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(54) **Title:** EMBOLIC PROTECTION IN CONNECTION WITH TRANSCAROTID ARTERY REVASCULARIZATION

(57) **Abstract:** Systems and methods are configured for accessing and treating carotid arterial vasculature and establishing retrograde blood flow during performance of carotid artery stenting and other procedures.

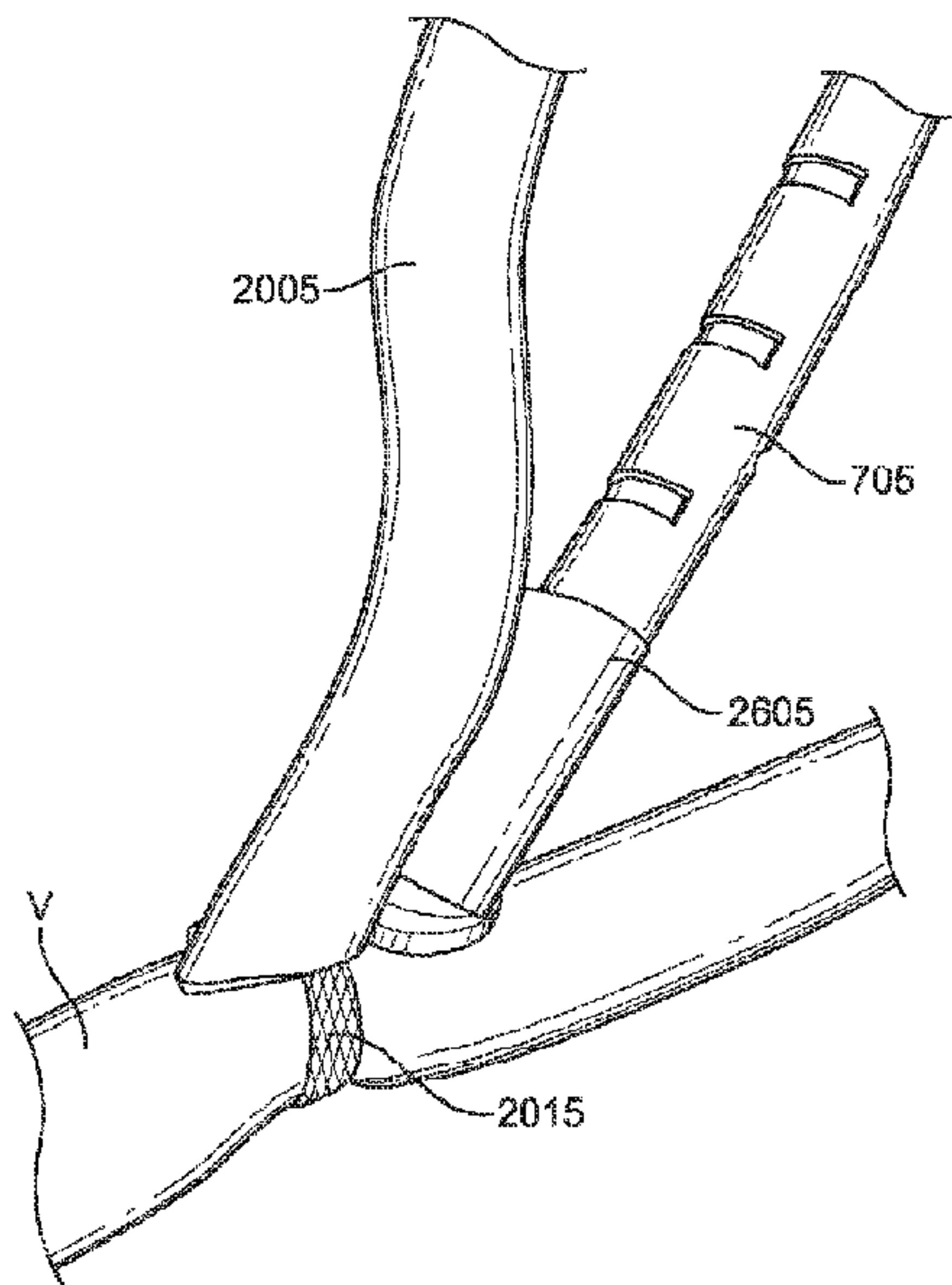


FIG. 30

EMBOLIC PROTECTION IN CONNECTION WITH TRANSCAROTID ARTERY REVASCULARIZATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Patent Application No. 62/936,998, filed November 18, 2019, entitled “EMBOLIC PROTECTION IN CONNECTION WITH TRANSCAROTID CAROTID ARTERY REVASCULARIZATION”, and U.S. Patent Application No. 63/037,476, filed June 10, 2020, entitled “EMBOLIC PROTECTION IN CONNECTION WITH TRANSCAROTID CAROTID ARTERY REVASCULARIZATION”, the contents of which are hereby incorporated by reference herein in their entirety.

BACKGROUND

[0002] The present disclosure relates generally to medical methods and devices. More particularly, the present disclosure relates to methods, system, and devices for accessing and treating carotid arterial vasculature and establishing retrograde blood flow during performance of carotid artery stenting and other procedures. The present disclosure also relates to methods and systems for accessing and treating the cerebral arterial vasculature such as for the treatment of stroke, Intracranial Atherosclerotic Disease (ICAD), transient ischemic attack (TIA), acute ischemic stroke (AIS), tandem lesions, ruptured and unruptured intra- and extra-cranial aneurysm embolization, chronic occlusions, and other disease conditions of the neurovasculature.

SUMMARY

[0003] Disclosed are systems and methods for accessing and treating carotid arterial vasculature and establishing retrograde blood flow during performance of carotid artery stenting and other procedures. In one aspect, there is disclosed a system for compress a blood vessel, the system comprising: a vessel compression device formed of: an elongated shaft having an internal lumen; a vessel support structure positioned on a distal end of the shaft, wherein the vessel support structure defines an atraumatic outer surface; and a clamping structure movably coupled to the elongated shaft, wherein the clamping structure includes a distal portion is configured to clamp a blood vessel when a blood vessel is

positioned between the distal portion of the clamping structure and the vessel support structure, wherein the distal portion clamps the blood vessel in a manner that flattens the blood vessel.

[0004] In another aspect, there is disclosed a method of compressing a blood vessel, comprising: inserting an arterial access device into a carotid artery, the arterial access device having a distal sheath portion; coupling a vessel compression device to the carotid artery, the vessel compression device formed of: an elongated shaft having an internal lumen; a vessel support structure positioned on a distal end of the shaft, wherein the vessel support structure defines an atraumatic outer surface; a clamping structure movably coupled to the elongated shaft, wherein the clamping structure includes a distal portion is configured to clamp the carotid artery when the carotid artery is positioned between the distal portion of the clamping structure and the vessel support structure, wherein the distal portion clamps the carotid artery in a manner that flattens the carotid artery without bunching; and compressing the carotid artery between the distal portion of the clamping structure and the vessel support structure of the vessel compression device.

[0005] Other features and advantages should be apparent from the following description of various embodiments, which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1A is a schematic illustration of a retrograde blood flow system including a flow control assembly wherein an arterial access device accesses the common carotid artery via a transcarotid approach and a venous return device communicates with the internal jugular vein.

[0007] FIG. 1B is a schematic illustration of a retrograde blood flow system wherein an arterial access device accesses the common carotid artery via a transcarotid approach and a venous return device communicates with the femoral vein.

[0008] FIG. 1C is a schematic illustration of a retrograde blood flow system wherein an arterial access device accesses the common carotid artery via a transfemoral approach and a venous return device communicates with the femoral vein.

[0009] FIG. 1D is a schematic illustration of a retrograde blood flow system wherein retrograde flow is collected in an external receptacle.

[0010] FIG. 2A is an enlarged view of the carotid artery wherein the carotid artery is occluded with an occlusion element on the sheath and connected to a reverse flow shunt, and an interventional device, such as a stent delivery system or other working catheter, is introduced into the carotid artery via an arterial access device.

[0011] FIG. 2B is an alternate system wherein the carotid artery is occluded with a separate external occlusion device and connected to a reverse flow shunt, and an interventional device, such as a stent delivery system or other working catheter, is introduced into the carotid artery via an arterial access device.

[0012] FIG. 3 is an alternate system wherein the carotid artery is connected to a reverse flow shunt and an interventional device, such as a stent delivery system or other working catheter, is introduced into the carotid artery via an arterial access device, and the carotid artery is occluded with a separate occlusion device.

[0013] FIG. 4 illustrates a normal cerebral circulation diagram including the Circle of Willis.

[0014] FIG. 5 illustrates the vasculature in a patient's neck, including the common carotid artery CCA, the internal carotid artery ICA, the external carotid artery ECA, and the internal jugular vein IJV.

[0015] FIG. 6A illustrates an arterial access device useful in the methods and systems of the present disclosure.

[0016] FIG. 6B illustrates an additional arterial access device construction with a reduced diameter distal end.

[0017] FIGs. 7A and 7B illustrate a tube useful with the sheath of Figure 6A.

[0018] FIG. 7C show an embodiment of a sheath stopper.

[0019] FIG. 7D shows the sheath stopper of FIG. 7C positioned on a sheath.

[0020] FIGs. 7E and 7F show the malleable sheath stopper in use.

[0021] FIG. 7G shows an embodiment of a sheath with a flexible distal segment and a sheath stopper in use.

[0022] FIG. 8A illustrates an additional arterial access device construction with an expandable occlusion element.

[0023] FIG. 8B illustrates an additional arterial access device construction with an expandable occlusion element and a reduced diameter distal end.

[0024] FIGs. 9A and 9B illustrate an additional embodiment of an arterial access device.

[0025] FIGs. 9C and 9D illustrate an embodiment of a valve on the arterial access device.

[0026] FIGs. 10A through 10D illustrate embodiments of a venous return device useful in the methods and systems of the present disclosure.

[0027] FIG. 11 illustrates the system of FIG. 1 including a flow control assembly.

[0028] FIGs. 12A-12B illustrate an embodiment of a variable flow resistance component useful in the methods and systems of the present disclosure.

[0029] FIGs. 13A-13D illustrate an embodiment of a fenestrated sheath.

[0030] FIGs. 14A -14E illustrate the exemplary blood flow paths during a procedure for implanting a stent at the carotid bifurcation in accordance with the principles of the present disclosure.

[0031] FIGS. 15-18C show embodiments of a sheath stopper.

[0032] FIGS. 19A-24 show embodiments of a Rumel tourniquet.

[0033] FIGS. 25-27 show a system that combines a Rumel tourniquet and sheath stopper.

[0034] FIGS. 28-30 show a Rumel shaft and sheath stopper system in use with a blood vessel.

[0035] FIGS. 31-37 show an embodiment of a blood vessel clamping device.

[0036] FIGS. 38-40 show another embodiment of the blood vessel clamping device.

DETAILED DESCRIPTION

[0037] The disclosed methods, apparatus, and systems establish and facilitate retrograde or reverse flow blood circulation in the region of the carotid artery bifurcation in order to limit or prevent the release of emboli into the cerebral vasculature, particularly into

the internal carotid artery. The methods are particularly useful for interventional procedures, such as stenting and angioplasty, atherectomy, performed through a transcarotid approach or transfemoral into the common carotid artery, either using an open surgical technique or using a percutaneous technique, such as a modified Seldinger technique or a micropuncture technique.

[0038] Access into the common carotid artery (Figure 5) is established by placing a sheath or other tubular access cannula into a lumen of the artery, typically having a distal end of the sheath positioned proximal to the junction or bifurcation B from the common carotid artery to the internal and external carotid arteries. The sheath may have an occlusion member at the distal end, for example a compliant occlusion balloon. A catheter or guidewire with an occlusion member, such as a balloon, may be placed through the access sheath and positioned in the proximal external carotid artery ECA to inhibit the entry of emboli, but occlusion of the external carotid artery is usually not necessary. A second return sheath is placed in the venous system, for example the internal jugular vein IJV or femoral vein FV. The arterial access and venous return sheaths are connected to create an external arterial-venous shunt.

[0039] Retrograde flow is established and modulated to meet the patient's requirements. Flow through the common carotid artery is occluded, either with an external vessel loop or tape, a vascular clamp, an internal occlusion member such as a balloon, or other type of occlusion means. When flow through the common carotid artery is blocked, the natural pressure gradient between the internal carotid artery and the venous system will cause blood to flow in a retrograde or reverse direction from the cerebral vasculature through the internal carotid artery and through the shunt into the venous system.

[0040] Alternately, the venous sheath could be eliminated and the arterial sheath could be connected to an external collection reservoir or receptacle. The reverse flow could be collected in this receptacle. If desired, the collected blood could be filtered and subsequently returned to the patient during or at the end of the procedure. The pressure of the receptacle could be open to atmospheric pressure, causing the pressure gradient to create blood to flow in a reverse direction from the cerebral vasculature to the receptacle or the pressure of the receptacle could be a negative pressure.

[0041] Optionally, to achieve or enhance reverse flow from the internal carotid artery, flow from the external carotid artery may be blocked, typically by deploying a balloon

or other occlusion element in the external carotid just above (i.e., distal) the bifurcation within the internal carotid artery.

[0042] Although the procedures and protocols described hereinafter will be particularly directed at carotid stenting, it will be appreciated that the methods for accessing the carotid artery described herein would also be useful for angioplasty, artherectomy, and any other interventional procedures which might be carried out in the carotid arterial system, particularly at a location near the bifurcation between the internal and external carotid arteries. In addition, it will be appreciated that some of these access, vascular closure, and embolic protection methods will be applicable in other vascular interventional procedures, for example the treatment of acute stroke.

[0043] The present disclosure includes a number of specific aspects for improving the performance of carotid artery access protocols. At least some of these individual aspects and improvements can be performed individually or in combination with one or more other of the improvements in order to facilitate and enhance the performance of the particular interventions in the carotid arterial system.

[0044] FIG. 1A shows a first embodiment of a retrograde flow system 100 that is adapted to establish and facilitate retrograde or reverse flow blood circulation in the region of the carotid artery bifurcation in order to limit or prevent the release of emboli into the cerebral vasculature, particularly into the internal carotid artery. The system 100 interacts with the carotid artery to provide retrograde flow from the carotid artery to a venous return site, such as the internal jugular vein (or to another return site such as another large vein or an external receptacle in alternate embodiments.) The retrograde flow system 100 includes an arterial access device 110, a venous return device 115, and a shunt 120 that provides a passageway for retrograde flow from the arterial access device 110 to the venous return device 115. A flow control assembly 125 interacts with the shunt 120. The flow control assembly 125 is adapted to regulate and/or monitor the retrograde flow from the common carotid artery to the internal jugular vein, as described in more detail below. The flow control assembly 125 interacts with the flow pathway through the shunt 120, either external to the flow path, inside the flow path, or both. The arterial access device 110 at least partially inserts into the common carotid artery CCA and the venous return device 115 at least partially inserts into a venous return site such as the internal jugular vein IJV, as described in more detail below. The arterial access device 110 and the venous return device 115 couple to the shunt 120 at connection locations 127a and 127b. When flow through the common

carotid artery is blocked, the natural pressure gradient between the internal carotid artery and the venous system causes blood to flow in a retrograde or reverse direction RG (Figure 2A) from the cerebral vasculature through the internal carotid artery and through the shunt 120 into the venous system. The flow control assembly 125 modulates, augments, assists, monitors, and/or otherwise regulates the retrograde blood flow.

[0045] In the embodiment of FIG. 1A, the arterial access device 110 accesses the common carotid artery CCA via a transcarotid approach. Transcarotid access provides a short length and non-tortuous pathway from the vascular access point to the target treatment site thereby easing the time and difficulty of the procedure, compared for example to a transfemoral approach. In an embodiment, the arterial distance from the arteriotomy to the target treatment site (as measured traveling through the artery) is 15 cm or less. In an embodiment, the distance is between 5 and 10 cm. Additionally, this access route reduces the risk of emboli generation from navigation of diseased, angulated, or tortuous aortic arch or common carotid artery anatomy. At least a portion of the venous return device 115 is placed in the internal jugular vein IJV. In an embodiment, transcarotid access to the common carotid artery is achieved percutaneously via an incision or puncture in the skin through which the arterial access device 110 is inserted. If an incision is used, then the incision can be about 0.5 cm in length. An occlusion element 129, such as an expandable balloon, can be used to occlude the common carotid artery CCA at a location proximal of the distal end of the arterial access device 110. The occlusion element 129 can be located on the arterial access device 110 or it can be located on a separate device. In an alternate embodiment, the arterial access device 110 accesses the common carotid artery CCA via a direct surgical transcarotid approach. In the surgical approach, the common carotid artery can be occluded using a tourniquet 2105. The tourniquet 2105 is shown in phantom to indicate that it is a device that is used in the optional surgical approach.

[0046] In another embodiment, shown in FIG. 1B, the arterial access device 110 accesses the common carotid artery CCA via a transcarotid approach while the venous return device 115 access a venous return site other than the jugular vein, such as a venous return site comprised of the femoral vein FV. The venous return device 115 can be inserted into a central vein such as the femoral vein FV via a percutaneous puncture in the groin.

[0047] In another embodiment, shown in FIG. 1C, the arterial access device 110 accesses the common carotid artery via a femoral approach. According to the femoral approach, the arterial access device 110 approaches the CCA via a percutaneous puncture

into the femoral artery FA, such as in the groin, and up the aortic arch AA into the target common carotid artery CCA. The venous return device 115 can communicate with the jugular vein JV or the femoral vein FV.

[0048] FIG. 1D shows yet another embodiment, wherein the system provides retrograde flow from the carotid artery to an external receptacle 130 rather than to a venous return site. The arterial access device 110 connects to the receptacle 130 via the shunt 120, which communicates with the flow control assembly 125. The retrograde flow of blood is collected in the receptacle 130. If desired, the blood could be filtered and subsequently returned to the patient. The pressure of the receptacle 130 could be set at zero pressure (atmospheric pressure) or even lower, causing the blood to flow in a reverse direction from the cerebral vasculature to the receptacle 130. Optionally, to achieve or enhance reverse flow from the internal carotid artery, flow from the external carotid artery can be blocked, typically by deploying a balloon or other occlusion element in the external carotid artery just above the bifurcation with the internal carotid artery. FIG. 1D shows the arterial access device 110 arranged in a transcarotid approach with the CCA although it should be appreciated that the use of the external receptacle 130 can also be used with the arterial access device 110 in a transfemoral approach.

[0049] With reference to the enlarged view of the carotid artery in FIG. 2A, an interventional device, such as a stent delivery system 135 or other working catheter, can be introduced into the carotid artery via the arterial access device 110, as described in detail below. The stent delivery system 135 can be used to treat the plaque P such as to deploy a stent into the carotid artery. The arrow RG in FIG. 2A represents the direction of retrograde flow.

[0050] FIG. 2B shows an alternative embodiment, wherein the occlusion element 129 can be introduced into the carotid artery on a second sheath 112 separate from the distal sheath 605 of the arterial access device 110. The second or "proximal" sheath 112 can be adapted for insertion into the common carotid artery in a proximal or "downward" direction away from the cerebral vasculature. The second, proximal sheath can include an inflatable balloon 129 or other occlusion element, generally as described above. The distal sheath 605 of the arterial access device 110 can be then placed into the common carotid artery distal of the second, proximal sheath and generally oriented in a distal direction toward the cerebral vasculature. By using separate occlusion and access sheaths, the size of the arteriotomy needed for introducing the access sheath can be reduced.

[0051] FIG. 3 shows yet another embodiment of a two arterial sheath system, wherein the interventional devices are introduced via an introducer sheath 114 separate from the distal sheath 605 of the arterial device 110. A second or “distal” sheath 114 can be adapted for insertion into the common carotid artery distal to the arterial access device 110. As with the previous embodiment, the use of two separate access sheaths allows the size of each arteriotomy to be reduced.

DESCRIPTION OF ANATOMY

Collateral Brain Circulation

[0052] The Circle of Willis CW is the main arterial anastomatic trunk of the brain where all major arteries which supply the brain, namely the two internal carotid arteries (ICAs) and the vertebral basilar system, connect. The blood is carried from the Circle of Willis by the anterior, middle and posterior cerebral arteries to the brain. This communication between arteries makes collateral circulation through the brain possible. Blood flow through alternate routes is made possible thereby providing a safety mechanism in case of blockage to one or more vessels providing blood to the brain. The brain can continue receiving adequate blood supply in most instances even when there is a blockage somewhere in the arterial system (e.g., when the ICA is ligated as described herein). Flow through the Circle of Willis ensures adequate cerebral blood flow by numerous pathways that redistribute blood to the deprived side.

[0053] The collateral potential of the Circle of Willis is believed to be dependent on the presence and size of its component vessels. It should be appreciated that considerable anatomic variation between individuals can exist in these vessels and that many of the involved vessels may be diseased. For example, some people lack one of the communicating arteries. If a blockage develops in such people, collateral circulation is compromised resulting in an ischemic event and potentially brain damage. In addition, an autoregulatory response to decreased perfusion pressure can include enlargement of the collateral arteries, such as the communicating arteries, in the Circle of Willis. An adjustment time is occasionally required for this compensation mechanism before collateral circulation can reach a level that supports normal function. This autoregulatory response can occur over the space of 15 to 30 seconds and can only compensate within a certain range of pressure and flow drop. Thus, it is possible for a transient ischemic attack to occur during the adjustment period. Very high retrograde flow rate for an extended period of time can lead to conditions

where the patient's brain is not getting enough blood flow, leading to patient intolerance as exhibited by neurologic symptoms or in some cases a transient ischemic attack.

