneurysm that can extend from the aorta adjacent and proximal to the inlet end **145** of the intravascular tubular member **85** are able to receive blood flow from the native vessel between the inlet end **145** or the intravascular tubular member and the displaced attachment anchor **760**. In the case of treating abdominal aortic aneurysm the right and left renal arteries **45** & **50** can be located between the displaced attachment anchor **760** and the

inlet end **145** of the vascular tubular member. Only a minimal number of attachment strands **765** are needed to attach the displaced attachment anchor **760** to the inlet end **145** of the tubular member, ranging from two to approximately sixteen. Preferably the number of attachment strands **765** ranges from approximately three to six. The likelihood of an attachment strand crossing over a vessel side branch is reduced with a smaller number of attachment strands **765**. A single attachment strand **765** extending from a generally axial metallic strand **755** that crosses over an inlet to a vessel branch will not significantly affect the flow rate of blood to that side branch vessel. The displaced attachment anchor **760** can have barbs **250** to help provide a more firm attachment to the vessel wall such as the vessel wall of the aorta. Either the displaced anchor **760** or the attachment anchor **245** attached at or near the inlet end **145** of the tubular member can have barbs **250** or can be provided without barbs **250**.

[0205] The attachment anchor **245** positioned at the inlet end **145** or outlet end **148** of the intravascular tubular member can also be efficiently attached to any generally axial metallic strands **755** or generally axial polymeric strands **750** of the wall structure described in FIG. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, **18**B, or **20**. Preferably the attachment anchor **245** is attached to a plurality of generally axial metallic strands **755** that can form a firm attachment to the attachment anchor **245**. The general axial metallic strands **755** can efficiently attach to the attachment anchor **245** using the intranodal openings **385** as sites for attachment. A generally circumferential metallic strand **745** near the inlet end **145** or outlet end **148** of the vascular tubular member can be removed to provide the intravascular tubular member **85** formed with curved circumferential polymeric strands **630** with stretchability with an ability to accommodate error in the estimated diameter of the native vessel as was discussed in FIG. **17**A. This wall structure allows the inlet end **145** or outlet end **148** to stretch and enlarge in diameter by up to approximately fifty percent and provide a better diametrical fit to the native vessel without leakage. The attachment anchor **245** attached to the stretchable inlet end **145** or outlet end **148** of the intravascular tubular member can make a tighter seal with the native vessel wall without requiring overlap of the wall structure near the inlet end **145** or outlet end **148** between the attachment anchor **245** and the native vessel wall or native lumen. The braided wall structure of the vascular tubular member shown in FIG. **19** can also be used with the displaced attachment anchor **760**. A plurality of right spiral metallic strands **715** or left spiral metallic strands **725** can be extended proximally beyond the inlet end **145** and attached to the displaced attachment anchor **760** in a manner similar to that described for the woven vascular tubular member **460**.