[0054] FIG. 4 depicts a normal cerebral circulation and formation of Circle of Willis CW. The aorta AO gives rise to the brachiocephalic artery BCA, which branches into the left common carotid artery LCCA and left subclavian artery LSCA. The aorta AO further gives rise to the right common carotid artery RCCA and right subclavian artery RSCA. The left and right common carotid arteries CCA gives rise to internal carotid arteries ICA which branch into the middle cerebral arteries MCA, posterior communicating artery PcoA, and anterior cerebral artery ACA. The anterior cerebral arteries ACA deliver blood to some parts of the frontal lobe and the corpus striatum. The middle cerebral arteries MCA are large arteries that have tree-like branches that bring blood to the entire lateral aspect of each hemisphere of the brain. The left and right posterior cerebral arteries PCA arise from the basilar artery BA and deliver blood to the posterior portion of the brain (the occipital lobe).

[0055] Anteriorly, the Circle of Willis is formed by the anterior cerebral arteries ACA and the anterior communicating artery ACoA which connects the two ACAs. The two posterior communicating arteries PCoA connect the Circle of Willis to the two posterior cerebral arteries PCA, which branch from the basilar artery BA and complete the Circle posteriorly.

[0056] The common carotid artery CCA also gives rise to external carotid artery ECA, which branches extensively to supply most of the structures of the head except the brain and the contents of the orbit. The ECA also helps supply structures in the neck and face.

Carotid Artery Bifurcation

[0057] FIG. 5 shows an enlarged view of the relevant vasculature in the patient's neck. The common carotid artery CCA branches at bifurcation B into the internal carotid artery ICA and the external carotid artery ECA. The bifurcation is located at approximately the level of the fourth cervical vertebra. FIG. 5 shows plaque P formed at the bifurcation B.

[0058] As discussed above, the arterial access device 110 can access the common carotid artery CCA via a transcarotid approach. Pursuant to the transcarotid approach, the arterial access device 110 is inserted into the common carotid artery CCA at an arterial access location L, which can be, for example, a surgical incision or puncture in the

wall of the common carotid artery CCA. There is typically a distance D of around 5 to 7 cm between the arterial access location L and the bifurcation B. When the arterial access device 110 is inserted into the common carotid artery CCA, it is undesirable for the distal tip of the arterial access device 110 to contact the bifurcation B as this could disrupt the plaque P and cause generation of embolic particles. In order to minimize the likelihood of the arterial access device 110 contacting the bifurcation B, in an embodiment only about 2 - 4 cm of the distal region of the arterial access device is inserted into the common carotid artery CCA during a procedure.

[0059] The common carotid arteries are encased on each side in a layer of fascia called the carotid sheath. This sheath also envelops the internal jugular vein and the vagus nerve. Anterior to the sheath is the sternocleidomastoid muscle. Transcarotid access to the common carotid artery and internal jugular vein, either percutaneous or surgical, can be made immediately superior to the clavicle, between the two heads of the sternocleidomastoid muscle and through the carotid sheath, with care taken to avoid the vagus nerve.

[0060] At the upper end of this sheath, the common carotid artery bifurcates into the internal and external carotid arteries. The internal carotid artery continues upward without branching until it enters the skull to supply blood to the retina and brain. The external carotid artery branches to supply blood to the scalp, facial, ocular, and other superficial structures. Intertwined both anterior and posterior to the arteries are several facial and cranial nerves. Additional neck muscles may also overlay the bifurcation. These nerve and muscle structures can be dissected and pushed aside to access the carotid bifurcation during a carotid endarterectomy procedure. In some cases the carotid bifurcation is closer to the level of the mandible, where access is more challenging and with less room available to separate it from the various nerves which should be spared. In these instances, the risk of inadvertent nerve injury can increase and an open endarterectomy procedure may not be a good option.

RETROGRADE BLOOD FLOW SYSTEM

[0061] As discussed, the retrograde flow system 100 includes the arterial access device 110, venous return device 115, and shunt 120 which provides a passageway for retrograde flow from the arterial access device 110 to the venous return device 115. The system also includes the flow control assembly 125, which interacts with the shunt 120 to regulate and/or monitor retrograde blood flow through the shunt 120. Exemplary embodiments of the components of the retrograde flow system 100 are now described.

Arterial Access Device

[0062] FIG. 6A shows an exemplary embodiment of the arterial access device 110, which comprises a distal sheath 605, a proximal extension 610, a flow line 615, an adaptor or Y-connector 620, and a hemostasis valve 625. The arterial access device may also comprise a dilator 645 with a tapered tip 650 and an introducer guide wire 611. The arterial access device together with the dilator and introducer guidewire are used together to gain access to a vessel. Features of the arterial access device may be optimized for transcarotid access. For example, the design of the access device components may be optimized to limit the potential injury on the vessel due to a sharp angle of insertion, allow atraumatic and secure sheath insertion, and limiting the length of sheath, sheath dilator, and introducer guide wire inserted into the vessel.

[0063] The distal sheath 605 is adapted to be introduced through an incision or puncture in a wall of a common carotid artery, either an open surgical incision or a percutaneous puncture established, for example, using the Seldinger technique. The length of the sheath can be in the range from 5 to 15 cm, usually being from 10 cm to 12 cm. The inner diameter is typically in the range from 7 Fr (1 Fr = 0.33 mm), to 10 Fr, usually being 8 Fr. Particularly when the sheath is being introduced through the transcarotid approach, above the clavicle but below the carotid bifurcation, it is desirable that the sheath 605 be highly flexible while retaining hoop strength to resist kinking and buckling. Thus, the distal sheath 605 can be circumferentially reinforced, such as by braid, helical ribbon, helical wire, cut tubing, or the like and have an inner liner so that the reinforcement structure is sandwiched between an outer jacket layer and the inner liner. The inner liner may be a low friction material such as PTFE. The outer jacket may be one or more of a group of materials including Pebax, thermoplastic polyurethane, or nylon. In an embodiment, the reinforcement structure or material and/or outer jacket material or thickness may change over the length of the sheath 605 to vary the flexibility along the length. In an alternate embodiment, the distal sheath is adapted to be introduced through a percutaneous puncture into the femoral artery, such as in the groin, and up the aortic arch AA into the target common carotid artery CCA.

[0064] The distal sheath 605 can have a stepped or other configuration having a reduced diameter distal region 630, as shown in FIG. 6B, which shows an enlarged view of the distal region 630 of the sheath 605. The distal region 630 of the sheath can be sized for insertion into the carotid artery, typically having an inner diameter in the range from 2.16 mm (0.085 inch) to 2.92 mm (0.115 inch) with the remaining proximal region of the sheath

having larger outside and luminal diameters, with the inner diameter typically being in the range from 2.794 mm (0.110 inch) to 3.43 mm (0.135 inch). The larger luminal diameter of the proximal region minimizes the overall flow resistance of the sheath. In an embodiment, the reduced-diameter distal section 630 has a length of approximately 2 cm to 4 cm. The relatively short length of the reduced-diameter distal section 630 permits this section to be positioned in the common carotid artery CCA via the transcarotid approach with reduced risk that the distal end of the sheath 605 will contact the bifurcation B. Moreover, the reduced diameter section 630 also permits a reduction in size of the arteriotomy for introducing the sheath 605 into the artery while having a minimal impact in the level of flow resistance. Further, the reduced distal diameter section may be more flexible and thus more conformal to the lumen of the vessel.

[0065] With reference again to FIG. 6A, the proximal extension 610, which is an elongated body, has an inner lumen which is contiguous with an inner lumen of the sheath 605. The lumens can be joined by the Y-connector 620 which also connects a lumen of the flow line 615 to the sheath. In the assembled system, the flow line 615 connects to and forms a first leg of the retrograde shunt 120 (FIG. 1). The proximal extension 610 can have a length sufficient to space the hemostasis valve 625 well away from the Y-connector 620, which is adjacent to the percutaneous or surgical insertion site. By spacing the hemostasis valve 625 away from a percutaneous insertion site, the physician can introduce a stent delivery system or other working catheter into the proximal extension 610 and sheath 605 while staying out of the fluoroscopic field when fluoroscopy is being performed. In an embodiment, the proximal extension is about 16.9 cm from a distal most junction (such as at the hemostasis valve) with the sheath 605 to the proximal end of the proximal extension. In an embodiment, the proximal extension has an inner diameter of 0.125 inch and an outer diameter of 0.175 inch. In an embodiment, the proximal extension has a wall thickness of 0.025 inch. The inner diameter may range, for example, from 0.60 inch to 0.150 inch with a wall thickness of 0.010 inch to 0.050 inch. In another embodiment, the inner diameter may range, for example, from 0.150 inch to 0.250 inch with a wall thickness of 0.025 inch to 0.100 inch. The dimensions of the proximal extension may vary. In an embodiment, the proximal extension has a length within the range of about 12-20 cm. In another embodiment, the proximal extension has a length within the range of about 20-30 cm.

[0066] In an embodiment, the distance along the sheath from the hemostasis valve 625 to the distal tip of the sheath 605 is in the range of about 25 and 40 cm. In an

embodiment, the distance is in the range of about 30 and 35 cm. With a system configuration that allows 2.5 cm of sheath introduction into the artery, and an arterial distance of between 5 and 10 cm from the arteriotomy site to the target site, this system enables a distance in the range of about 32.5 cm to 42.5 cm from the hemostasis valve 625 (the location of interventional device introduction into the access sheath) to the target site of between 32 and 43 cm. This distance is about a third the distance required in prior art technology.

[0067] A flush line 635 can be connected to the side of the hemostasis valve 625 and can have a stopcock 640 at its proximal or remote end. The flush-line 635 allows for the introduction of saline, contrast fluid, or the like, during the procedures. The flush line 635 can also allow pressure monitoring during the procedure. A dilator 645 having a tapered distal end 650 can be provided to facilitate introduction of the distal sheath 605 into the common carotid artery. The dilator 645 can be introduced through the hemostasis valve 625 so that the tapered distal end 650 extends through the distal end of the sheath 605, as best seen in FIG. 7A. The dilator 645 can have a central lumen to accommodate a guide wire. Typically, the guide wire is placed first into the vessel, and the dilator/sheath combination travels over the guide wire as it is being introduced into the vessel.

[0068] Optionally, a sheath stopper 705 such as in the form of a tube may be provided which is coaxially received over the exterior of the distal sheath 605, also as seen in FIG. 7A. The sheath stopper 705 is configured to act as a sheath stopper to prevent the sheath from being inserted too far into the vessel. The sheath stopper 705 is sized and shaped to be positioned over the sheath body 605 such that it covers a portion of the sheath body 605 and leaves a distal portion of the sheath body 605 exposed. The sheath stopper 705 may have a flared proximal end 710 that engages the adapter 620, and a distal end 715. Optionally, the distal end 715 may be beveled, as shown in FIG. 7B. The sheath stopper 705 may serve at least two purposes. First, the length of the sheath stopper 705 limits the introduction of the sheath 605 to the exposed distal portion of the sheath 605, as seen in FIG. 7A, such that the sheath insertion length is limited to the exposed distal portion of the sheath. In an embodiment, the sheath stopper limits the exposed distal portion to a range between 2 and 3 cm. In an embodiment, the sheath stopper limited the exposed distal portion to 2.5 cm. In other words, the sheath stopper may limit insertion of the sheath into the artery to a range between about 2 and 3 cm or to 2.5 cm. Second, the sheath stopper 705 can engage a pre-deployed puncture closure device disposed in the carotid artery wall, if present, to permit the sheath 605 to be withdrawn without dislodging the closure device. The sheath stopper 705

may be manufactured from clear material so that the sheath body may be clearly visible underneath the sheath stopper 705. The sheath stopper 705 may also be made from flexible material, or the sheath stopper 705 include articulating or sections of increased flexibility so that it allows the sheath to bend as needed in a proper position once inserted into the artery. The sheath stopper may be plastically bendable such that it can be bent into a desired shape such that it retains the shape when released by a user. The distal portion of the sheath stopper may be made from stiffer material, and the proximal portion may be made from more flexible material. In an embodiment, the stiffer material is 85A durometer and the more flexible section is 50A durometer. In an embodiment, the stiffer distal portion is 1 to 4 cm of the sheath stopper 705. The sheath stopper 705 may be removable from the sheath so that if the user desired a greater length of sheath insertion, the user could remove the sheath stopper 705, cut the length (of the sheath stopper) shorter, and re-assemble the sheath stopper 705 onto the sheath such that a greater length of insertable sheath length protrudes from the sheath stopper 705.

[0069] FIG. 7C shows another embodiment of a sheath stopper 705 positioned adjacent a sheath 605 with a dilator 645 positioned therein. The sheath stopper 705 of FIG. 7C may be deformed from a first shaped, such as a straight shape, into a second different from the first shape wherein the sheath stopper retains the second shape until a sufficient external force acts on the sheath stopper to change its shape. The second shape may be for example non-straight, curved, or an otherwise contoured or irregular shape. For example, FIG. 7C shows the sheath stopper 705 having multiple bends as well as straight sections. FIG. 7C shows just an example and it should be appreciated that the sheath stopper 705 may be shaped to have any quantity of bends along its longitudinal axis. FIG. 7D shows the sheath stopper 705 positioned on the sheath 605. The sheath stopper 705 has a greater stiffness than the sheath 605 such that the sheath 605 takes on a shape or contour that conforms to the shape of contour of the sheath stopper 705.

[0070] The sheath stopper 705 may be shaped according to an angle of the sheath insertion into the artery and the depth of the artery or body habitus of the patient. This feature reduces the force of the sheath tip in the blood vessel wall, especially in cases where the sheath is inserted at a steep angle into the vessel. The sheath stopper may be bent or otherwise deformed into a shape that assists in orienting the sheath coaxially with the artery being entered even if the angle of the entry into the arterial incision is relatively steep. The sheath stopper may be shaped by an operator prior to sheath insertion into the patient. Or,

the sheath stopper may be shaped and/or re-shaped *in situ* after the sheath has been inserted into the artery. FIGs. 7E and 7F show an example of the malleable sheath stopper 705 in use. FIG. 7E shows the sheath stopper 705 positioned on the sheath 605 with the sheath stopper 705 in a straight shape. The sheath 605 takes on the straight shape of the sheath stopper 705 and is entering the artery A at a relatively steep angle such that the distal tip of the sheath 605 abuts or faces the wall of the artery. In FIG. 7F, a user has bent the sheath stopper 705 so as to adjust the angle of entry of the sheath 605 so that the longitudinal axis of the sheath 605 is more aligned with the axis of the artery A. In this manner, the sheath stopper 705 has been formed by a user into a shape that assists in directing the sheath 605 away from the opposing wall of the artery A and into a direction that is more coaxial with the axis of the artery A relative to the shape in FIG. 7E.

[0071] In an embodiment, the sheath stopper 705 is made from malleable material, or with an integral malleable component positioned on or in the sheath stopper. In another embodiment, the sheath stopper is constructed to be articulated using an actuator such as concentric tubes, pull wires, or the like. The wall of the sheath stopper may be reinforced with a ductile wire or ribbon to assist it in holding its shape against external forces such as when the sheath stopper encounters an arterial or entryway bend. Or the sheath stopper may be constructed of a homogeneous malleable tube material, including metal and polymer. The sheath stopper body may also be at least partially constructed of a reinforced braid or coil capable of retaining its shape after deformation.

[0072] Another sheath stopper embodiment is configured to facilitate adjustment of the sheath stopper position (relative to the sheath) even after the sheath is positioned in the vessel. One embodiment of the sheath stopper includes a tube with a slit along most or all of the length, so that the sheath stopper can be peeled away from the sheath body, moved forward or backwards as desired, and then re-positioned along the length of the sheath body. The tube may have a tab or feature on the proximal end so it may be grasped and more easily to peel away.

[0073] In another embodiment, the sheath stopper is a very short tube (such as a band), or ring that resides on the distal section of the sheath body. The sheath stopper may include a feature that could be grasped easily by forceps, for example, and pulled back or forwards into a new position as desired to set the sheath insertion length to be appropriate for the procedure. The sheath stopper may be fixed to the sheath body through either friction from the tube material, or a clamp that can be opened or closed against the sheath body. The

clamp may be a spring-loaded clamp that is normally clamped onto the sheath body. To move the sheath stopper, the user may open the clamp with his or her fingers or an instrument, adjust the position of the clamp, and then release the clamp. The clamp is designed not to interfere with the body of the sheath.

[0074] In another embodiment, the sheath stopper includes a feature that allows suturing the sheath stopper and sheath to the tissue of the patient, to improve securement of the sheath and reduce risk of sheath dislodgement. The feature may be suture eyelets that are attached or molded into the sheath stopper tube.

[0075] In another embodiment, as shown in FIG. 9A, the sheath stopper 705 includes a distal base or flange 710 sized and shaped to distribute the force of the sheath stopper over a larger area on the vessel wall and thereby reduce the risk of vessel injury or accidental insertion of the sheath stopper through the arteriotomy and into the vessel. The flange 710 may have a rounded shape or other atraumatic shape that is sufficiently large to distribute the force of the sheath stopper over a large area on the vessel wall. In an embodiment, the flange is inflatable or mechanically expandable. For example, the arterial sheath and sheath stopper may be inserted through a small puncture in the skin into the surgical area, and then expanded prior to insertion of the sheath into the artery.

[0076] The sheath stopper may include one or more cutouts or indents 720 along the length of the sheath stopper which are patterned in a staggered configuration such that the indents increase the bendability of the sheath stopper while maintaining axial strength to allow forward force of the sheath stopper against the arterial wall. The indents may also be used to facilitate securement of the sheath to the patient via sutures, to mitigate against sheath dislodgement. The sheath stopper may also include a connector element 730 on the proximal end which corresponds to features on the arterial sheath such that the sheath stopper can be locked or unlocked from the arterial sheath. For example, the connector element is a hub with generally L-shaped slots 740 that correspond to pins 750 on the hub to create a bayonet mount-style connection. In this manner, the sheath stopper can be securely attached to the hub to reduce the likelihood that the sheath stopper will be inadvertently removed from the hub unless it is unlocked from the hub.

[0077] The distal sheath 605 can be configured to establish a curved transition from a generally anterior-posterior approach over the common carotid artery to a generally axial luminal direction within the common carotid artery. Arterial access through the

common carotid arterial wall either from a direct surgical cut down or a percutaneous access may require an angle of access that is typically larger than other sites of arterial access. This is due to the fact that the common carotid insertion site is much closer to the treatment site (i.e., carotid bifurcation) than from other access points. A larger access angle is needed to increase the distance from the insertion site to the treatment site to allow the sheath to be inserted at an adequate distance without the sheath distal tip reaching the carotid bifurcation. For example, the sheath insertion angle is typically 30-45 degrees or even larger via a transcarotid access, whereas the sheath insertion angle may be 15-20 degrees for access into a femoral artery. Thus the sheath must take a greater bend than is typical with introducer sheaths, without kinking and without causing undue force on the opposing arterial wall. In addition, the sheath tip desirably does not abut or contact the arterial wall after insertion in a manner that would restrict flow into the sheath. The sheath insertion angle is defined as the angle between the luminal axis of the artery and the longitudinal axis of the sheath.

[0078] The sheath body 605 can be formed in a variety of ways to allow for this greater bend required by the angle of access. For example, the sheath and/or the dilator may have a combined flexible bending stiffness less than typical introducer sheaths. In an embodiment, the sheath/dilator combination (i.e., the sheath with the dilator positioned inside the sheath) has a combined flexible stiffness ($E \cdot I$) in the range of about 80 and $100 \text{ N-m}^2 \times 10^{-6}$, where E is the elastic modulus and I is the area moment of inertia of the device. The sheath alone may have a bending stiffness in the range of about 30 to $40 \text{ N-m}^2 \times 10^{-6}$ and the dilator alone has a bending stiffness in the range of about 40 to $60 \text{ N-m}^2 \times 10^{-6}$. Typical sheath/dilator bending stiffnesses are in the range of 150 to $250 \text{ N-m}^2 \times 10^{-6}$. The greater flexibility may be achieved through choice of materials or design of the reinforcement. For example, the sheath may have a ribbon coil reinforcement of stainless steel with dimensions .002" to .003" thick and .005" to .015" width, and with outer jacket durometer of between 40 and 55D. In an embodiment, the coil ribbon is .003" x .010", and the outer jacket durometer is 45D. In an embodiment, the sheath 605 can be pre-shaped to have a curve or an angle some set distance from the tip, typically 0.5 to 1 cm. The pre-shaped curve or angle can typically provide for a turn in the range from 5° to 90° , preferably from 10° to 30° . For initial introduction, the sheath 605 can be straightened with an obturator or other straight or shaped instrument such as the dilator 645 placed into its lumen. After the sheath 605 has been at least partially introduced through the percutaneous or other arterial wall penetration, the obturator can be withdrawn to allow the sheath 605 to reassume its pre-shaped configuration

into the arterial lumen. To retain the curved or angled shape of the sheath body after having been straightened during insertion, the sheath may be heat set in the angled or curved shape during manufacture. Alternately, the reinforcement structure may be constructed out of nitinol and heat shaped into the curved or angled shape during manufacture. Alternately, an additional spring element may be added to the sheath body, for example a strip of spring steel or nitinol, with the correct shape, added to the reinforcement layer of the sheath.