[0206] FIG. **21** shows a vascular tubular member **83** with a folded tubular section **125** and with a woven wall structure as described in FIGS. **14**, **16**A-**16**C, **17**A-**17**C, **18**A, and **18**B. The woven wall structure can be formed from generally circumferential metallic strands **745**, generally circumferential polymeric strands **740**, generally axial metallic strands **755** and generally axial polymeric strands **750** that have been defined in the description of FIG. **20**. The woven structure containing metallic monofilament strands **490** and polymeric multifilament strands **510** is well suited to forming the folded tubular section **125** of the straight intravascular folded tubular member **95** or the bifurcated intravascular folded tubular member **260**. The folded tubular section **125** can be formed with a minimal triple wall thickness **770** for the folded tubular section walls **330** due to the wall structure of the present invention. Having the generally axial metallic strands **755** and generally circumferential metallic strands **745** woven into the wall provides the present invention with the advantage that a greater number of smaller thickness metallic strands **600** can be used to provide the outward force generated by the generally circumferential metallic strands **745**. Also the generally circumferential metallic strands **745** and generally axial metallic strands **755** do not require an additional binding means to bind them to the vascular tubular member **83** as required by other prior art devices. Providing the general circumferential metallic strands **745** as part of the weave also allows the folded tubular section **125** to unfold smoothly and evenly without catching or snagging such as on a protruding metal wire or stents attached to the outside of the walls of other prior art stent-graft devices. The woven wall structure of the present invention will allow the folded tubular section **125** to unfold with a steady uniform force as the intravascular folded tubular member extends in length from a partially deployed state to a deployed state. It is understood that the woven structure described in this invention can be applied to straight intravascular folded tubular member **95** or bifurcated intravascular folded tubular member **260**. In addition, the woven structure can be applied to the straight intravascular folded tubular member **95** or the bifurcated intravascular folded tubular member **260** that do not contain a folded tubular section **125** and are intended for intravascular use. Also, the woven wall structure can be applied to straight or bifurcated vascular tubular members **83** that can be used for standard surgical implant for treatment of vascular injuries. The straight **95** or bifurcated **260** intravascular folded tubular member is also well suited to be formed entirely from only generally circumferential polymeric strands **740** and generally axial polymeric strands **750** as shown in FIG. **22**. The thin wall thickness **663** provides the folded tubular section walls **330** with a thin overall wall thickness for the three walls. The smooth wall structure formed from the woven polymeric multifilament strands **510** will allow for smooth and uniform unfolding of the folded tubular section **125** without binding as it unfolds during deployment to a fully deployed state. All reference numerals correspond to those elements previously or otherwise described. The woven vascular tubular member **460** shown in FIGS. **14**, **16**A-C, **17**A-C, **18**A, and **18**B are well suited to forming a straight **95** or bifurcated **260** intravascular folded tubular member. In placing the outlet end **148** in its appropriate position it is important that the woven vascular tubular member **460** does not reduce in diameter as the outlet end **148** is being placed and the folded tubular section **125** is unfolding. The woven vascular tubular member **460** does not reduce in diameter if it is pulled from each end in tension. The woven vascular tubular member **460** does not reduce in diameter when used as a straight **95** or bifurcated **260** intravascular folded tubular member that is being extended in length and forms a fully deployed state. The presence of straight **660** or curved **650** circumferential metallic strands further helps to maintain the deployed diameter **237** at a constant value without necking down or reducing in diameter in extending to a fully deployed state. The woven wall structure is also well suited to the straight **95** or bifurcated **260** intravascular folded tubular member because the axial strands **475** provide a significant resistance to axial length change in the material itself. Thus during deployment from a partially deployed state to a fully deployed state the

extension to a deployed tubular member length will occur primarily due to the unfolding of the folded tubular section **125**.