[0079] Other sheath configurations include having a deflection mechanism such that the sheath can be placed and the catheter can be deflected *in situ* to the desired deployment angle. In still other configurations, the catheter has a non-rigid configuration when placed into the lumen of the common carotid artery. Once in place, a pull wire or other stiffening mechanism can be deployed in order to shape and stiffen the sheath into its desired configuration. One particular example of such a mechanism is commonly known as "shape-lock" mechanisms as well described in medical and patent literature.

[0080] Another sheath configuration comprises a curved dilator inserted into a straight but flexible sheath, so that the dilator and sheath are curved during insertion. The sheath is flexible enough to conform to the anatomy after dilator removal.

[0081] Another sheath embodiment is a sheath that includes one or more flexible distal sections, such that once inserted and in the angled configuration, the sheath is able to bend at a large angle without kinking and without causing undue force on the opposing arterial wall. In one embodiment, there is a distalmost section of sheath body 605 which is more flexible than the remainder of the sheath body. For example, the flexural stiffness of the distalmost section is one half to one tenth the flexural stiffness of the remainder of the sheath body 605. In an embodiment, the distalmost section has a flexural stiffness in the range 30 to 300 N-mm² and the remaining portion of the sheath body 605 has a flexural stiffness in the range 500 to 1500 N-mm². For a sheath configured for a CCA access site, the flexible, distal most section comprises a significant portion of the sheath body 222 which may be expressed as a ratio. In an embodiment, the ratio of length of the flexible, distalmost section to the overall length of the sheath body 222 is at least one tenth and at most one half the length of the entire sheath body 222. This change in flexibility may be achieved by various methods. For example, the outer jacket may change in durometer and/or material at various sections. Alternately, the reinforcement structure or the materials may change over the length of the sheath body. In an embodiment, the distal-most flexible section ranges from 1 cm to 3 cm. In an embodiment with more than one flexible section, a less flexible

section (with respect to the distal-most section) may be 1 cm to 2 cm from the distal-most proximal section. In an embodiment, the distal flexible section has a bending stiffness in the range of about 30 to $50 \text{ N-m}^2 \times 10^{-6}$ and the less flexible section has a bending stiffness in the range of about 50 and $100 \text{ N-m}^2 \times 10^{-6}$. In another embodiment, a more flexible section is located between 0.5 and 1.5 cm for a length of between 1 and 2 cm, to create an articulating section that allows the distal section of the sheath to align more easily with the vessel axis though the sheath enters the artery at an angle. These configurations with variable flexibility sections may be manufactured in several manners. For example the reinforced, less flexible section may vary such that there is stiffer reinforcement in the proximal section and more flexible reinforcement in the distal section or in the articulating section. In an embodiment, an outer-most jacket material of the sheath is 45D to 70D durometer in the proximal section and 80A to 25D in the distalmost section. In an embodiment, the flexibility of the sheath varies continuously along the length of the sheath body. FIG. 7G shows such a sheath inserted in the artery, with the flexible distal section allowing the sheath body to bend and the distal tip to be in general alignment with the vessel lumen. In an embodiment, the distal section is made with a more flexible reinforcement structure, either by varying the pitch of a coil or braid or by incorporating a cut hypotube with differing cut patterns. Alternately the distal section has a different reinforcement structure than the proximal section.

[0082] In an embodiment, the distal sheath tapered tip is manufactured from harder material than the distal sheath body. A purpose of this is to facilitate ease of sheath insertion by allowing for a very smooth taper on the sheath and reduce the change of sheath tip distortion or ovalizing during and after sheath insertion into the vessel. In one example the distal tapered tip material is manufactured from a higher durometer material, for example a $60\text{-}72\text{D}$ shore material. In another example, distal tip is manufactured from a separate material, for example HDPE, stainless steel, or other suitable polymers or metals. In an additional embodiment, the distal tip is manufactured from radiopaque material, either as an additive to the polymer material, for example tungsten or barium sulfate, or as an inherent property of the material (as is the case with most metal materials).

[0083] In another embodiment, the dilator 645 may also have variable stiffness. For example the tapered tip 650 of the dilator may be made from more flexible material than the proximal portion of the dilator, to minimize the risk of vessel injury when the sheath and dilator are inserted into the artery. In an embodiment, the distal flexible section has a bending stiffness in the range of about 45 to $55 \text{ N-m}^2 \times 10^{-6}$ and a less flexible proximal

section has a bending stiffness in the range of about 60 and 90 N-m² x 10⁻⁶. The taper shape of the dilator may also be optimized for transcarotid access. For example, to limit the amount of sheath and dilator tip that enter the artery, the taper length and the amount of the dilator that extends past the sheath should be shorter than typical introducer sheaths. For example, the taper length may be 1 to 1.5 cm, and extend 1.5 to 2 cm from the end of the sheath body. In an embodiment, the dilator contains a radiopaque marker at the distal tip so that the tip position is easily visible under fluoroscopy.

[0084] In another embodiment, the introducer guide wire is optimally configured for transcarotid access. Typically when inserting an introducer sheath into a vessel, an introducer guide wire is first inserted into the vessel. This may be done either with a micropuncture technique or a modified Seldinger technique. Usually there is a long length of vessel in the direction that the sheath is to be inserted into which an introducer guidewire may be inserted, for example into the femoral artery. In this instance, a user may introduce a guide wire between 10 and 15 cm or more into the vessel before inserting the sheath. The guide wire is designed to have a flexible distal section so as not to injure the vessel when being introduced into the artery. The flexible section of an introducer sheath guide wire is typically 5 to 6 cm in length, with a gradual transition to the stiffer section. Inserting the guide wire 10 to 15 cm means the stiffer section of the guide wire is positioned in the area of the puncture and allows a stable support for subsequent insertion of the sheath and dilator into the vessel. However, in the case of transcarotid sheath insertion into the common carotid artery, there is a limit on how much guide wire may be inserted into the carotid artery. In cases with carotid artery disease at the bifurcation or in the internal carotid artery, it is desirable to minimize the risk of emboli by inserting the wire into the external carotid artery (ECA), which would mean only about 5 to 7 cm of guide wire insertion, or to stop it before it reaches the bifurcation, which would be only 3 to 5 cm of guide wire insertion. Thus, a transcarotid sheath guidewire may have a distal flexible section of between 3 and 4 cm, and/or a shorter transition to a stiffer section. Alternately, a transcarotid sheath guidewire has an atraumatic tip section but have a very distal and short transition to a stiffer section. For example, the soft tip section is 1.5 to 2.5 cm, followed by a transition section with length from 3 to 5 cm, followed by a stiffer proximal segment, with the stiffer proximal section comprising the remainder of the wire.

[0085] In addition to the configurations described above, features may be included in the introducer guide wire, or the micropuncture catheter, or the micropuncture

catheter guide wire, to prevent inadvertent advancement of these devices into the diseased portion of the carotid artery. For example, a stopper feature may be positioned over the introducer guide wire, micropuncture catheter and/or the micropuncture guide wire to limit the length these devices can be inserted. The stopper feature may be, for example, a short section of tubing which can be slideably positioned on the device, and once positioned remains in place on the device via friction. For example, the stopper feature may be manufactured from soft polymer material such as silicone rubber, polyurethane, or other thermoplastic elastomer. The stopper feature may have an inner diameter the same size or even slightly smaller than the device diameter. Alternately the stopper feature may be configured to clamp on to the device, such that the user must squeeze or otherwise unlock the stopper feature to unclamp and reposition the device, and then release or otherwise relock the stopper feature onto the device. The stopper feature may be positioned for optimal entry into the vessel based on location of the puncture site, distance of the bifurcation with respect to the puncture site, and amount of disease in the carotid bifurcation.

[0086] The sheath guide wire may have guide wire markings to help the user determine where the tip of the wire is with respect to the dilator. For example, there may be a marking on the proximal end of the wire corresponding to when the tip of the wire is about to exit the micro access cannula tip. This marking would provide rapid wire position feedback to help the user limit the amount of wire insertion. In another embodiment, the wire may include an additional mark to let the user know the wire has exited the cannula by a set distance, for example 5 cm. Alternately, the introducer guide wire, micropuncture catheter and/or the micropuncture guide wire may be constructed or have sections constructed out of material which is markable with a marking pen, wherein the mark is easily visible in a cath lab or operating room (OR) setting. In this embodiment, the user pre-marks the components based on the anatomic information as described above, and uses these marks to determine the amount of maximal insertion for each component. For example, the guide wires may have a white coating around the section to be marked.

[0087] In an embodiment, the sheath has built-in puncturing capability and atraumatic tip analogous to a guide wire tip. This eliminates the need for needle and wire exchange currently used for arterial access according to the micropuncture technique, and can thus save time, reduce blood loss, and require less surgeon skill.

[0088] In another embodiment, the sheath dilator is configured to be inserted over an 0.018" guide wire for transcarotid access. Standard sheath insertion using a

micropuncture kit requires first insertion of an .018" guide wire through a 22 Ga needle, then exchange of the guide wire to an .035" or .038" guide wire using a micropuncture catheter, and finally insertion of the sheath and dilator over the .035" or .038" guide wire. There exist sheaths which are insertable over a .018" guidewire, thus eliminating the need for the wire exchange. These sheaths, usually labeled "transradial" as they are designed for insertion into the radial artery, typically have a longer dilator taper, to allow an adequate diameter increase from the .018" wire to the body of the sheath. Unfortunately for transcarotid access, the length for sheath and dilator insertion is limited and therefore these existing sheaths are not appropriate. Another disadvantage is that the .018" guide wire may not have the support needed to insert a sheath with a sharper angle into the carotid artery. In the embodiment disclosed here, a transcarotid sheath system includes a sheath body, a sheath dilator, and an inner tube with a tapered distal edge that slidably fits inside the sheath dilator and can accommodate an .018" guide wire.

[0089] To use this sheath system embodiment, the .018" guide wire is first inserted into the vessel through a 22 Ga needle. The sheath system which is coaxially assembled is inserted over the .018" wire. The inner tube is first advanced over the .018" wire which essentially transforms it into the equivalent of an .035" or .038" guide wire in both outer diameter and mechanical support. It is locked down to the .018" wire on the proximal end. The sheath and dilator are then advanced over the .018" wire and inner tube into the vessel. This configuration eliminates the wire exchange step without the need for a longer dilator taper as with current transradial sheaths and with the same guide wire support as standard introducer sheaths. As described above, this configuration of sheath system may include stopper features which prevent inadvertent advancement too far of the .018" guide wire and/or inner tube during sheath insertion. Once the sheath is inserted, the dilator, inner tube, and .018" guide wire are removed.

[0090] FIG. 8A shows another embodiment of the arterial access device 110. This embodiment is substantially the same as the embodiment shown in FIG. 6A, except that the distal sheath 605 includes an occlusion element 129 for occluding flow through, for example the common carotid artery. If the occluding element 129 is an inflatable structure such as a balloon or the like, the sheath 605 can include an inflation lumen that communicates with the occlusion element 129. The occlusion element 129 can be an inflatable balloon, but it could also be an inflatable cuff, a conical or other circumferential element which flares outwardly to engage the interior wall of the common carotid artery to

block flow therepast, a membrane-covered braid, a slotted tube that radially enlarges when axially compressed, or similar structure which can be deployed by mechanical means, or the like. In the case of balloon occlusion, the balloon can be compliant, non-compliant, elastomeric, reinforced, or have a variety of other characteristics. In an embodiment, the balloon is an elastomeric balloon which is closely received over the exterior of the distal end of the sheath prior to inflation. When inflated, the elastomeric balloon can expand and conform to the inner wall of the common carotid artery. In an embodiment, the elastomeric balloon is able to expand to a diameter at least twice that of the non-deployed configuration, frequently being able to be deployed to a diameter at least three times that of the undeployed configuration, more preferably being at least four times that of the undeployed configuration, or larger.

[0091] As shown in FIG. 8B, the distal sheath 605 with the occlusion element 129 can have a stepped or other configuration having a reduced diameter distal region 630. The distal region 630 can be sized for insertion into the carotid artery with the remaining proximal region of the sheath 605 having larger outside and luminal diameters, with the inner diameter typically being in the range from 2.794 mm (0.110 inch) to 3.43 mm (0.135 inch). The larger luminal diameter of the proximal region minimizes the overall flow resistance of the sheath. In an embodiment, the reduced-diameter distal section 630 has a length of approximately 2 cm to 4 cm. The relatively short length of the reduced-diameter distal section 630 permits this section to be positioned in the common carotid artery CCA via the transcarotid approach with reduced risk that the distal end of the sheath 605 will contact the bifurcation B.

[0092] In a situation with a sharp sheath insertion angle and/or a short length of sheath inserted in the artery, such as one might see in a transcarotid access procedure, the distal tip of the sheath has a higher likelihood of being partially or totally positioned against the vessel wall, thereby restricting flow into the sheath. In an embodiment, the sheath is configured to center the tip in the lumen of the vessel. One such embodiment includes a balloon such as the occlusion element 129 described above. In another embodiment, a balloon may not be occlusive to flow but still center the tip of the sheath away from a vessel wall, like an inflatable bumper. In another embodiment, expandable features are situated at the tip of the sheath and mechanically expanded once the sheath is in place. Examples of mechanically expandable features include braided structures or helical structures or longitudinal struts which expand radially when shortened.

[0093] In an embodiment, occlusion of the vessel proximal to the distal tip of the sheath may be done from the outside of the vessel, as in a Rumel tourniquet or vessel loop proximal to sheath insertion site. In an alternate embodiment, an occlusion device may fit externally to the vessel around the sheath tip, for example an elastic loop, inflatable cuff, or a mechanical clamp that could be tightened around the vessel and distal sheath tip. In a system of flow reversal, this method of vessel occlusion minimizes the area of static blood flow, thereby reducing risk of thrombus formation, and also ensure that the sheath tip is axially aligned with vessel and not partially or fully blocked by the vessel wall.

[0094] Another arterial access device is shown in FIGs. 9A – 9D. This configuration has a different style of connection to the flow shunt than the versions described previously. FIG. 9A shows the components of the arterial access device 110 including arterial access sheath 605, sheath dilator 645, sheath stopper 705, and sheath guidewire 611. Figure 9B shows the arterial access device 110 as it would be assembled for insertion over the sheath guide wire 611 into the carotid artery. After the sheath is inserted into the artery and during the procedure, the sheath guide wire 611 and sheath dilator 705 are removed. In this configuration, the sheath has a sheath body 605, proximal extension 610, and proximal hemostasis valve 625 with flush line 635 and stopcock 640. The proximal extension 610 extends from a Y-adapter 660 to the hemostasis valve 625 where the flush line 635 is connected. The sheath body 605 is the portion that is sized to be inserted into the carotid artery and is actually inserted into the artery during use.

[0095] Instead of a Y-connector with a flow line connection terminating in a valve, the sheath has a Y-adaptor 660 that connects the distal portion of the sheath to the proximal extension 610. The Y-adapter can also include a valve 670 that can be operated to open and close fluid connection to a connector or hub 680 that can be removably connected to a flow line such as a shunt. The valve 670 is positioned immediately adjacent to an internal lumen of the adapter 660, which communicates with the internal lumen of the sheath body 605. FIGs. 9C and 9D show details in cross section of the Y-adaptor 660 with the valve 670 and the hub 680. FIG. 9C shows the valve closed to the connector. This is the position that the valve would be in during prep of the arterial sheath. The valve is configured so that there is no potential for trapped air during prep of the sheath. FIG. 9D shows the valve open to the connector. This position would be used once the flow shunt 120 is connected to hub 680, and would allow blood flow from the arterial sheath into the shunt. This configuration eliminates the need to prep both a flush line and flow line, instead allowing prep from the

single flush line 635 and stopcock 640. This single-point prep is identical to prep of conventional introducer sheaths which do not have connections to shunt lines, and is therefore more familiar and convenient to the user. In addition, the lack of flow line on the sheath makes handling of the arterial sheath easier during prep and insertion into the artery.

[0096] With reference again to FIG. 9A, the sheath may also contain a second more distal connector 690, which is separated from the Y-adaptor 660 by a segment of tubing 665. A purpose of this second connector and the tubing 665 is to allow the valve 670 to be positioned further proximal from the distal tip of the sheath, while still limiting the length of the insertable portion of the sheath 605, and therefore allow a reduced level of exposure of the user to the radiation source as the flow shunt is connected to the arterial sheath during the procedure. In an embodiment, the distal connector 690 contains suture eyelets to aid in securement of the sheath to the patient once positioned.

[0097] During a transcarotid artery revascularization (TCAR) procedure, the arterial sheath 605 can be inserted into the common carotid artery (CCA) of the patient. As described elsewhere herein, to achieve reverse flow of blood, the CCA may be occluded to stop antegrade blood flow from the aorta through the CCA. Flow through the CCA can be occluded with an external vessel loop or tape, a vascular clamp, an internal occlusion member such as a balloon, or other type of occlusion means. When flow through CCA is blocked, the natural pressure gradient between the internal carotid artery (ICA) and the venous system will cause blood to flow in a retrograde or reverse direction from the cerebral vasculature. Blood from the ICA and the external carotid artery (ECA) flows in a retrograde direction and the systems described herein allow the retrograde blood to flow into the sheath 605, through the flow controller 1130, the venous sheath 910, and then returned into the patient's femoral vein as described elsewhere herein. Loose embolic material can be carried with the retrograde blood flow into the arterial sheath 605.

[0098] FIGs. 13A-13B illustrate an arterial sheath 605 inserted within a vessel V, such as the carotid artery, exposed through an incision I. A sheath guidewire 611 and an arterial access sheath dilator 645 protrude out from a distal opening 641 near the distal region 630 of the sheath 605. A sheath stopper 705 can be used with the sheath 605, as described elsewhere herein. Manual occlusion of the vessel V by a clinician at an occlusion location proximal to the distal tip of the sheath 605 may be provided from the outside of the vessel V using a vascular clamp 800, such as a Rumel tourniquet or vessel loop positioned proximal to the sheath insertion site. An occlusion device may fit externally to the vessel V around the

sheath tip, for example, an elastic loop, inflatable cuff, or a mechanical clamp that can be tightened around the vessel and the distal sheath tip. In a flow reversal system, this type of vessel occlusion can minimize creation of a zone of static blood flow, thereby reducing the risk of thrombus formation. This also ensures that the sheath tip is axially aligned with the vessel V and avoids partially or fully blocking the distal opening 641 by the vessel wall.

[0099] During a non-limiting implementation of a transcarotid artery revascularization procedure, the sheath 605 is inserted into the common carotid artery (CCA) of the patient. To achieve reverse flow of blood, the CCA is clamped, which stops antegrade blood flow from the aorta through the CCA. Blood from the internal and external carotid arteries then flows in a retrograde direction into the sheath 605 (then into the flow controller, venous sheath (when used), and then into the patient's femoral vein if a venous sheath is used. Loose embolic material is carried with the blood into the sheath 605 via the reverse flow.

[00100] Despite these clamp techniques, the zone of static blood flow can still be created. FIG. 13B illustrates a system for retrograde blood flow into the distal opening 641 of the arterial sheath 605 after removal of the access sheath dilator 645. The location of the vascular clamp 800 in FIG. 13B is partially obscured by the presence of the sheath stopper 705. Embolic material within the retrograde blood flow may drift and be trapped within a zone 905 of static blood flow within the vessel V between the distal opening 641 of the arterial sheath 605 and the location of the vascular clamp 800 proximal to the sheath insertion location. Embolic material may remain within this zone 905 rather than flow into the distal opening 641 of the arterial sheath 605. Once the target vessel has been treated by the operator, the vascular clamp 800 is released permitting resumption of antegrade blood flow. Embolic material from this zone 905 may then be carried into the neurovasculature when the vascular clamp 800 is released and antegrade blood flow resumes. The trapped embolic material within the zone 905 may cause an ischemic event despite the use of reverse flow embolic protection during the procedure because it fails to ever enter the lumen of the arterial sheath 605 during the period of retrograde flow.

Sheath Stopper and Rumel Tourniquet Implementations

[00101] As discussed above, the sheath stopper 705 is configured to limit insertion length of the sheath 605 into the artery, such as limiting the sheath 605 to being inserted only 2.5 cm into the artery for example. One reason for this is to minimize the risk of

the tip of the sheath 605 inadvertently contacting diseased portions of the carotid artery during insertion of the sheath 605. With only a small length of sheath insertion (such as 2.5 cm), there is risk that the arterial sheath 605 may inadvertently become dislodged from the artery, leading to bleeding and the need to re-access the sheath 605 into the artery.