[0207] FIG. **23** shows a bifurcated intravascular folded tubular member **260** formed with a woven wall structure. The woven wall structure can be formed from generally circumferential metallic strands **745**, generally circumferential polymeric strands **740**, generally axial metallic strands **755** and generally axial polymeric strands **750** that have been defined in the description of FIG. **20**. The folded tubular sections **125** are formed from the woven wall structure. The inlet end **145** has an attachment anchor **245** attached, the attachment anchor **245** having barbs **250**. Each outlet end **148** has an attachment anchor **245** attached, each attachment anchor **245** at the outlet end **148** being without barbs **250**. As shown in FIG. **23**, this bifurcated intravascular folded tubular member **260** is intended as an intravascular tubular member **85** that is delivered to the site of a vascular injury through a proximal or distal vessel adjacent to and connecting to the injured vessel. One common application for this intravascular tubular member is for the treatment of abdominal aortic aneurysm. For this application, the tubular member is generally delivered through a smaller diameter delivery sheath **225** (see FIG. **4**C) that is capable of being introduced into one of the common femoral arteries **30**. Typically, a small surgical cutdown may be required to access the femoral artery and provide access for a delivery sheath **225** through which the bifurcated intravascular folded tubular member **260** is delivered. The common femoral artery **30** which provides the main access for the intravascular tubular member **85** including the access for the inlet end **145** of the intravascular tubular member **85** will be referred to as the ipsilateral artery or the ipsilateral side. The intravascular tubular member **85** is delivered to the injury site in a nondeployed state, with a smaller bifurcated nondeployed inlet end diameter **230** and nondeployed outlet end diameter **235**, and a shorter bifurcated nondeployed tubular member length **280** (see FIG. **4**B). The bifurcated intravascular folded tubular member **260** is preferred to have an attachment anchor **245** at the inlet end **145** of the intravascular tubular member to ensure a tight and leak free fit with the aorta in a deployed state although the attachment anchor **245** is not required of the present invention. It is understood that the bifurcated intravascular folded tubular member **260** can have generally circumferential metallic strands **745** woven within the wall structure of the tubular member. Therefore, it is not a requirement that the bifurcated intravascular folded tubular member **260** of the present invention have an attachment anchor **245** at the inlet end **145** or at the outlet end **148**. It is preferred to have an attachment anchor **245** at the inlet end **145** to better and more firmly attach the intravascular folded tubular member to the blood vessel wall proximal to the vessel injury without blood leakage at that site or migration of the intravascular folded tubular member. The bifurcated intravascular folded tubular member **260** can be a self-expandable tubular member that is contained within the smaller diameter tubular delivery sheath **225** (see. FIGS. **4**C and **4**D) for delivery and assist in deployment. Upon removal of the intravascular tubular member from the delivery sheath **225**, the bifurcated intravascular folded tubular member **260** and each attachment anchor **245** is capable of expanding outward and can exert an outward force against the aortic or other arterial wall. The bifurcated intravascular folded tubular member **260** can also be a balloon-expandable tubular member that can be delivered to the site of vessel injury mounted on a balloon catheter. Either the folded tubular member **125**, each attachment anchor **245**, or both the folded tubular member **125** and the attachment anchors **245** can require expansion from a dilitation balloon to force them outward and into close approximation with the aorta, the wall of the native lumen, or to a radially deployed inlet end diameter **105** and deployed attachment anchor diameter **320**. Whether the intravascular tubular member and attachment anchor **245** are self-expandable or balloon-expandable, the attachment anchor **245** located at the inlet end **145** of the tubular member is carefully placed such that it is positioned adjacent and just distal to the renal arteries or within the proximal aortic neck **90** prior to deployment (see FIG. **1**B). For treatment of abdominal aortic aneurysm the short axial length of the attachment anchor **245**, along with the understanding that the attachment anchor **245** is formed of a metal such as tantalum or contains metal that can be easily visualized under fluoroscopy, allows the attachment anchor **245** to be positioned accurately and close to the renal arteries. Barbs **250** can be located on the attachment anchor **245** to ensure that the attachment anchor **245** is well seated into the aorta and cannot migrate distally although they are not required for all embodiments of this invention. It is further understood that a displaced attachment anchor **760** can also be located proximal to the renal arteries and attached to the bifurcated intravascular folded tubular member **260** using attachment strands **765** as described earlier.

[0208] After the inlet end **145** of the bifurcated intravascular folded tubular member **260** has been deployed and attached to the aorta for the case of abdominal aortic aneurysm repair with the attachment anchor **245**, each outlet end **148** of the tubular member is moved into its appropriate location within the iliac **20** & **25** or femoral **30** artery. As the outlet ends **148** of the bifurcated tubular member are moved to their appropriate location, the folded tubular sections **125** of each leg can be unfolded to allow the distal tubular section **130** and bifurcated proximal tubular section **265** to extend in length. An attachment anchor **245** can be located at each outlet end **148** although it is not required for the present invention to have any such attachment anchor **245**. The attachment anchor **245** located at each outlet end **148** of the bifurcated intravascular folded tubular member **260** can be of a self-expandable or balloon-expandable nature as described earlier for the attachment anchor **245** that can be located at the inlet end **145**. The attachment anchor **245** at each outlet end **148** is then expanded or allowed to expand placing the distal tubular section **130** into close contact with the wall of the native vessel or the native lumen wall. The bifurcated intravascular folded tubular member **260** has then been fully deployed to its radially deployed inlet end diameter **105** and radially deployed outlet end diameter **110** and to its bifurcated deployed tubular member length **290** (see FIG. **4**B). Each outlet end **148** can be placed precisely in its desired position in the iliac or femoral artery while observing or real time fluoroscopy the placement of each outlet end **148**.