Decreasing the length of sheath insertion into the artery (without negatively impacting sheath stability) may have the following benefits: (1) it decreases the risk of inadvertent sheath dilator contact with the disease artery; and (2) it decreases the length of the zone 905 (described above with reference to Figure 13B).

[00102] There is now disclosed an alternative version of the sheath stopper 705 that is configured to reduce or eliminate the likelihood of the sheath 605 inadvertently become dislodged from the artery. Figure 15 shows an implementation of the sheath stopper 705 wherein the distal base 710 of the sheath stopper 705 includes one or more eyelets 1505. The distal base 710 can be a portion of the sheath stopper that contacts an artery at an insertion location to the artery. A vessel attachment element, such as an elastic vessel loop 1510, can be disposed and looped through the eyelets 1505 and can be used to secure the sheath stopper 705 to a vessel.

[00103] With the sheath 605 inserted into the artery and the distal base 710 of the sheath stopper 705 positioned against an anterior wall of the artery, the vessel loop 1510 may be passed through one eyelet 1505, wrapped around the artery A (or blood vessel), then passed through the second eyelet 1505, as shown in Figure 16. In the configuration shown in Figure 16, a first eyelet 1505a is a simple, closed hole positioned through the distal base 710 of the sheath stopper 705. A second eyelet 1505b optionally includes a slot that extends to an edge of the base of the sheath stopper 705. The slot allows for quick attachment or removal of the vessel loop relative to the base of the sheath stopper 705.

[00104] Wrapping the vessel loop 1510 around the artery A stabilizes the sheath 605 and sheath stopper 705 against the artery thereby reducing the likelihood of inadvertent sheath dislodgement. With the improvement of sheath stabilization provided by locally securing the arterial sheath to the blood vessel, it may be possible to reduce the length of sheath inserted into the artery relative to where the sheath stabilization feature not being present. The vessel loop 1510 may be tightened around the artery A to stop antegrade flow through the artery. In an example procedure, the artery A is clamped proximal to the sheath insertion point. By clamping the vessel at the base 710 of the sheath stopper 705, the length of the zone 905 is or can be reduced. When the vessel loop 1510 is tightened around the

artery, the tip of the sheath 605 effectively becomes centered within (and coaxial to) the artery A, which is desirable when delivering devices such as guidewires, balloon catheters, or stent delivery systems into the artery through the sheath.

[00105] The aforementioned implementation of the sheath stopper 705 thus provides several benefits including, for example: (1) Local securement of the sheath 605 to artery A which improves stability; (2) Tightening of the vessel loop around the artery and sheath which centers the sheath within artery and improves delivery of devices through the sheath; (3) Improved stability of the sheath, which reduces the required length of sheath insertion into artery; and (4) Clamping of the artery clamped at the base of the sheath stopper, which reduces the length of the zone 905.

[00106] Figure 17 shows an enlarged view of a distal base 710 of the sheath stopper 705 in an alternative implementation. The shape of the base 710 is curved or otherwise contoured to follow or complement a contour of an outer surface of the blood vessel (e.g., artery.) The contoured base 710 may serve to further improve the stability of the sheath and sheath stopper with respect to its connection to the artery in that the base 710 can sit flush against an outer surface of the artery. At least a portion of the distal base 710 can be made of a malleable, soft, or conformable material configured to atraumatically conform to an outer shape of an artery.

[00107] In yet another implementation of the sheath stopper 705 (or any elongate structure that interacts with a blood vessel), the sheath stopper 705 can have a distal base 710 that is configured to clamp to an artery. As shown in Figures 18A-18C, the distal base is formed of two or more clamping portions 1805. The clamping portions 1805 can be positioned around the artery including, for example, a first clamping portion that is configured to be positioned against an anterior surface of an artery. A second clamping portion is configured to be positioned against a posterior surface of the artery. A tightening component 1810, such as an elastic vessel, umbilical tape, tethering material, or the like is attached to the clamping portions 1805 such that the tightening component 1810 attaches both the anterior clamping portion and the posterior clamping portion. A user draws the clamping portions 1805 toward one another by tightening or otherwise tensioning the tightening component 1810. This causes the clamping portions 1805 to move toward one another and thereby clamp the artery between the clamping portions 1805. The clamping portions 1805 can have a contoured shape that complements or otherwise is configured to sit flush against an outer shape of the artery.

[00108] As discussed, Rumel Tourniquets are commonly used to secure catheters within blood vessels and may sometimes be used to create a vessel clamp in order to occlude blood flow. Figures 19A and 19B show sectional views of a Rumel Tourniquet or device for compressing an artery or vein. The device has a shaft 1905 (such as a Rumel shaft) and clamping member 1907 being used to secure a catheter 1910 within a blood vessel such as an artery A (with the artery A shown in partial view in order to show the inner catheter 1910.) When using a Rumel Tourniquet to occlude a blood vessel without an inner supportive catheter, folding or bunching of the vessel wall may occur as the tourniquet is tightened such as shown in Figure 19B. This may result in (a) incomplete occlusion of the vessel and/or (b) damage to the vessel. Such a situation may be mitigated or eliminated if a catheter is positioned within the vessel given that the catheter can take up a significant amount of space within the vessel so there is less “excess tissue” to wrinkle or pucker. However, if a Rumel Tourniquet is used to occlude a vessel outright (without the benefit of a supporting member like a catheter taking up excess space within the lumen), then there is an increased likelihood of the vessel puckering or folding. This can cause an incomplete seal of the blood vessel. In order to achieve a complete seal, the user may over-tighten the tourniquet which can result in vessel damage.

[00109] With reference to Figure 20 and Figure 21, there is now disclosed a vessel compression device configured to compress a blood vessel and configured to eliminate or reduce the likelihood of the vessel puckering or folding even when a support structure such as a catheter is not present in the vessel. . The device can be configured similarly to a Rumel tourniquet. The device includes an elongated shaft 2005 having a distal tip on which is formed a support structure 2010. The shaft 2005 may have an internal lumen. The support structure 2010 has an enlarged shape and can be circular in cross-section such that it has an outer surface that is atraumatic, such as rounded or convex. The support structure 2010 may also be hollow or tubular with an internal lumen. A clamping structure 2015 is movably coupled to the shaft 2005. The clamping structure can be any type of element configured to compress an artery, such as umbilical tape (e.g., cotton or dacron material). The tourniquet can be a flexible material. A distal portion of the tourniquet, such as a loop, can be tightened such as to a blood vessel when the blood vessel is positioned between the distal portion of the clamping structure and the support structure 2010. The support structure 2010 provides a support or “backstop” against which the artery A may be drawn as the clamping structure 2015 is tightened. In an embodiment, the support structure has a cylindrical cross-section

with a long axis of the cylinder being at an angle (such as a normal angle) relative to a long axis of the shaft 2005.

[00110] Figure 22 shows the modified Rumel tourniquet adjacent an artery A (or any blood vessel) wherein the artery is positioned adjacent the support structure 2010 and the clamping structure 2015 is coupled to both the support structure 2010 and the artery prior to tightening of the clamping structure 2015. In Figure 23, the clamping structure 2015 has been tightened to clamp the artery A against the support structure 2010. This results in a more predictable closure of the vessel. The clamping structure 2015 essentially flattens the artery A and minimize the amount of bunching and folding that may otherwise occur with a traditional Rumel Tourniquet.

[00111] In a nonlimiting example, the shaft 2005 and the support structure 2010 may be constructed from soft elastomeric materials (e.g., silicone tubing with a durometer range of 25A to 70A). The compliance of these softer materials mediates the amount of force applied to the vessel as the clamping structure 2015 is tightened, thereby reducing the probability of damaging the vessel by over-tightening. Figure 24 shows the modified Rumel tourniquet secured and tightened to a blood vessel V. The circular, hollow-tube cross-section of the support structure 2010 provides additional system compliance to mediate force during possible over-tightening of the clamping structure 2015.

[00112] In an alternate embodiment, the shaft 2005 and/or the support structure 2010 may be constructed from a rigid material, while the clamping structure 2015 is fabricated from an elastomeric or compliant material. Such material can include, in a non-limiting example, silicone with a durometer of 25A to 70A. The use of a compliant material for the clamping structure can reduce the likelihood of damage to the vessel due to over-tightening. The elastomeric clamping structure 2015 may have a shape, structure, or size configured to further mitigate against vessel damage. For example, width of the clamping structure can range from 1mm to 10mm, with an example width of 3-5mm. The width of the clamping structure distributes the force applied to the vessel across an increased area, enabling effective clamping of the vessel with less probability of causing damage to the vessel.

[00113] Figure 25 shows another implementation of a Rumel tourniquet device that couples to a sheath stopper 705 (or to at least a portion of the arterial access device described herein.) In one implementation, the Rumel tourniquet device is removably and/or

slidably coupled to the sheath stopper 705. In another implementation, the Rumel tourniquet is fixedly attached to the sheath stopper 705 such that it can't be moved or removed relative to the sheath stopper.

[00114] With reference to Figure 25, a coupling element such as a tubular coupling element 2605 is attached to the Rumel shaft 2005 such that it is positioned adjacent the shaft 2005. The coupling element 2605 defines an internal lumen through which the sheath stopper 705 is slidably positioned. The cross-sectional shape of the internal lumen of the coupling element 2605 can vary and can be selected to complement an outer shape of the sheath stopper 705 such as to facilitate sliding of the sheath stopper 705 through the coupling element 2605.

[00115] The coupling element 2605 can fixedly attached to the Rumel shaft 2005 but also allow sliding movement of the sheath stopper 705 through the coupling element 2605 and relative to the Rumel shaft 2005. When the Rumel shaft 2005 is not in use, the Rumel shaft 2005 may be slid in a proximal direction (i.e., to the right relative to Figure 25) relative to the sheath stopper 705 such that the Rumel shaft 2005 is moved out of the way. When a user wishes to apply a tourniquet, the Rumel shaft 2005 can be distantly advanced relative to the sheath stopper 705 such that the distal edge of the Rumel shaft 2005 is immediately adjacent or in direct contact with an outer surface of the blood vessel or the distal edge of the sheath stopper 705, as shown in Figure 26.

[00116] As shown in Figure 27, a cut out or relief 2705 can be located on the distal base of the sheath stopper 705 and/or Rumel shaft 2005. The relief 2705 is shaped to allow the Rumel shaft and/or sheath stopper to be advanced all the way in contact with an outer surface of the blood vessel. That is the relief 2705 is shaped so that an outer contour of the blood vessel can fit, such as in a snug manner, within the relief 2705.

[00117] Figures 28-30 show the Rumel shaft and sheath stopper in use with a blood vessel V. In Figure 28, the distal base 710 of the sheath stopper 705 is positioned adjacent to blood vessel V. The clamping structure 2015 is not yet tightened and the distal tip of the Rumel shaft 2005 is not yet positioned immediately adjacent to the blood vessel V. In Figure 29, the Rumel shaft 2005 is now positioned immediately adjacent to the blood vessel V as a result of the Rumel shaft 2005 sliding distally along the sheath stopper 705 via the coupling element 2605. The clamping structure 2015 is not yet fully tightened. In Figure 30, the clamping structure 2015 is tightened around the blood vessel V.

[00118] The disclosed system that combines the Rumel shaft and the sheath stopper facilitates proper positioning of the tourniquet. The presence of the coupling element 2605 makes it difficult if not impossible for the tourniquet to slip distal to the tip of the sheath 605. The coupling element 2605 is configured to secure or fix the position of the tourniquet relative to the sheath stopper such as to mitigate against the tourniquet from slipping distal to the sheath. If the tourniquet slips distal to the sheath tip, then the vessel can be completely occluded with respect to both antegrade and retrograde flow, which can be undesirable. If the tourniquet is properly secured around the sheath, then (1) antegrade flow in the carotid artery is occluded and (2) retrograde flow from the distal carotid artery into the sheath is permitted. The system also facilitates securement of the sheath 605 to the vessel thereby reducing the possibility that the sheath inadvertently becomes dislodged during manipulation of the sheath.

[00119] Figure 31 shows an embodiment of a clamping device that is configured to control or retract and expose blood vessel and/or to clamp the blood vessel. The device includes an elongated shaft 3115 that is sized and shaped to access a blood vessel. The shaft 3115 has a distal end on which a backstop or support structure 2010 is positioned. The support structure 2010 can be similarly configured to the support structure 2010 described above in that it has a rounded, curved, or atraumatic outer contour. The elongated shaft 3115 can have an internal lumen in which a clamping structure formed of a clamp 3110 is coaxially and slidably positioned. The clamp 3110 has a proximal, elongated portion that is slidably positioned within the internal lumen such that it can slide relative to the shaft 3115. The sliding movement can change or otherwise adjust the relative position between a distal end region of the clamp 3110 and the support structure 2010. Figure 32 shows the device with the clamp 3110 retracted into the shaft 3115 such that a distal region of the clamp 3110 abuts the support structure 2010.

[00120] With reference to Figures 32 and 33, the clamp 3110 has an elongated proximal region that extends through the internal lumen of the elongated shaft 3115. A distal region or end of the clamp 3110 has a hook region 3210. The hook region 3210 can have any of a variety of shapes including a rounded, hook-like structure that is sized and shaped to at least partially wrap around the support structure 2010 as shown in Figure 32. The hook region 3210 has a rounded portion that is a hook as well as a straight portion that can be offset (such as in a parallel manner) from a longitudinal axis defined by the elongated proximal portion of the clamp 3110. The hook region 3210 exits the internal lumen of the elongated shaft 3115 through a side hole in the elongated shaft 3115.

[00121] The clamp 3110 can be constructed of a rigid or semi rigid material. The hook region 3210 is shaped in such a manner that allows it to be safely placed around an exposed blood vessel. In this regard, the hook region 3210 can be shaped such as in a rounded manner to provide an atraumatic contact with a blood vessel. Once positioned around a vessel, the hook region 3210 can be used to manually suspend or retract the vessel. A user can capture the blood vessel between the hook region 3210 and the support structure 2010 so as to effectively clamp the blood vessel to temporarily prevent blood flow through the vessel. As mentioned, the hook region 3210 can be moved relative to the support structure 2010 so as to vary the amount of pressure that the hook region 3210 provides to the blood vessel when the blood vessel is positioned between the support structure 2010 and the hook region 3210.

[00122] Figures 33, 34, and 35 illustrate securement and clamping of a vessel V using the hook region 3210 of the clamp 3110. The hook region 3210 is sized and shaped to permit the hook region 3210 to clamp the blood vessel V in a manner that provides a uniform distribution of force around the blood vessel so as to reduce or eliminate the likelihood of the blood vessel bunching or puckering as can sometimes happen if using a Rumel tourniquet to clamp the vessel. This has the benefit of more reliably clamping the blood vessel since blood can sometimes leak through a bunched or puckered blood vessel clamp with a Rumel tourniquet. The clamping modality may also be less traumatic to the artery so as to reduce the risk of vessel damage or dissection.

[00123] The relative size and shape of the support structure 2010 and the hook region 3210 can be modified to enhance or otherwise optimize the clamping effect on the blood vessel and to also to minimize potential trauma to the blood vessel. For example, the width or contour of the hook region 3210 can be increased from the relative size shown in the figures so as to provide a broader size clamping zone. This can reduce the amount of pressure applied to the blood vessel required to prevent the blood from flowing through the blood vessel.

[00124] The hook region 3210 and the support structure 2010 can be shaped such that they provide flat, parallel clamping surfaces similar to the jaws of a traditional surgical vessel clamp. The hook region and the support structure may be constructed from, covered with, or at least partially constructed of a soft, elastic material that is less likely to cause damage to a vessel during clamping.

[00125] Figures 36 and 37 show the device in use with a blood vessel V via a surgical opening in the skin of a patient. The proximal shaft region of the clamp 3110 may at least partially be made of a malleable or flexible material to allow a portion of the device that sits outside of the patient's body to be easily configured to sit in an unobstructed or on obtrusive location while still maintaining retraction of the vessel. The shaft 3115 of the clamp 3110 may allow for spring expansion or compression thereby modulating the compressive force applied to the vessel to mitigate against damage. In an example embodiment the shaft 3115 is made of an elastomeric tubing material that modulates the maximum clamping force applied to the vessel.

[00126] Figure 38 shows another embodiment of the clamping device wherein the hook region 3210 of the clamp 3110 includes a leg 3805 that is longer or more pronounced relative to a corresponding leg of the embodiment previously described. The leg 3805 can be straight, curved or a combination thereof. The leg 3805 has a sufficient length such that it can extend past the entire diameter of the vessel V when the hook region 3210 is wrapped around the vessel V. Figure 38 shows the hook region 3210 wrapped around the vessel V with the vessel V spaced from the support structure 2010.

[00127] Figure 39 shows the device with the clamp 3110 partially retracted into the outer sheath such that the vessel V is secured in a space between the support structure 2010 and the hook region 3210. The hook region 3210 including the leg 3805 is sufficiently sized such that the vessel V can be secured within the space without the hook region 3210 applying any clamping force between the vessel V and the support structure 2010. That is, the hook region 3210 does not compress the vessel V against the support structure 2010 while still securing the vessel V in the space between the hook region 3210 and the support structure 2010.

[00128] As shown in Figure 40, the clamp 3110 can be further retracted into the outer sheath such that the hook region 3210 exerts a force on to the blood vessel V so as to clamp the blood vessel V between the support structure 2010 and the hook region 3210. That is, the hook region 3210 clamps the blood vessel V against the support structure 2010.

Fenestrated Sheath

[00129] FIG. 13C illustrates a distal end region of an implementation of an arterial sheath 605 having a fenestrated distal portion 643. The fenestrated distal portion 643 of the sheath 605 includes one or more side holes or fenestrations 646 in the side wall of the

sheath 605. As described above, blood from zone 905 may potentially contain embolic material that would otherwise flow into the neurovasculature upon release of the vascular clamp 800. Material from this zone 905 can enter the sheath 605 through the fenestrations 646 in the sidewall of the sheath 605. The fenestrations 646 can also maintain flow into the sheath 605 even if the distal opening 641 at the distal tip of sheath 605 is partially or fully blocked by arterial wall. Blood and any embolic material can flow into the lumen of the sheath 604 through the one or more fenestrations 646 and transported proximally through the embolic protection system with the retrograde blood flow.

[00130] The location, distribution, shape, and size of the fenestrations 646 can vary. The fenestrations 646 can be distributed longitudinally and/or circumferentially along the distal portion 643 of the arterial sheath 605. The location and distribution of the fenestrations 646 can be selected based on whether a sheath stopper 705 is to be used with the sheath 605. For example, a sheath stopper 705 can be positioned on the arterial sheath 605 to limit an insertion depth of the sheath 605 into the vessel. In some implementations, the sheath stopper 705 limits the insertion depth to 2.5 cm. Thus, the one or more fenestrations 646 can be distributed along the distal-most 2.5 cm of the sheath 605. Fenestrations 646 may also be distributed along the sheath 605 over a greater distance. The proximal sheath fenestrations 646 sitting external to the vessel can be blocked by a sleeve or other feature of the system thereby preventing leakage.

[00131] As described elsewhere herein, the sheath 605 can be reinforced to provide improved flexibility and kink-resistance. The reinforcement can be a spiral-wound stainless steel ribbon, braid, or mesh as is known in the art. The one or more fenestrations 646 can be positioned such that they extend through and/or align with the side wall in the space(s) between the reinforcement material such that the fenestrations 646 and the space(s) collectively form passageways through which fluid can flow into the internal lumen of the sheath 605. The spaces within the reinforcement layer can include gaps between individual coils, circular or diamond-shaped holes through the braid or mesh, etc. The fenestrations 646 through the sidewall of the sheath 605 align with these spaces or gaps in the reinforcement layer thereby providing additional entrance points for blood and embolic material while maintaining the structural benefits of the reinforcement layer. The orientation of the fenestrations 646 can be such that they align with these spaces between the reinforcement material (see FIG. 13D). The fenestrations 646 can vary in their number, size, and shape, including circular, oval, rectangular, or other elongate shape. The elongate fenestrations 646

can extend along an axis perpendicular or at an angle to the longitudinal axis of the sheath overall such that they fit within or align with the spaces between the reinforcement layer.

[00132] For example, as described elsewhere herein the arterial sheath 605 may have a ribbon coil reinforcement of stainless steel with dimensions .002" to .003" thick and .005" to .015" width. In an embodiment, the coil ribbon is .003" x .010". The nominal spacing between the reinforcement coils of the sheath 605 can vary, but generally is about 0.020". The elongated fenestrations 646 can thus have a width of about this size such that they extend through the wall between the reinforcement coils. In some implementations, the fenestrations 646 can be between about 0.010" to about 0.080", with a nominal range of about 0.015" – 0.020". Depending on the spacing between the reinforcement, the elongated fenestrations 646 can have a size between 0.015" x 0.030" to about 0.040" x 0.080". Elongated fenestrations 646 that fit between or within the gaps in the reinforcement material can be up to about 0.020", with a maximum envisioned dimension of about 0.020" x 0.080". It may be possible to vary the pitch of the coils as well as the width of the coil ribbon to adjust and optimize the flexibility and performance of the sheath 605 and the size of the fenestrations 646. For example, the reinforcement material can be a coil ribbon.