[0209] The firm anchoring provided by the attachment anchor **245** of this invention will ensure that the inlet end **145** of the bifurcated intravascular folded tubular member **260** will not migrate during the unfolding of the folded tubular section **125** and after the bifurcated intravascular folded tubular member **260** is implanted. The attachment anchor **245** combined with the one-piece construction provides a leak free seal to completely isolate the aneurysmal space from the blood flow passage **100** within the bifurcated intravascular

folded tubular member **260**. The wall structure allows a displaced attachment anchor **760** (see FIG. **20**) to be attached to the bifurcated intravascular folded tubular member **260**. The generally axial metallic strands **755** can extend proximally beyond the inlet end **145** and form a direct attachment to the displaced attachment anchor **760** (see FIG. **20**) by attaching to the intranodal openings **385**. It is understood that a straight intravascular folded tubular member **95** could have similarly been shown with the woven wall structure and attachment anchor **245** described in this embodiment. The present invention is intended to include both straight **95** and bifurcated **260** intravascular folded tubular member including all of the features described in this disclosure.

Delivery Procedure

[0210] It is further an additional embodiment of this invention to provide a bifurcated intravascular folded tubular member **260** that can be delivered and fully deployed either percutaneously or through a small surgical cutdown in one common femoral artery **30** and placed within the aorta for treatment of abdominal aortic aneurysm without the need for access to the contralateral artery such as the contralateral common femoral artery **30**. This can be accomplished by first delivering the bifurcated intravascular folded tubular member **260** to the abdominal aorta at the site of the abdominal aortic aneurysm **5** between the renal arteries and the aorto-iliac bifurcation **57** (see FIGS. **1**A and **1**B). After the inlet end **145** of the bifurcated intravascular folded tubular member **260** has been placed proximal to the aortic injury, the entire bifurcated intravascular folded tubular member as shown in FIG. **4**B, **5**, or **23** can be located entirely within the abdominal aorta and proximal to aorto-iliac bifurcation **57** (see FIG. **1**B). One outlet end **148** of the bifurcated intravascular folded tubular member **260** on the ipsilateral side can be deployed to its appropriate position in the iliac or femoral artery. The outlet end **148** of the bifurcated intravascular folded tubular member **260** on the contralateral side can then be placed into appropriate position with a contralateral side outlet end placement means. This contralateral side outlet end placement means is introduced through the ipsilateral femoral artery and can move the outlet end **148** of the bifurcated intravascular folded tubular member **260** such that the folded tubular section **125** can unfold allowing the proximal or distal section to extend and provide an extension of the tubular member on the contralateral side so as to place the outlet end **148** in an appropriate position. The attachment anchor **245** located on the contralateral side is expanded or allowed to expand to hold the outlet end **148** of the bifurcated intravascular folded tubular member **260** securely in contact with the arterial wall or the inside of the vessel lumen.

[0211] The present invention includes a one piece bifurcated intravascular folded tubular member **260** which is different than the modular systems described in the prior art for treating abdominal aortic aneurysm. The one piece construction of the present invention cannot form leak pathways such as those that occur between the union of various segments found in modular systems. The present intravascular tubular member provides a device for treating vascular injury such as abdominal aortic aneurysm where the axial length of the native lumen extending through the aortic aneurysm is very difficult to measure using angiographic means. Estimating the length angiographically will very often lead to an incorrect estimation of the length of intravascular graft that is needed. The result can be the implantation or another prior art stent-graft device that is too short and does not extend beyond the injured artery to the region that is not injured or healthy. If the prior art stent-graft is too long, it can extend beyond an appropriate point in the iliac or femoral artery and can block a side branch such as the internal iliac artery **80**. With the intravascular tubular member **85** of the present invention, the length of the intravascular tubular member **85** or vascular tubular member **83** is determined in situ or while it is being placed. Therefore, the intravascular tubular member **85** of the present invention can be extended precisely to the appropriate length without concern for the inaccuracies associated with trying to estimate the length of the tortuous path for the intravascular tubular member.

1-34. (canceled)

35. A wall structure for a cylindrical member that is deliverable to the site of a lesion within a tubular vessel of the body, the cylindrical member having a nondeployed state and capable of undergoing an expansion deformation to a deployed state with a larger diameter, said wall structure comprised of;

A. one or more hinges and one or more struts,

B. said hinges being adapted to bend substantially only in the direction of the hinge width,

C. said struts having a strut width that is greater than a strut radial dimension wherein said strut is unable to bend substantially in the direction of the strut width and is adapted to flex elastically and not substantially plastically in the radial direction.

36. The wall structure of claim **35** wherein the said hinges provide a plastic deformation of a material as said hinges deform during the expansion deformation.

37. The wall structure of claim **36** wherein said struts formed of said material are adapted to bend elastically in the radial direction due to an external crush force and return to the original shape upon removal of the crush force, thereby providing a cylindrical member that is adapted to be balloon expandable but not plastically crushable.

38. The wall structure of claim **35** wherein said hinges have an expansion yield force in the direction of said hinge width and said struts have an outward crush elastic force in the radial direction that are uncoupled from each other thereby allowing these forces to be adjusted independently from each other.

39. The wall structure of claim **35** wherein said hinges provide an elastic expansion force in the direction of said hinge width that is uncoupled from a crush elastic force provided by said struts in a radial direction.

40. A cylindrical wall structure for use within a tubular vessel of the body, deliverable to a site that requires a supporting structure, said cylindrical wall structure having the ability to exert an expansion force outward that is transmitted toward the tubular vessel wall, said cylindrical wall structure further having an independent ability to tolerate a temporarily applied external crush force by becoming oval in shape and then returning back to its approximate initial shape upon removal of the external force, said tubular wall structure comprised of;

A. hinges and struts that are interconnected within said cylindrical wall structure,

B. said struts having a width enough greater than the width of said hinges such that the struts do not contribute significantly to the expansion force that is predominantly determined by said hinges,

C. said hinges having a radial dimension enough greater than the radial dimension of said struts such that the

hinges do not contribute significantly to the elastic crush resistance force that is predominantly determined by said struts.

41. The method of use for a cylindrical member that is deliverable to the site of a lesion within a tubular vessel of the body, the cylindrical member having a nondeployed state and capable of undergoing an expansion deformation to a deployed state of larger diameter, the method comprising; providing a wall structure with hinges and struts, said hinges being adapted to be unable to bend substantially in the radial direction; said struts being adapted to be substantially unbendable in the direction of the strut width and adapted to flex elastically and not significantly plastically in the radial direction; whereby said cylindrical member is thereby adapted to reversibly form an oval shape during a crush deformation.

42. The method of use of claim **41** wherein at least some of said hinges bend plastically in the direction of the hinge width during the expansion deformation thereby adapting said cylindrical member to be balloon expandable while said struts adapt said cylindrical member to not be plastically crushable.

43. The method of claim **41** wherein the hinge width is made wider to increase the force required to pivot the hinge.

44. The method of claim **41** wherein said hinge has a hinge length that is decreased to cause a relatively elastic material to bend plastically within a relatively small amount of rotation.

45. The method of claim **41** wherein said hinge has a hinge length that is increased to cause a relatively plastic material to bend elastically throughout a relatively large amount of rotation.

46. The method of claim **41** wherein the hinge radial dimension is increased beyond that which is necessary to prevent the strut from causing said hinge to flex in the radial direction, thereby providing an increase the force required to pivot the hinge.

47. The method of claim **41** wherein the strut radial dimension is made thicker to increase the force required to flex said strut in the radial direction.

48. The method of claim **41** wherein the strut radial dimension is decreased to reduce the force required to flex said strut in the radial direction, and adapt said strut when formed from a relatively plastic material to bend elastically throughout a relatively large degree of flexing in the radial direction.

49. The method of claim **41** wherein said strut width is made wider than that which is necessary to prevent bending in the direction which said hinges pivot, thereby providing an increase in the force required to flex said strut in the radial direction.

50. The method of claim **41** wherein said strut has a strut length that is increased to cause said strut when formed from a relatively plastic material to bend elastically throughout a relatively large degree of flexing in the radial direction.

51. The method of claim **41** wherein the hinge width and hinge radial dimension of any of said hinges, and the strut width and strut radial dimension of any of said struts are adapted to have different hinge width and hinge radial dimension than another of said hinges and different strut width and strut radial dimension than another of said struts.

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