[00133] The width between the individual coils can be increased near where one or more fenestrations 646 would extend through the wall of the sheath 605. The width near this location can be increased from 0.020" to 0.050". The fenestrations 646 need not be limited to the location of the gaps in the reinforcement. For example, the reinforcement material can be a wire or polymer mesh. One or more regions of the mesh can be cut to create a larger sized space (while taking into consideration maintaining the overall functionality of the sheath) and the one or more fenestrations 646 co-located to that larger space.

[00134] The embolic protection system can include a passive method of driving retrograde blood flow into the distal opening 641 at the sheath tip and the fenestrations 646 in the distal end region 643, for example, by relying upon arterial-venous pressure differential. The embolic protection system can also incorporate active aspiration of blood through the arterial sheath 605 to enhance the withdrawal of embolic material into the distal opening 641 as well as through the fenestrations 646. The fenestrations 646 can also be useful in delivering materials into the vessel through the fenestrations 646. In some implementations, a gentle injection of saline through the lumen of the sheath 605 into the vessel through the fenestrations 646 can cause turbulence/agitation within the zone 905 of static blood. The

flush of fluid can induce any particulates trapped within the zone 905 to be drawn into the fluid flow path and to enter the sheath 605, either through the fenestrations 646 upon resumption of aspiration forces or through the distal opening 641.

[00135] The arterial sheath 605 having one or more fenestrations 646 on the distal end portion 643 can be delivered in combination with a delivery tool (not shown) configured to facilitate a smooth delivery into the vessel and prevent the edges of the fenestrations 646 from catching on tissue as the sheath 605 is inserted through the vessel wall. The fenestrations 646 may also impact delivery of guidewires, balloon catheters, or other devices through the lumen of the arterial sheath 605. As such, the arterial sheath 605 can incorporate a secondary sleeve on the inside or outside of the arterial sheath 605. The secondary sleeve can be initially positioned such that the sheath fenestrations 646 are covered or closed, thereby permitting smooth passage of guidewires and other devices through the lumen of the arterial sheath 605. Once the devices have been passed through the sheath, the secondary sleeve can be rotated, advanced and/or retracted to uncover or open the fenestrations. A lubricious coating of material on the inner and/or outer surfaces of the sheath 605 can be provided to improve advancement of materials. In addition, a coating of heparin can be provided to decrease the likelihood of thrombus formation on the sheath 605.

Venous Return Device

[00136] Referring now to Figure 10, the venous return device 115 can comprise a distal sheath 910 and a flow line 915, which connects to and forms a leg of the shunt 120 when the system is in use. The distal sheath 910 is adapted to be introduced through an incision or puncture into a venous return location, such as the jugular vein or femoral vein. The distal sheath 910 and flow line 915 can be permanently affixed, or can be attached using a conventional luer fitting, as shown in Figure 10A. Optionally, as shown in Figure 10B, the sheath 910 can be joined to the flow line 915 by a Y-connector 1005. The Y-connector 1005 can include a hemostasis valve 1010. The venous return device also comprises a venous sheath dilator 1015 and an introducer guide wire 611 to facilitate introduction of the venous return device into the internal jugular vein or other vein. As with the arterial access dilator 645, the venous dilator 1015 includes a central guide wire lumen so the venous sheath and dilator combination can be placed over the guide wire 611. Optionally, the venous sheath 910 can include a flush line 1020 with a stopcock 1025 at its proximal or remote end.

[00137] An alternate configuration is shown in Figures 10C and 10D. Figure 10C shows the components of the venous return device 115 including venous return sheath 910, sheath dilator 1015, and sheath guidewire 611. Figure 10D shows the venous return device 115 as it would be assembled for insertion over the sheath guide wire 611 into a central vein. Once the sheath is inserted into the vein, the dilator and guidewire are removed. The venous sheath can include a hemostasis valve 1010 and flow line 915. A stopcock 1025 on the end of the flow line allows the venous sheath to be flushed via the flow line prior to use. This configuration allows the sheath to be prepped from a single point, as is done with conventional introducer sheaths. Connection to the flow shunt 120 is made with a connector 1030 on the stopcock 1025.

[00138] In order to reduce the overall system flow resistance, the arterial access flow line 615 (Figure 6A) and the venous return flow line 915, and Y-connectors 620 (Figure 6A) and 1005, can each have a relatively large flow lumen inner diameter, typically being in the range from 2.54 mm (0.100 inch) to 5.08 mm (0.200 inch), and a relatively short length, typically being in the range from 10 cm to 20 cm. The low system flow resistance is desirable since it permits the flow to be maximized during portions of a procedure when the risk of emboli is at its greatest. The low system flow resistance also allows the use of a variable flow resistance for controlling flow in the system, as described in more detail below. The dimensions of the venous return sheath 910 can be generally the same as those described for the arterial access sheath 605 above. In the venous return sheath, an extension for the hemostasis valve 1010 is not required.

Retrograde Shunt

[00139] The shunt 120 can be formed of a single tube or multiple, connected tubes that provide fluid communication between the arterial access catheter 110 and the venous return catheter 115 to provide a pathway for retrograde blood flow therebetween. As shown in Figure 1A, the shunt 120 connects at one end (via connector 127a) to the flow line 615 of the arterial access device 110, and at an opposite end (via connector 127b) to the flow line 915 of the venous return catheter 115.

[00140] In an embodiment, the shunt 120 can be formed of at least one tube that communicates with the flow control assembly 125. The shunt 120 can be any structure that provides a fluid pathway for blood flow. The shunt 120 can have a single lumen or it can have multiple lumens. The shunt 120 can be removably attached to the flow control

assembly 125, arterial access device 110, and/or venous return device 115. Prior to use, the user can select a shunt 120 with a length that is most appropriate for use with the arterial access location and venous return location. In an embodiment, the shunt 120 can include one or more extension tubes that can be used to vary the length of the shunt 120. The extension tubes can be modularly attached to the shunt 120 to achieve a desired length. The modular aspect of the shunt 120 permits the user to lengthen the shunt 120 as needed depending on the site of venous return. For example, in some patients, the internal jugular vein IJV is small and/or tortuous. The risk of complications at this site may be higher than at some other locations, due to proximity to other anatomic structures. In addition, hematoma in the neck may lead to airway obstruction and/or cerebral vascular complications. Consequently, for such patients it may be desirable to locate the venous return site at a location other than the internal jugular vein IJV, such as the femoral vein. A femoral vein return site may be accomplished percutaneously, with lower risk of serious complication, and also offers an alternative venous access to the central vein if the internal jugular vein IJV is not available. Furthermore, the femoral venous return changes the layout of the reverse flow shunt such that the shunt controls may be located closer to the “working area” of the intervention, where the devices are being introduced and the contrast injection port is located.

[00141] In an embodiment, the shunt 120 has an internal diameter of 4.76 mm (3/16 inch) and has a length of 40-70 cm. As mentioned, the length of the shunt can be adjusted. In an embodiment, connectors between the shunt and the arterial and/or venous access devices are configured to minimize flow resistance. In an embodiment, the arterial access sheath 110, the retrograde shunt 120, and the venous return sheath 115 are combined to create a low flow resistance arterio-venous AV shunt, as shown in Figures 1A-1D. As described above, the connections and flow lines of all these devices are optimized to minimize or reduce the resistance to flow. In an embodiment, the AV shunt has a flow resistance which enables a flow of up to 300 mL/minute when no device is in the arterial sheath 110 and when the AV shunt is connected to a fluid source with the viscosity of blood and a static pressure head of 60 mmHg. The actual shunt resistance may vary depending on the presence or absence of a check valve 1115 or a filter 1145 (as shown in Figure 11), or the length of the shunt, and may enable a flow of between 150 and 300 mL/min.

[00142] When there is a device such as a stent delivery catheter in the arterial sheath, there is a section of the arterial sheath that has increased flow resistance, which in turn increases the flow resistance of the overall AV shunt. This increase in flow resistance

has a corresponding reduction in flow. In an embodiment, the Y-arm 620 as shown in Figure 6A connects the arterial sheath body 605 to the flow line 615 some distance away from the hemostasis valve 625 where the catheter is introduced into the sheath. This distance is set by the length of the proximal extension 610. Thus the section of the arterial sheath that is restricted by the catheter is limited to the length of the sheath body 605. The actual flow restriction will depend on the length and inner diameter of the sheath body 605, and the outer diameter of the catheter. As described above, the sheath length may range from 5 to 15 cm, usually being from 10 cm to 12 cm, and the inner diameter is typically in the range from 7 Fr (1 Fr = 0.33 mm), to 10 Fr, usually being 8 Fr. Stent delivery catheters may range from 3.7 Fr. to 5.0 or 6.0 Fr, depending on the size of the stent and the manufacturer. This restriction may further be reduced if the sheath body is designed to increase in inner diameter for the portion not in the vessel (a stepped sheath body), as shown in Figure 6B. Since flow restriction is proportional to luminal distances to the fourth power, small increases in luminal or annular areas result in large reductions in flow resistance.

[00143] Actual flow through the AV shunt when in use will further depend on the cerebral blood pressures and flow resistances of the patient.

Flow Control Assembly - Regulation and Monitoring of Retrograde Flow

[00144] The flow control assembly 125 interacts with the retrograde shunt 120 to regulate and/or monitor the retrograde flow rate from the common carotid artery to the venous return site, such as the femoral vein, internal jugular vein, or to the external receptacle 130. In this regard, the flow control assembly 125 enables the user to achieve higher maximum flow rates than existing systems and to also selectively adjust, set, or otherwise modulate the retrograde flow rate. Various mechanisms can be used to regulate the retrograde flow rate, as described more fully below. The flow control assembly 125 enables the user to configure retrograde blood flow in a manner that is suited for various treatment regimens, as described below.

[00145] In general, the ability to control the continuous retrograde flow rate allows the physician to adjust the protocol for individual patients and stages of the procedure. The retrograde blood flow rate will typically be controlled over a range from a low rate to a high rate. The high rate can be at least two fold higher than the low rate, typically being at least three fold higher than the low rate, and often being at least five fold higher than the low rate, or even higher. In an embodiment, the high rate is at least three fold higher than the low

rate and in another embodiment the high rate is at least six fold higher than the low rate. While it is generally desirable to have a high retrograde blood flow rate to maximize the extraction of emboli from the carotid arteries, the ability of patients to tolerate retrograde blood flow will vary. Thus, by having a system and protocol which allows the retrograde blood flow rate to be easily modulated, the treating physician can determine when the flow rate exceeds the tolerable level for that patient and set the reverse flow rate accordingly. For patients who cannot tolerate continuous high reverse flow rates, the physician can chose to turn on high flow only for brief, critical portions of the procedure when the risk of embolic debris is highest. At short intervals, for example between 15 seconds and 1 minute, patient tolerance limitations are usually not a factor.

[00146] In specific embodiments, the continuous retrograde blood flow rate can be controlled at a base line flow rate in the range from 10 ml/min to 200 ml/min, typically from 20 ml/min to 100 ml/min. These flow rates will be tolerable to the majority of patients. Although flow rate is maintained at the base line flow rate during most of the procedure, at times when the risk of emboli release is increased, the flow rate can be increased above the base line for a short duration in order to improve the ability to capture such emboli. For example, the retrograde blood flow rate can be increased above the base line when the stent catheter is being introduced, when the stent is being deployed, pre- and post-dilatation of the stent, removal of the common carotid artery occlusion, and the like.

[00147] The flow rate control system can be cycled between a relatively low flow rate and a relatively high flow rate in order to "flush" the carotid arteries in the region of the carotid bifurcation prior to reestablishing antegrade flow. Such cycling can be established with a high flow rate which can be approximately two to six fold greater than the low flow rate, typically being about three fold greater. The cycles can typically have a length in the range from 0.5 seconds to 10 seconds, usually from 2 seconds to 5 seconds, with the total duration of the cycling being in the range from 5 seconds to 60 seconds, usually from 10 seconds to 30 seconds.

[00148] Figure 11 shows an example of the system 100 with a schematic representation of the flow control assembly 125, which is positioned along the shunt 120 such that retrograde blood flow passes through or otherwise communicates with at least a portion of the flow control assembly 125. The flow control assembly 125 can include various controllable mechanisms for regulating and/or monitoring retrograde flow. The mechanisms can include various means of controlling the retrograde flow, including one or more pumps

1110, valves 1115, syringes 1120 and/or a variable resistance component 1125. The flow control assembly 125 can be manually controlled by a user and/or automatically controlled via a controller 1130 to vary the flow through the shunt 120. For example, by varying the flow resistance, the rate of retrograde blood flow through the shunt 120 can be controlled. The controller 1130, which is described in more detail below, can be integrated into the flow control assembly 125 or it can be a separate component that communicates with the components of the flow control assembly 125.

[00149] In addition, the flow control assembly 125 can include one or more flow sensors 1135 and/or anatomical data sensors 1140 (described in detail below) for sensing one or more aspects of the retrograde flow. A filter 1145 can be positioned along the shunt 120 for removing emboli before the blood is returned to the venous return site. When the filter 1145 is positioned upstream of the controller 1130, the filter 1145 can prevent emboli from entering the controller 1145 and potentially clogging the variable flow resistance component 1125. It should be appreciated that the various components of the flow control assembly 125 (including the pump 1110, valves 1115, syringes 1120, variable resistance component 1125, sensors 1135/1140, and filter 1145) can be positioned at various locations along the shunt 120 and at various upstream or downstream locations relative to one another. The components of the flow control assembly 125 are not limited to the locations shown in Figure 11. Moreover, the flow control assembly 125 does not necessarily include all of the components but can rather include various sub-combinations of the components. For example, a syringe could optionally be used within the flow control assembly 125 for purposes of regulating flow or it could be used outside of the assembly for purposes other than flow regulation, such as to introduce fluid such as radiopaque contrast into the artery in an antegrade direction via the shunt 120.

[00150] Both the variable resistance component 1125 and the pump 1110 can be coupled to the shunt 120 to control the retrograde flow rate. The variable resistance component 1125 controls the flow resistance, while the pump 1110 provides for positive displacement of the blood through the shunt 120. Thus, the pump can be activated to drive the retrograde flow rather than relying on the perfusion stump pressures of the ECA and ICA and the venous back pressure to drive the retrograde flow. The pump 1110 can be a peristaltic tube pump or any type of pump including a positive displacement pump. The pump 1110 can be activated and deactivated (either manually or automatically via the controller 1130) to selectively achieve blood displacement through the shunt 120 and to

control the flow rate through the shunt 120. Displacement of the blood through the shunt 120 can also be achieved in other manners including using the aspiration syringe 1120, or a suction source such as a vacutainer, vaculock syringe, or wall suction may be used. The pump 1110 can communicate with the controller 1130.

[00151] One or more flow control valves 1115 can be positioned along the pathway of the shunt. The valve(s) can be manually actuated or automatically actuated (via the controller 1130). The flow control valves 1115 can be, for example one-way valves to prevent flow in the antegrade direction in the shunt 120, check valves, or high pressure valves which would close off the shunt 120, for example during high-pressure contrast injections (which are intended to enter the arterial vasculature in an antegrade direction). In an embodiment, the one-way valves are low flow-resistance valves for example that described in US Patent 5,727,594, or other low resistance valves.

[00152] In an embodiment of a shunt with both a filter 1145 and a one-way check valve 1115, the check valve is located down stream of the filter. In this manner, if there is debris traveling in the shunt, it is trapped in the filter before it reaches the check valve. Many check valve configurations include a sealing member that seals against a housing that contains a flow lumen. Debris may have the potential to be trapped between the sealing member and the housing, thus compromising the ability of the valve to seal against backwards pressure.

[00153] The controller 1130 communicates with components of the system 100 including the flow control assembly 125 to enable manual and/or automatic regulation and/or monitoring of the retrograde flow through the components of the system 100 (including, for example, the shunt 120, the arterial access device 110, the venous return device 115 and the flow control assembly 125). For example, a user can actuate one or more actuators on the controller 1130 to manually control the components of the flow control assembly 125. Manual controls can include switches or dials or similar components located directly on the controller 1130 or components located remote from the controller 1130 such as a foot pedal or similar device. The controller 1130 can also automatically control the components of the system 100 without requiring input from the user. In an embodiment, the user can program software in the controller 1130 to enable such automatic control. The controller 1130 can control actuation of the mechanical portions of the flow control assembly 125. The controller 1130 can include circuitry or programming that interprets signals generated by sensors

1135/1140 such that the controller 1130 can control actuation of the flow control assembly 125 in response to such signals generated by the sensors.

[00154] The representation of the controller 1130 in Figure 11 is merely exemplary. It should be appreciated that the controller 1130 can vary in appearance and structure. The controller 1130 is shown in Figure 11 as being integrated in a single housing. This permits the user to control the flow control assembly 125 from a single location. It should be appreciated that any of the components of the controller 1130 can be separated into separate housings. Further, Figure 11 shows the controller 1130 and flow control assembly 125 as separate housings. It should be appreciated that the controller 1130 and flow control regulator 125 can be integrated into a single housing or can be divided into multiple housings or components.

Flow State Indicator(s)

[00155] The controller 1130 can include one or more indicators that provides a visual and/or audio signal to the user regarding the state of the retrograde flow. An audio indication advantageously reminds the user of a flow state without requiring the user to visually check the flow controller 1130. The indicator(s) can include a speaker 1150 and/or a light 1155 or any other means for communicating the state of retrograde flow to the user. The controller 1130 can communicate with one or more sensors of the system to control activation of the indicator. Or, activation of the indicator can be tied directly to the user actuating one of the flow control actuators 1165. The indicator need not be a speaker or a light. The indicator could simply be a button or switch that visually indicates the state of the retrograde flow. For example, the button being in a certain state (such as a pressed or down state) may be a visual indication that the retrograde flow is in a high state. Or, a switch or dial pointing toward a particular labeled flow state may be a visual indication that the retrograde flow is in the labeled state.

[00156] The indicator can provide a signal indicative of one or more states of the retrograde flow. In an embodiment, the indicator identifies only two discrete states: a state of “high” flow rate and a state of “low” flow rate. In another embodiment, the indicator identifies more than two flow rates, including a “high” flow rate, a “medium” flow rate, and a “low” rate. The indicator can be configured to identify any quantity of discrete states of the retrograde flow or it can identify a graduated signal that corresponds to the state of the

retrograde flow. In this regard, the indicator can be a digital or analog meter 1160 that indicates a value of the retrograde flow rate, such as in ml/min or any other units.

[00157] In an embodiment, the indicator is configured to indicate to the user whether the retrograde flow rate is in a state of “high” flow rate or a “low” flow rate. For example, the indicator may illuminate in a first manner (e.g., level of brightness) and/or emit a first audio signal when the flow rate is high and then change to a second manner of illumination and/or emit a second audio signal when the flow rate is low. Or, the indicator may illuminate and/or emit an audio signal only when the flow rate is high, or only when the flow rate is low. Given that some patients may be intolerant of a high flow rate or intolerant of a high flow rate beyond an extended period of time, it can be desirable that the indicator provide notification to the user when the flow rate is in the high state. This would serve as a fail safe feature.

[00158] In another embodiment, the indicator provides a signal (audio and/or visual) when the flow rate changes state, such as when the flow rate changes from high to low and/or vice-versa. In another embodiment, the indicator provides a signal when no retrograde flow is present, such as when the shunt 120 is blocked or one of the stopcocks in the shunt 120 is closed.

Flow Rate Actuators

[00159] The controller 1130 can include one or more actuators that the user can press, switch, manipulate, or otherwise actuate to regulate the retrograde flow rate and/or to monitor the flow rate. For example, the controller 1130 can include a flow control actuator 1165 (such as one or more buttons, knobs, dials, switches, etc.) that the user can actuate to cause the controller to selectively vary an aspect of the reverse flow. For example, in the illustrated embodiment, the flow control actuator 1165 is a knob that can be turned to various discrete positions each of which corresponds to the controller 1130 causing the system 100 to achieve a particular retrograde flow state. The states include, for example, (a) OFF; (b) LO-FLOW; (c) HI-FLOW; and (d) ASPIRATE. It should be appreciated that the foregoing states are merely exemplary and that different states or combinations of states can be used. The controller 1130 achieves the various retrograde flow states by interacting with one or more components of the system, including the sensor(s), valve(s), variable resistance component, and/or pump(s). It should be appreciated that the controller 1130 can also

include circuitry and software that regulates the retrograde flow rate and/or monitors the flow rate such that the user wouldn't need to actively actuate the controller 1130.

[00160] The OFF state corresponds to a state where there is no retrograde blood flow through the shunt 120. When the user sets the flow control actuator 1165 to OFF, the controller 1130 causes the retrograde flow to cease, such as by shutting off valves or closing a stop cock in the shunt 120. The LO-FLOW and HI-FLOW states correspond to a low retrograde flow rate and a high retrograde flow rate, respectively. When the user sets the flow control actuator 1165 to LO-FLOW or HI-FLOW, the controller 1130 interacts with components of the flow control regulator 125 including pump(s) 1110, valve(s) 1115 and/or variable resistance component 1125 to increase or decrease the flow rate accordingly. Finally, the ASPIRATE state corresponds to opening the circuit to a suction source, for example a vacutainer or suction unit, if active retrograde flow is desired.

[00161] The system can be used to vary the blood flow between various states including an active state, a passive state, an aspiration state, and an off state. The active state corresponds to the system using a means that actively drives retrograde blood flow. Such active means can include, for example, a pump, syringe, vacuum source, etc. The passive state corresponds to when retrograde blood flow is driven by the perfusion stump pressures of the ECA and ICA and possibly the venous pressure. The aspiration state corresponds to the system using a suction source, for example a vacutainer or suction unit, to drive retrograde blood flow. The off state corresponds to the system having zero retrograde blood flow such as the result of closing a stopcock or valve. The low and high flow rates can be either passive or active flow states. In an embodiment, the particular value (such as in ml/min) of either the low flow rate and/or the high flow rate can be predetermined and/or pre-programmed into the controller such that the user does not actually set or input the value. Rather, the user simply selects "high flow" and/or "low flow" (such as by pressing an actuator such as a button on the controller 1130) and the controller 1130 interacts with one or more of the components of the flow control assembly 125 to cause the flow rate to achieve the predetermined high or low flow rate value. In another embodiment, the user sets or inputs a value for low flow rate and/or high flow rate such as into the controller. In another embodiment, the low flow rate and/or high flow rate is not actually set. Rather, external data (such as data from the anatomical data sensor 1140) is used as the basis for affects the flow rate.

[00162] The flow control actuator 1165 can be multiple actuators, for example one actuator, such as a button or switch, to switch state from LO-FLOW to HI-FLOW and

another to close the flow loop to OFF, for example during a contrast injection where the contrast is directed antegrade into the carotid artery. In an embodiment, the flow control actuator 1165 can include multiple actuators. For example, one actuator can be operated to switch flow rate from low to high, another actuator can be operated to temporarily stop flow, and a third actuator (such as a stopcock) can be operated for aspiration using a syringe. In another example, one actuator is operated to switch to LO-FLOW and another actuator is operated to switch to HI-FLOW. Or, the flow control actuator 1165 can include multiple actuators to switch states from LO-FLOW to HI-FLOW and additional actuators for fine-tuning flow rate within the high flow state and low flow state. Upon switching between LO-FLOW and HI-FLOW, these additional actuators can be used to fine-tune the flow rates within those states. Thus, it should be appreciated that within each state (i.e. high flow state and low flow states) a variety of flow rates can be dialed in and fine-tuned. A wide variety of actuators can be used to achieve control over the state of flow.

[00163] The controller 1130 or individual components of the controller 1130 can be located at various positions relative to the patient and/or relative to the other components of the system 100. For example, the flow control actuator 1165 can be located near the hemostasis valve where any interventional tools are introduced into the patient in order to facilitate access to the flow control actuator 1165 during introduction of the tools. The location may vary, for example, based on whether a transfemoral or a transcarotid approach is used, as shown in figures 1 A-C. The controller 1130 can have a wireless connection to the remainder of the system 100 and/or a wired connection of adjustable length to permit remote control of the system 100. The controller 1130 can have a wireless connection with the flow control regulator 125 and/or a wired connection of adjustable length to permit remote control of the flow control regulator 125. The controller 1130 can also be integrated in the flow control regulator 125. Where the controller 1130 is mechanically connected to the components of the flow control assembly 125, a tether with mechanical actuation capabilities can connect the controller 1130 to one or more of the components. In an embodiment, the controller 1130 can be positioned a sufficient distance from the system 100 to permit positioning the controller 1130 outside of a radiation field when fluoroscopy is in use.

[00164] The controller 1130 and any of its components can interact with other components of the system (such as the pump(s), sensor(s), shunt, etc) in various manners. For example, any of a variety of mechanical connections can be used to enable communication between the controller 1130 and the system components. Alternately, the

controller 1130 can communicate electronically or magnetically with the system components. Electro-mechanical connections can also be used. The controller 1130 can be equipped with control software that enables the controller to implement control functions with the system components. The controller itself can be a mechanical, electrical or electro-mechanical device. The controller can be mechanically, pneumatically, or hydraulically actuated or electromechanically actuated (for example in the case of solenoid actuation of flow control state). The controller 1130 can include a computer, computer processor, and memory, as well as data storage capabilities.

[00165] Figure 11 shows an exemplary embodiment of a variable flow control element 1125. In this embodiment, the flow resistance through shunt 120 may be changed by providing two or more alternative flow paths to create a low and high resistance flow path. As shown in Figure 12A, the flow through shunt 120 passes through a main lumen 1700 as well as secondary lumen 1705. The secondary lumen 1705 is longer and/or has a smaller diameter than the main lumen 1700. Thus, the secondary lumen 1705 has higher flow resistance than the main lumen 1700. By passing the blood through both these lumens, the flow resistance will be at a minimum. Blood is able to flow through both lumens 1700 and 1705 due to the pressure drop created in the main lumen 1700 across the inlet and outlet of the secondary lumen 1705. This has the benefit of preventing stagnant blood. As shown in Figure 12B, by blocking flow through the main lumen 1700 of shunt 120, the flow is diverted entirely to the secondary lumen 1705, thus increasing the flow resistance and reducing the blood flow rate. It will be appreciated that additional flow lumens could also be provided in parallel to allow for a three, four, or more discrete flow resistances. The shunt 120 may be equipped with a valve 1710 that controls flow to the main lumen 1700 and the secondary lumen 1705. The valve position may be controlled by an actuator such as a button or switch on the housing of flow controller 125. The embodiment of Figures 12A and 12B has an advantage in that this embodiment in that it maintains precise flow lumen sizes even for the lowest flow setting. The secondary flow lumen size can be configured to prevent thrombus from forming under even the lowest flow or prolonged flow conditions. In an embodiment, the inner diameter of the secondary lumen 1705 lumen is 0.063 inches or larger.

[00166] In a preferred embodiment, the connectors which connect the elements of the reverse flow system are large bore, quick-connect style connectors. For example, a male large-bore hub 680 on the Y-adaptor 660 of arterial sheath 110, as seen in Figure 9B, connects to a female counterpart 1320 on the arterial side of flow shunt 120. Similarly, a

male large bore connector 1310 on the venous side of flow shunt 120 connects to a female counterpart connector 1310 on the flow line of venous sheath 115, as seen in Figure 10C. The connections can be standard female and male Luer connectors or other style of tubing connectors.

Sensor(s)

[00167] As mentioned, the flow control assembly 125 can include or interact with one or more sensors, which communicate with the system 100 and/or communicate with the patient's anatomy. Each of the sensors can be adapted to respond to a physical stimulus (including, for example, heat, light, sound, pressure, magnetism, motion, etc.) and to transmit a resulting signal for measurement or display or for operating the controller 1130. In an embodiment, the flow sensor 1135 interacts with the shunt 120 to sense an aspect of the flow through the shunt 120, such as flow velocity or volumetric rate of blood flow. The flow sensor 1135 could be directly coupled to a display that directly displays the value of the volumetric flow rate or the flow velocity. Or the flow sensor 1135 could feed data to the controller 1130 for display of the volumetric flow rate or the flow velocity.

[00168] The type of flow sensor 1135 can vary. The flow sensor 1135 can be a mechanical device, such as a paddle wheel, flapper valve, rolling ball, or any mechanical component that responds to the flow through the shunt 120. Movement of the mechanical device in response to flow through the shunt 120 can serve as a visual indication of fluid flow and can also be calibrated to a scale as a visual indication of fluid flow rate. The mechanical device can be coupled to an electrical component. For example, a paddle wheel can be positioned in the shunt 120 such that fluid flow causes the paddle wheel to rotate, with greater rate of fluid flow causing a greater speed of rotation of the paddle wheel. The paddle wheel can be coupled magnetically to a Hall-effect sensor to detect the speed of rotation, which is indicative of the fluid flow rate through the shunt 120.

[00169] In an embodiment, the flow sensor 1135 is an ultrasonic or electromagnetic, or electro-optic flow meter, which allows for blood flow measurement without contacting the blood through the wall of the shunt 120. An ultrasonic or electromagnetic flow meter can be configured such that it does not have to contact the internal lumen of the shunt 120. In an embodiment, the flow sensor 1135 at least partially includes a Doppler flow meter, such as a Transonic flow meter, that measures fluid flow through the shunt 120. In another embodiment, the flow sensor 1135 measures pressure

differential along the flow line to determine flow. It should be appreciated that any of a wide variety of sensor types can be used including an ultrasound flow meter and transducer. Moreover, the system can include multiple sensors.

[00170] The system 100 is not limited to using a flow sensor 1135 that is positioned in the shunt 120 or a sensor that interacts with the venous return device 115 or the arterial access device 110. For example, an anatomical data sensor 1140 can communicate with or otherwise interact with the patient's anatomy such as the patient's neurological anatomy. In this manner, the anatomical data sensor 1140 can sense a measurable anatomical aspect that is directly or indirectly related to the rate of retrograde flow from the carotid artery. For example, the anatomical data sensor 1140 can measure blood flow conditions in the brain, for example the flow velocity in the middle cerebral artery, and communicate such conditions to a display and/or to the controller 1130 for adjustment of the retrograde flow rate based on predetermined criteria. In an embodiment, the anatomical data sensor 1140 comprises a transcranial Doppler ultrasonography (TCD), which is an ultrasound test that uses reflected sound waves to evaluate blood as it flows through the brain. Use of TCD results in a TCD signal that can be communicated to the controller 1130 for controlling the retrograde flow rate to achieve or maintain a desired TCD profile. The anatomical data sensor 1140 can be based on any physiological measurement, including reverse flow rate, blood flow through the middle cerebral artery, TCD signals of embolic particles, or other neuromonitoring signals.

[00171] In an embodiment, the system 100 comprises a closed-loop control system. In the closed-loop control system, one or more of the sensors (such as the flow sensor 1135 or the anatomical data sensor 1140) senses or monitors a predetermined aspect of the system 100 or the anatomy (such as, for example, reverse flow rate and/or neuromonitoring signal). The sensor(s) feed relevant data to the controller 1130, which continuously adjusts an aspect of the system as necessary to maintain a desired retrograde flow rate. The sensors communicate feedback on how the system 100 is operating to the controller 1130 so that the controller 1130 can translate that data and actuate the components of the flow control regulator 125 to dynamically compensate for disturbances to the retrograde flow rate. For example, the controller 1130 may include software that causes the controller 1130 to signal the components of the flow control assembly 125 to adjust the flow rate such that the flow rate is maintained at a constant state despite differing blood pressures from the patient. In this embodiment, the system 100 need not rely on the user to determine

when, how long, and/or what value to set the reverse flow rate in either a high or low state. Rather, software in the controller 1130 can govern such factors. In the closed loop system, the controller 1130 can control the components of the flow control assembly 125 to establish the level or state of retrograde flow (either analog level or discrete state such as high, low, baseline, medium, etc.) based on the retrograde flow rate sensed by the sensor 1135.

[00172] In an embodiment, the anatomical data sensor 1140 (which measures a physiologic measurement in the patient) communicates a signal to the controller 1130, which adjusts the flow rate based on the signal. For example the physiological measurement may be based on flow velocity through the MCA, TCD signal, or some other cerebral vascular signal. In the case of the TCD signal, TCD may be used to monitor cerebral flow changes and to detect microemboli. The controller 1130 may adjust the flow rate to maintain the TCD signal within a desired profile. For example, the TCD signal may indicate the presence of microemboli (“TCD hits”) and the controller 1130 can adjust the retrograde flow rate to maintain the TCD hits below a threshold value of hits. (See, Ribo, *et al.*, “Transcranial Doppler Monitoring of Transcervical Carotid Stenting with Flow Reversal Protection: A Novel Carotid Revascularization Technique”, *Stroke* 2006, 37, 2846-2849; Shekel, *et al.*, “Experience of 500 Cases of Neurophysiological Monitoring in Carotid Endarterectomy”, *Acta Neurochir*, 2007, 149:681-689, which are incorporated by reference in their entirety.

[00173] In the case of the MCA flow, the controller 1130 can set the retrograde flow rate at the “maximum” flow rate that is tolerated by the patient, as assessed by perfusion to the brain. The controller 1130 can thus control the reverse flow rate to optimize the level of protection for the patient without relying on the user to intercede. In another embodiment, the feedback is based on a state of the devices in the system 100 or the interventional tools being used. For example, a sensor may notify the controller 1130 when the system 100 is in a high risk state, such as when an interventional catheter is positioned in the sheath 605. The controller 1130 then adjusts the flow rate to compensate for such a state.

[00174] The controller 1130 can be used to selectively augment the retrograde flow in a variety of manners. For example, it has been observed that greater reverse flow rates may cause a resultant greater drop in blood flow to the brain, most importantly the ipsilateral MCA, which may not be compensated enough with collateral flow from the Circle of Willis. Thus a higher reverse flow rate for an extended period of time may lead to conditions where the patient’s brain is not getting enough blood flow, leading to patient intolerance as exhibited by neurologic symptoms. Studies show that MCA blood velocity

less than 10 cm/sec is a threshold value below which patient is at risk for neurological blood deficit. There are other markers for monitoring adequate perfusion to the brains, such as EEG signals. However, a high flow rate may be tolerated even up to a complete stoppage of MCA flow for a short period, up to about 15 seconds to 1 minute.

[00175] Thus, the controller 1130 can optimize embolic debris capture by automatically increasing the reverse flow only during limited time periods which correspond to periods of heightened risk of emboli generation during a procedure. These periods of heightened risk include the period of time while an interventional device (such as a dilatation balloon for pre or post stenting dilatation or a stent delivery device) crosses the plaque P. Another period is during an interventional maneuver such as deployment of the stent or inflation and deflation of the balloon pre- or post-dilatation. A third period is during injection of contrast for angiographic imaging of treatment area. During lower risk periods, the controller can cause the reverse flow rate to revert to a lower, baseline level. This lower level may correspond to a low reverse flow rate in the ICA, or even slight antegrade flow in those patients with a high ECA to ICA perfusion pressure ratio.

[00176] In a flow regulation system where the user manually sets the state of flow, there is risk that the user may not pay attention to the state of retrograde flow (high or low) and accidentally keep the circuit on high flow. This may then lead to adverse patient reactions. In an embodiment, as a safety mechanism, the default flow rate is the low flow rate. This serves as a fail safe measure for patient's that are intolerant of a high flow rate. In this regard, the controller 1130 can be biased toward the default rate such that the controller causes the system to revert to the low flow rate after passage of a predetermined period of time of high flow rate. The bias toward low flow rate can be achieved via electronics or software, or it can be achieved using mechanical components, or a combination thereof. In an embodiment, the flow control actuator 1165 of the controller 1130 and/or valve(s) 1115 and/or pump(s) 1110 of the flow control regulator 125 are spring loaded toward a state that achieves a low flow rate. The controller 1130 is configured such that the user may over-ride the controller 1130 such as to manually cause the system to revert to a state of low flow rate if desired.

[00177] In another safety mechanism, the controller 1130 includes a timer 1170 (Figure 11) that keeps time with respect to how long the flow rate has been at a high flow rate. The controller 1130 can be programmed to automatically cause the system 100 to revert to a low flow rate after a predetermined time period of high flow rate, for example after 15,

30, or 60 seconds or more of high flow rate. After the controller reverts to the low flow rate, the user can initiate another predetermined period of high flow rate as desired. Moreover, the user can override the controller 1130 to cause the system 100 to move to the low flow rate (or high flow rate) as desired.

[00178] In an exemplary procedure, embolic debris capture is optimized while not causing patient tolerance issues by initially setting the level of retrograde flow at a low rate, and then switching to a high rate for discreet periods of time during critical stages in the procedure. Alternately, the flow rate is initially set at a high rate, and then verifying patient tolerance to that level before proceeding with the rest of the procedure. If the patient shows signs of intolerance, the retrograde flow rate is lowered. Patient tolerance may be determined automatically by the controller based on feedback from the anatomical data sensor 1140 or it may be determined by a user based on patient observation. The adjustments to the retrograde flow rate may be performed automatically by the controller or manually by the user. Alternately, the user may monitor the flow velocity through the middle cerebral artery (MCA), for example using TCD, and then to set the maximum level of reverse flow which keeps the MCA flow velocity above the threshold level. In this situation, the entire procedure may be done without modifying the state of flow. Adjustments may be made as needed if the MCA flow velocity changes during the course of the procedure, or the patient exhibits neurologic symptoms.

Exemplary Methods of Use

[00179] Referring now to Figures 14A-14E, flow through the carotid artery bifurcation at different stages of the methods of the present disclosure will be described. Initially, as shown in Figure 14A, the distal sheath 605 of the arterial access device 110 is introduced into the common carotid artery CCA. As mentioned, entry into the common carotid artery CCA can be via a transcarotid or transfemoral approach, and can be either a direct surgical cut-down or percutaneous access. After the sheath 605 of the arterial access device 110 has been introduced into the common carotid artery CCA, the blood flow will continue in antegrade direction AG with flow from the common carotid artery entering both the internal carotid artery ICA and the external carotid artery ECA, as shown in Figure 14A.

[00180] The venous return device 115 is then inserted into a venous return site, such as the internal jugular vein IJV (not shown in Figures 14A-14E) or femoral vein. The shunt 120 is used to connect the flow lines 615 and 915 of the arterial access device 110 and

the venous return device 115, respectively (as shown in Figure 1A). In this manner, the shunt 120 provides a passageway for retrograde flow from the atrial access device 110 to the venous return device 115. In another embodiment, the shunt 120 connects to an external receptacle 130 rather than to the venous return device 115, as shown in Figure 1C.

[00181] Once all components of the system are in place and connected, flow through the common carotid artery CCA is stopped, typically by use of a tourniquet 2105 or other external vessel occlusion device to occlude the common carotid artery CCA. In an alternative embodiment, an occlusion element 129 is located on the distal end of arterial access device 110. Alternately, the occlusion element 129 is introduced on second occlusion device 112 separate from the distal sheath 605 of the arterial access device 110, as shown in Figure 2B. The ECA may also be occluded with a separate occlusion element, either on the same device 110 or on a separate occlusion device.

[00182] At that point retrograde flow RG from the external carotid artery ECA and internal carotid artery ICA will begin and will flow through the sheath 605, the flow line 615, the shunt 120, and into the venous return device 115 via the flow line 915. The flow control assembly 125 regulates the retrograde flow as described above. Figure 14B shows the occurrence of retrograde flow RG. While the retrograde flow is maintained, a stent delivery catheter 2110 is introduced into the sheath 605, as shown in Figure 14C. The stent delivery catheter 2110 is introduced into the sheath 605 through the hemostasis valve 615 and the proximal extension 610 (not shown in Figures 14A-14E) of the arterial access device 110. The stent delivery catheter 2110 is advanced into the internal carotid artery ICA and a stent 2115 deployed at the bifurcation B, as shown in Figure 14D.

[00183] The rate of retrograde flow can be increased during periods of higher risk for emboli generation for example while the stent delivery catheter 2110 is being introduced and optionally while the stent 2115 is being deployed. The rate of retrograde flow can be increased also during placement and expansion of balloons for dilatation prior to or after stent deployment. An atherectomy can also be performed before stenting under retrograde flow.

[00184] Still further optionally, after the stent 2115 has been expanded, the bifurcation B can be flushed by cycling the retrograde flow between a low flow rate and high flow rate. The region within the carotid arteries where the stent has been deployed or other procedure performed may be flushed with blood prior to reestablishing normal blood flow.

In particular, while the common carotid artery remains occluded, a balloon catheter or other occlusion element may be advanced into the internal carotid artery and deployed to fully occlude that artery. The same maneuver may also be used to perform a post-deployment stent dilatation, which is typically done currently in self-expanding stent procedures. Flow from the common carotid artery and into the external carotid artery may then be reestablished by temporarily opening the occluding means present in the artery. The resulting flow will thus be able to flush the common carotid artery which saw slow, turbulent, or stagnant flow during carotid artery occlusion into the external carotid artery. In addition, the same balloon may be positioned distally of the stent during reverse flow and forward flow then established by temporarily relieving occlusion of the common carotid artery and flushing. Thus, the flushing action occurs in the stented area to help remove loose or loosely adhering embolic debris in that region.

[00185] Optionally, while flow from the common carotid artery continues and the internal carotid artery remains blocked, measures can be taken to further loosen emboli from the treated region. For example, mechanical elements may be used to clean or remove loose or loosely attached plaque or other potentially embolic debris within the stent, thrombolytic or other fluid delivery catheters may be used to clean the area, or other procedures may be performed. For example, treatment of in-stent restenosis using balloons, atherectomy, or more stents can be performed under retrograde flow. In another example, the occlusion balloon catheter may include flow or aspiration lumens or channels which open proximal to the balloon. Saline, thrombolytics, or other fluids may be infused and/or blood and debris aspirated to or from the treated area without the need for an additional device. While the emboli thus released will flow into the external carotid artery, the external carotid artery is generally less sensitive to emboli release than the internal carotid artery. By prophylactically removing potential emboli which remain, when flow to the internal carotid artery is reestablished, the risk of emboli release is even further reduced. The emboli can also be released under retrograde flow so that the emboli flows through the shunt 120 to the venous system, a filter in the shunt 120, or the receptacle 130.

[00186] After the bifurcation has been cleared of emboli, the occlusion element 129 or alternately the tourniquet 2105 can be released, reestablishing antegrade flow, as shown in Figure 14E. The sheath 605 can then be removed.

[00187] A self-closing element may be deployed about the penetration in the wall of the common carotid artery prior to withdrawing the sheath 605 at the end of the

procedure. Usually, the self-closing element will be deployed at or near the beginning of the procedure, but optionally, the self-closing element could be deployed as the sheath is being withdrawn, often being released from a distal end of the sheath onto the wall of the common carotid artery. Use of the self-closing element is advantageous since it affects substantially the rapid closure of the penetration in the common carotid artery as the sheath is being withdrawn. Such rapid closure can reduce or eliminate unintended blood loss either at the end of the procedure or during accidental dislodgement of the sheath. In addition, such a self-closing element may reduce the risk of arterial wall dissection during access. Further, the self-closing element may be configured to exert a frictional or other retention force on the sheath during the procedure. Such a retention force is advantageous and can reduce the chance of accidentally dislodging the sheath during the procedure. A self-closing element eliminates the need for vascular surgical closure of the artery with suture after sheath removal, reducing the need for a large surgical field and greatly reducing the surgical skill required for the procedure.

[00188] The disclosed systems and methods may employ a wide variety of self-closing elements, typically being mechanical elements which include an anchor portion and a self-closing portion. The anchor portion may comprise hooks, pins, staples, clips, tine, suture, or the like, which are engaged in the exterior surface of the common carotid artery about the penetration to immobilize the self-closing element when the penetration is fully open. The self-closing element may also include a spring-like or other self-closing portion which, upon removal of the sheath, will close the anchor portion in order to draw the tissue in the arterial wall together to provide closure. Usually, the closure will be sufficient so that no further measures need be taken to close or seal the penetration. Optionally, however, it may be desirable to provide for supplemental sealing of the self-closing element after the sheath is withdrawn. For example, the self-closing element and/or the tissue tract in the region of the element can be treated with hemostatic materials, such as bioabsorbable polymers, collagen plugs, glues, sealants, clotting factors, or other clot-promoting agents. Alternatively, the tissue or self-closing element could be sealed using other sealing protocols, such as electrocautery, suturing, clipping, stapling, or the like. In another method, the self-closing element will be a self-sealing membrane or gasket material which is attached to the outer wall of the vessel with clips, glue, bands, or other means. The self-sealing membrane may have an inner opening such as a slit or cross cut, which would be normally closed against blood

pressure. Any of these self-closing elements could be designed to be placed in an open surgical procedure, or deployed percutaneously.

[00189] In another embodiment, carotid artery stenting may be performed after the sheath is placed and an occlusion balloon catheter deployed in the external carotid artery. The stent having a side hole or other element intended to not block the ostium of the external carotid artery may be delivered through the sheath with a guidewire or a shaft of an external carotid artery occlusion balloon received through the side hole. Thus, as the stent is advanced, typically by a catheter being introduced over a guidewire which extends into the internal carotid artery, the presence of the catheter shaft in the side hole will ensure that the side hole becomes aligned with the ostium to the external carotid artery as the stent is being advanced. When an occlusion balloon is deployed in the external carotid artery, the side hole prevents trapping the external carotid artery occlusion balloon shaft with the stent which is a disadvantage of the other flow reversal systems. This approach also avoids “jailing” the external carotid artery, and if the stent is covered with a graft material, avoids blocking flow to the external carotid artery.

[00190] In another embodiment, stents are placed which have a shape which substantially conforms to any preexisting angle between the common carotid artery and the internal carotid artery. Due to significant variation in the anatomy among patients, the bifurcation between the internal carotid artery and the external carotid artery may have a wide variety of angles and shapes. By providing a family of stents having differing geometries, or by providing individual stents which may be shaped by the physician prior to deployment, the physician may choose a stent which matches the patient's particular anatomy prior to deployment. The patient's anatomy may be determined using angiography or by other conventional means. As a still further alternative, the stent may have sections of articulation. These stents may be placed first and then articulated *in situ* in order to match the angle of bifurcation between a common carotid artery and internal carotid artery. Stents may be placed in the carotid arteries, where the stents have a sidewall with different density zones.

[00191] In another embodiment, a stent may be placed where the stent is at least partly covered with a graft material at either or both ends. Generally, the stent will be free from graft material and the middle section of the stent which will be deployed adjacent to the ostium to the external carotid artery to allow blood flow from the common carotid artery into the external carotid artery.

[00192] In another embodiment, a stent delivery system can be optimized for transcervicaltranscarotid access by making them shorter and/or more rigid than systems designed for transfemoral access. These changes will improve the ability to torque and position the stent accurately during deployment. In addition, the stent delivery system can be designed to align the stent with the ostium of the external carotid artery, either by using the external carotid occlusion balloon or a separate guide wire in the external carotid artery, which is especially useful with stents with sideholes or for stents with curves, bends, or angulation where orientation is critical.

[00193] In certain embodiments, the shunt is fixedly connected to the arterial access sheath and the venous return sheath so that the entire assembly of the replaceable flow assembly and sheaths may be disposable and replaceable as a unit. In other instances, the flow control assembly may be removably attached to either or both of the sheaths.

[00194] In an embodiment, the user first determines whether any periods of heightened risk of emboli generation may exist during the procedure. As mentioned, some exemplary periods of heightened risk include (1) during periods when the plaque P is being crossed by a device; (2) during an interventional procedure, such as during delivery of a stent or during inflation or deflation of a balloon catheter or guidewire; (3) during injection of contrast. The foregoing are merely examples of periods of heightened risk. During such periods, the user sets the retrograde flow at a high rate for a discreet period of time. At the end of the high risk period, or if the patient exhibits any intolerance to the high flow rate, then the user reverts the flow state to baseline flow. If the system has a timer, the flow state automatically reverts to baseline flow after a set period of time. In this case, the user may re-set the flow state to high flow if the procedure is still in a period of heightened embolic risk.

[00195] In another embodiment, if the patient exhibits an intolerance to the presence of retrograde flow, then retrograde flow is established only during placement of a filter in the ICA distal to the plaque P. Retrograde flow is then ceased while an interventional procedure is performed on the plaque P. Retrograde flow is then re-established while the filter is removed. In another embodiment, a filter is placed in the ICA distal of the plaque P and retrograde flow is established while the filter is in place. This embodiment combines the use of a distal filter with retrograde flow.

[00196] Although embodiments of various methods and devices are described herein in detail with reference to certain versions, it should be appreciated that other versions, embodiments, methods of use, and combinations thereof are also possible. Therefore the spirit and scope of the appended claims should not be limited to the description of the embodiments contained herein.

CLAIMS

1. A system for compress a blood vessel, the system comprising:
a vessel compression device formed of:
an elongated shaft having an internal lumen;
a vessel support structure positioned on a distal end of the shaft, wherein the vessel support structure defines an atraumatic outer surface; and
a clamping structure movably coupled to the elongated shaft, wherein the clamping structure includes a distal portion is configured to clamp a blood vessel when a blood vessel is positioned between the distal portion of the clamping structure and the vessel support structure, wherein the distal portion clamps the blood vessel in a manner that flattens the blood vessel.
2. The system of claim 1, wherein vessel support structure has a cylindrical shape in cross-section.
3. The system of claim 1, wherein the vessel support structure defines a first axis and the elongated shaft defines a second axis that is normal to the first axis.
4. The system of claim 1, wherein the outer surface of the vessel support structure is round.
5. The system of claim 1, wherein the vessel support structure is made of an elastomeric material.
6. The system of claim 1, wherein the clamping structure is a tourniquet.
7. The system of claim 1, wherein the distal portion of the clamping structure is a loop.
8. The system of claim 1, wherein at least a portion of the clamping structure is movably positioned within an internal lumen of the elongated shaft.

9. The system of claim 1, further comprising an arterial access device having an internal lumen, the arterial access device adapted to be introduced through an incision or puncture in a wall of a common carotid artery.

10. The system of claim 1, wherein the vessel compression device is attached to the arterial access device.

11. The system of claim 10, wherein the vessel compression device is slidably attached to the arterial access device.

12. The system of claim 11, wherein the vessel compression device includes a tubular coupling element in which the arterial access device is slidably positioned.

13. The system of claim 1, wherein the distal portion of the clamping structure is a hook.

14. The system of claim 13, wherein the clamping structure is rigid.

15. The system of claim 13, wherein the clamping structure is flexible.

16. The system of claim 13, wherein the clamping structure has a proximal portion slidably positioned within the elongated shaft of the vessel compression device.

17. A method of compressing a blood vessel, comprising:
inserting an arterial access device into a carotid artery, the arterial access device having a distal sheath portion;

coupling a vessel compression device to the carotid artery, the vessel compression device formed of:

an elongated shaft having an internal lumen;

a vessel support structure positioned on a distal end of the shaft,

wherein the vessel support structure defines an atraumatic outer surface;

a clamping structure movably coupled to the elongated shaft, wherein

the clamping structure includes a distal portion is configured to clamp the

carotid artery when the carotid artery is positioned between the distal portion of the clamping structure and the vessel support structure, wherein the distal portion clamps the carotid artery in a manner that flattens the carotid artery without bunching; and

compressing the carotid artery between the distal portion of the clamping structure and the vessel support structure of the vessel compression device.

18. The method of claim 17, further comprising sliding at least a portion of the clamping structure within the elongated shaft of the vessel compression device.

19. The method of claim 18, wherein the clamping structure is rigid.

20. The method of claim 18, wherein the clamping structure is flexible.

21. The method of claim 18, wherein the clamping structure includes a hook.

22. The method of claim 18, wherein the clamping structure includes a tourniquet.

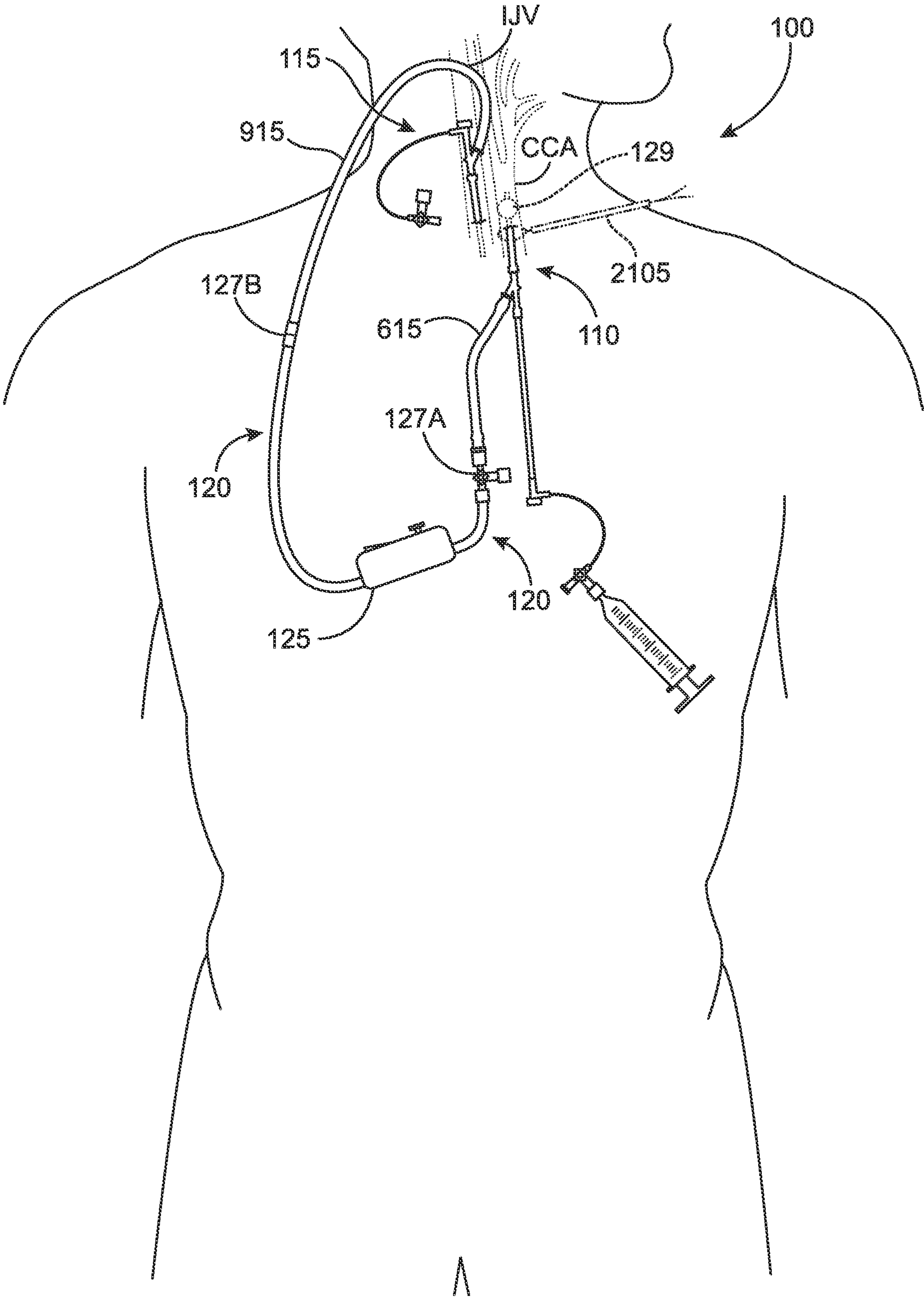


FIG. 1A

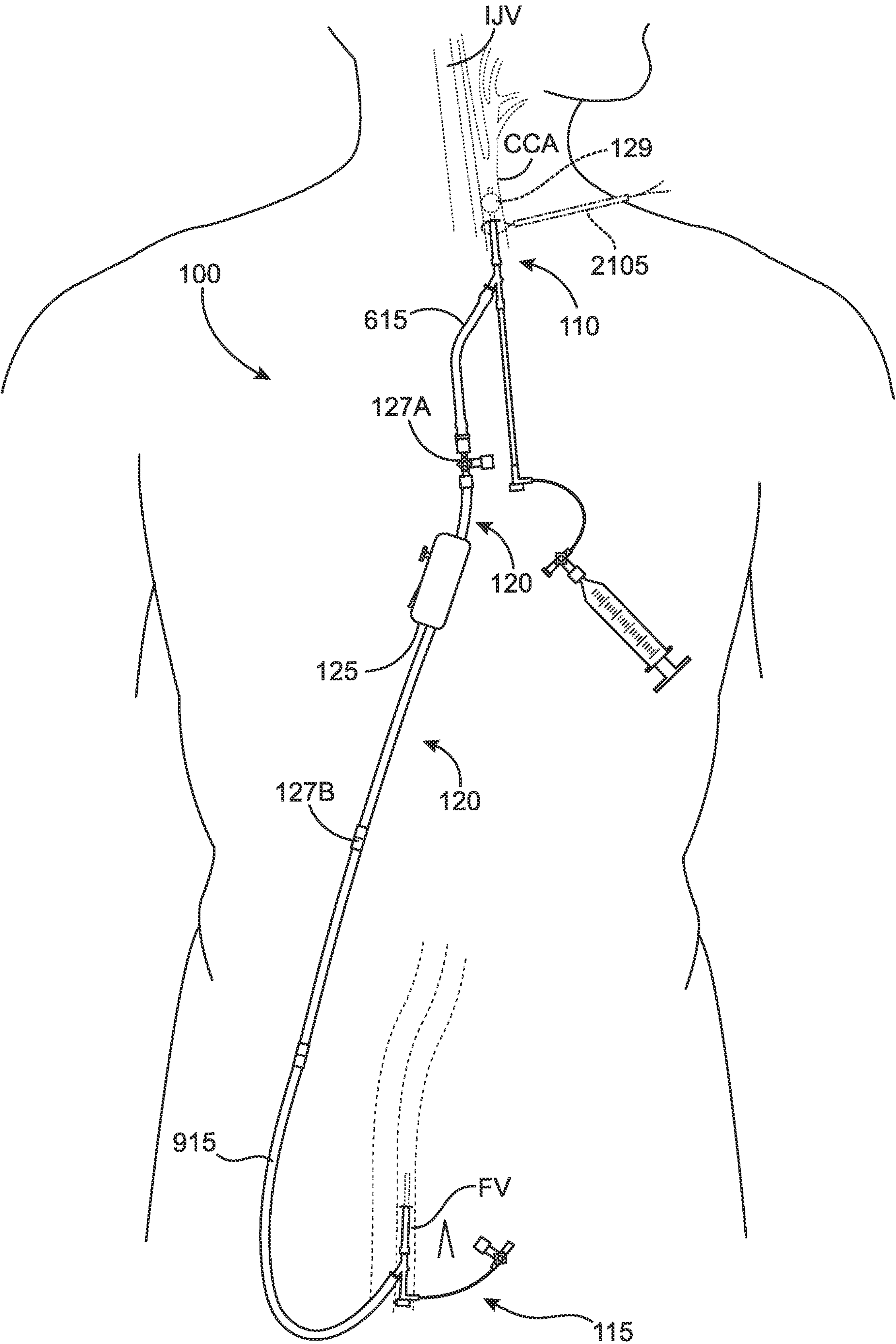


FIG. 1B

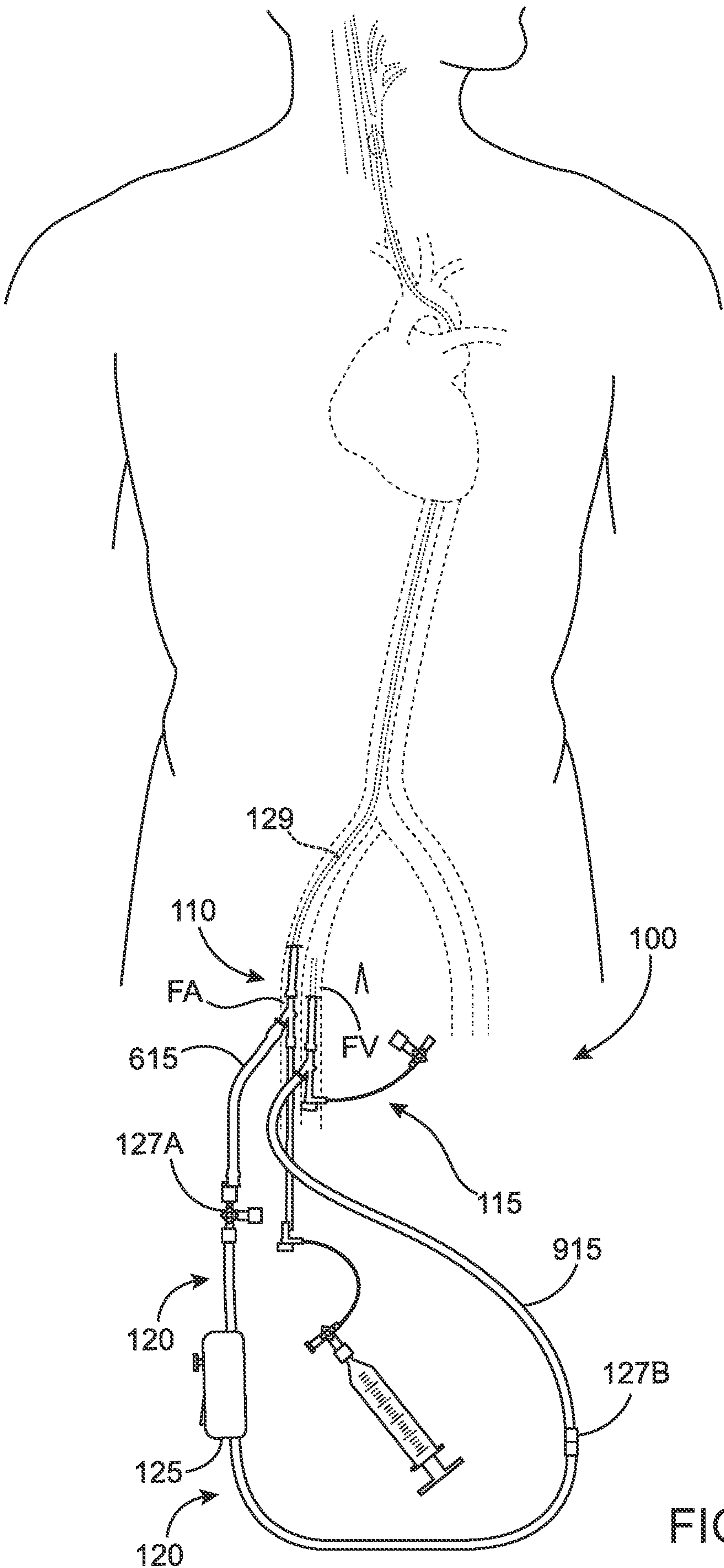


FIG. 1C

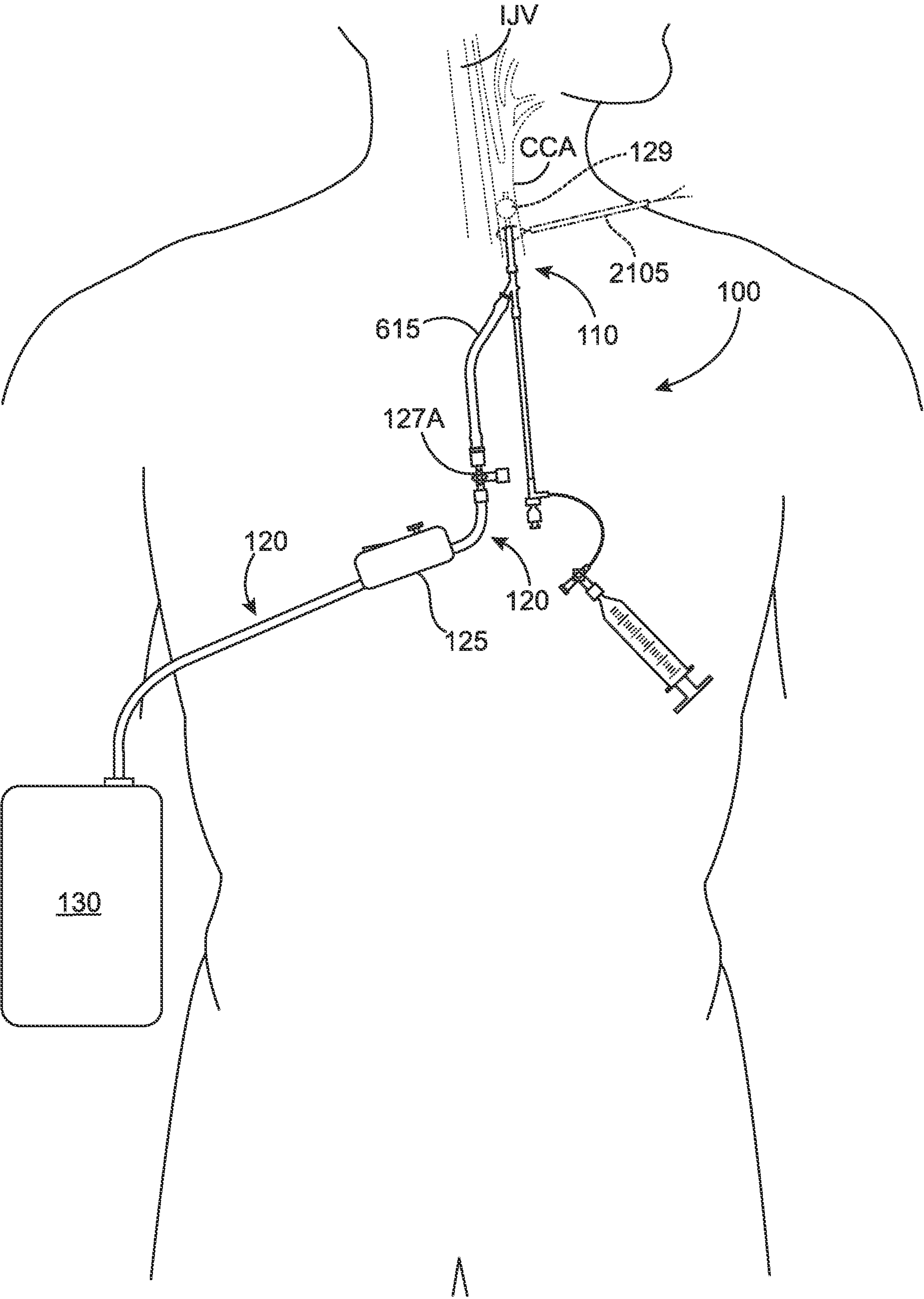


FIG. 1D

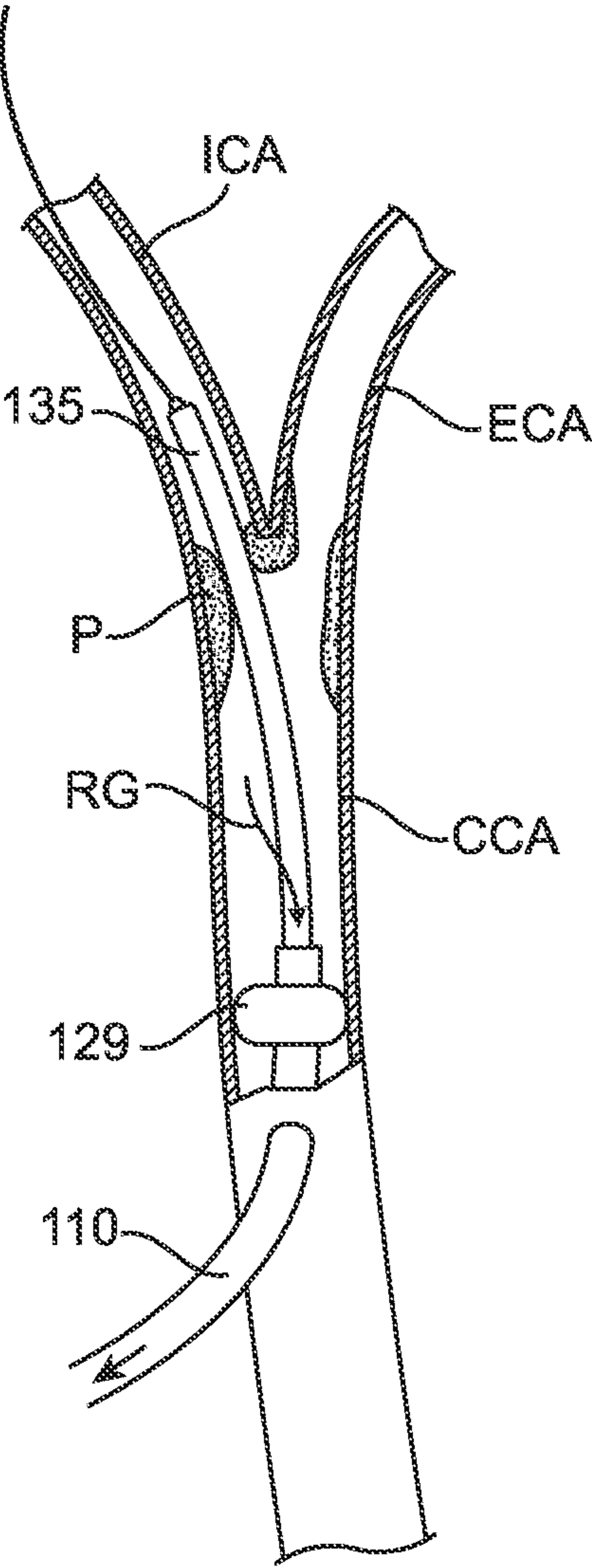


FIG. 2A

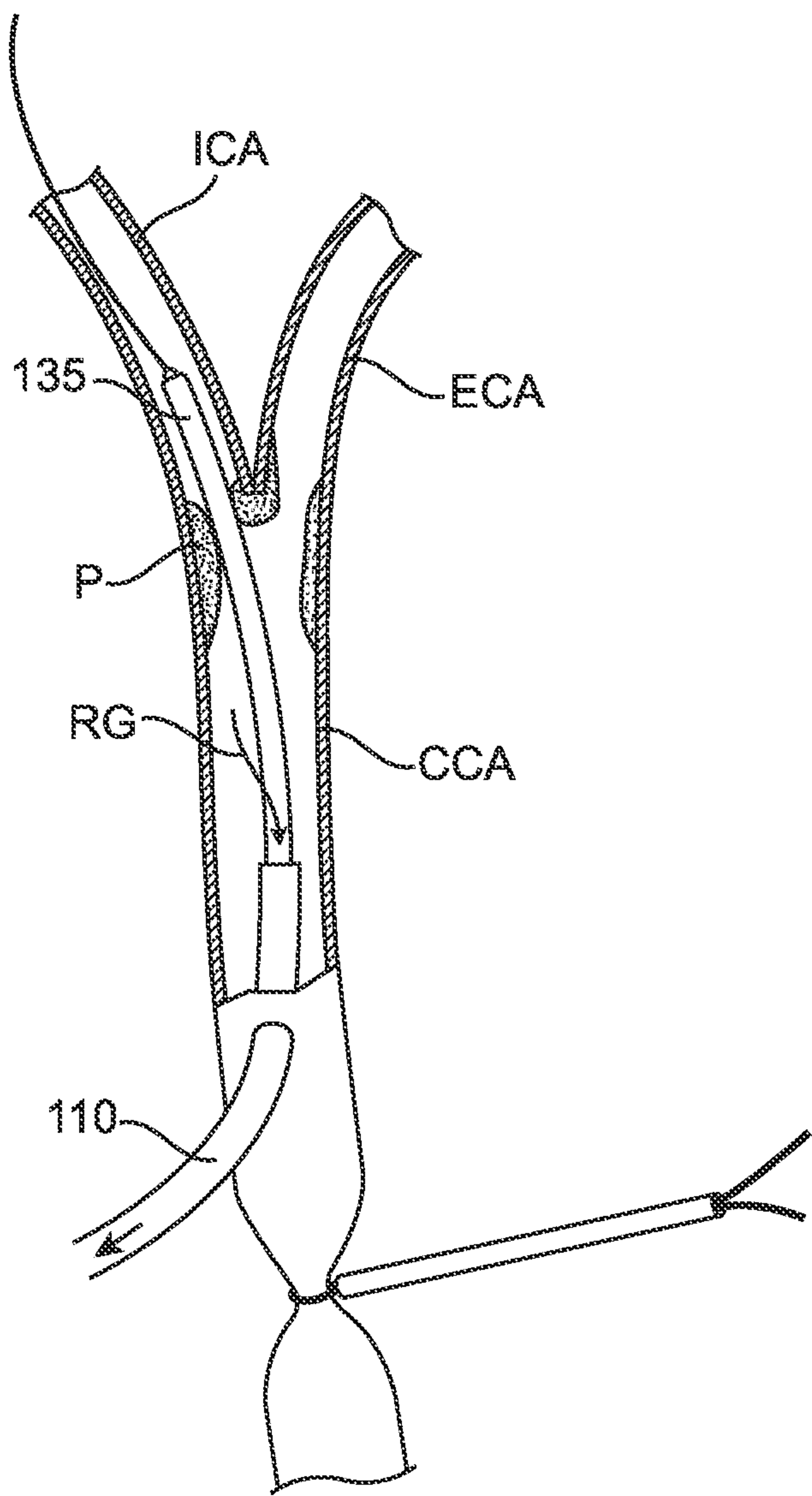


FIG. 2B

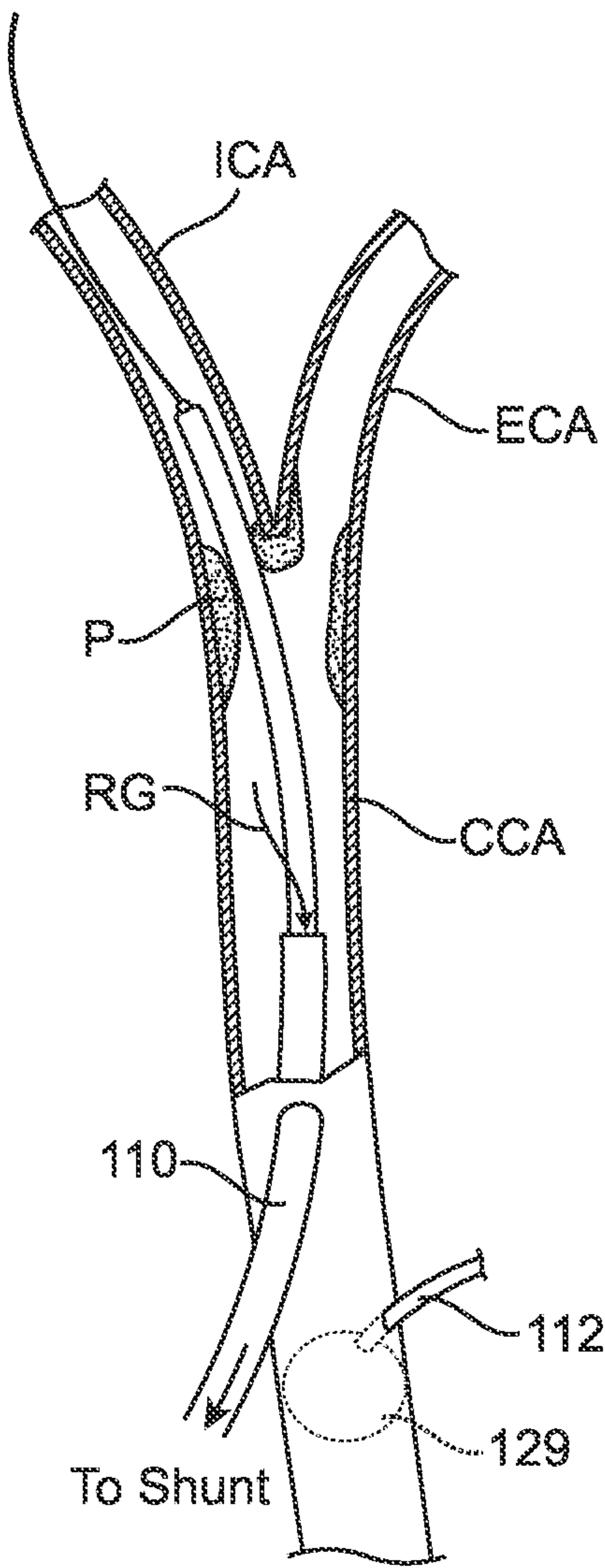


FIG. 3

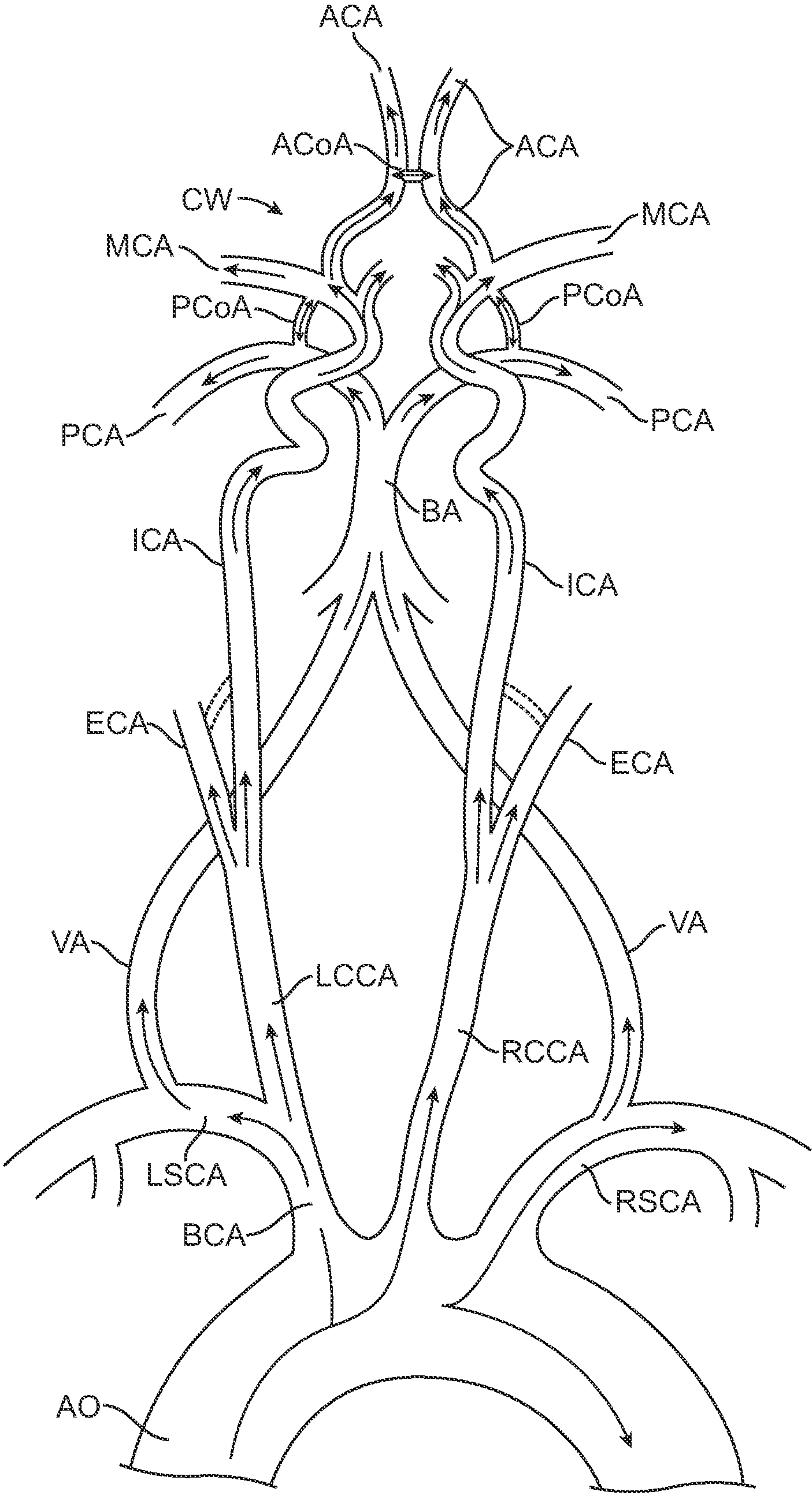


FIG. 4

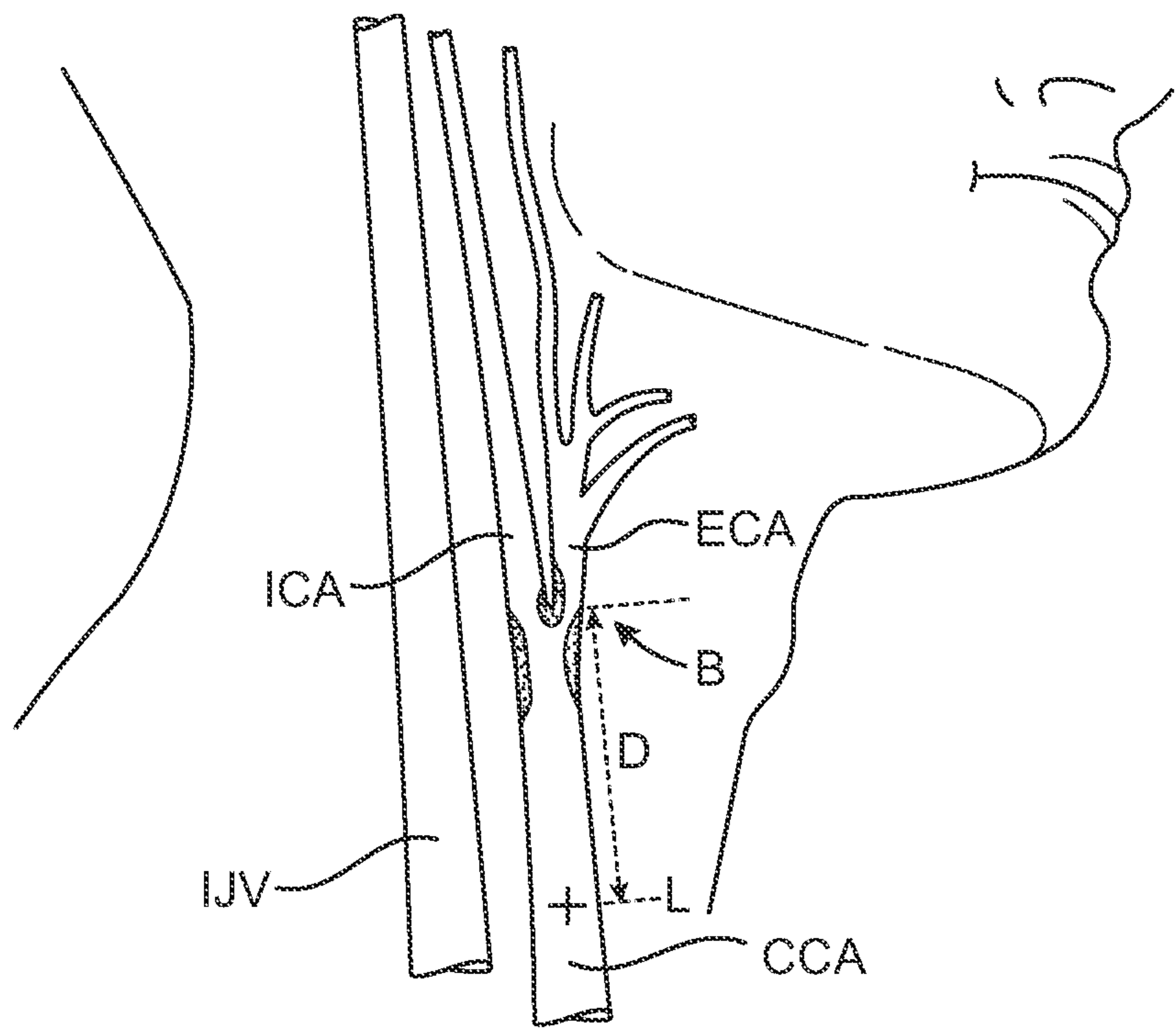


FIG. 5

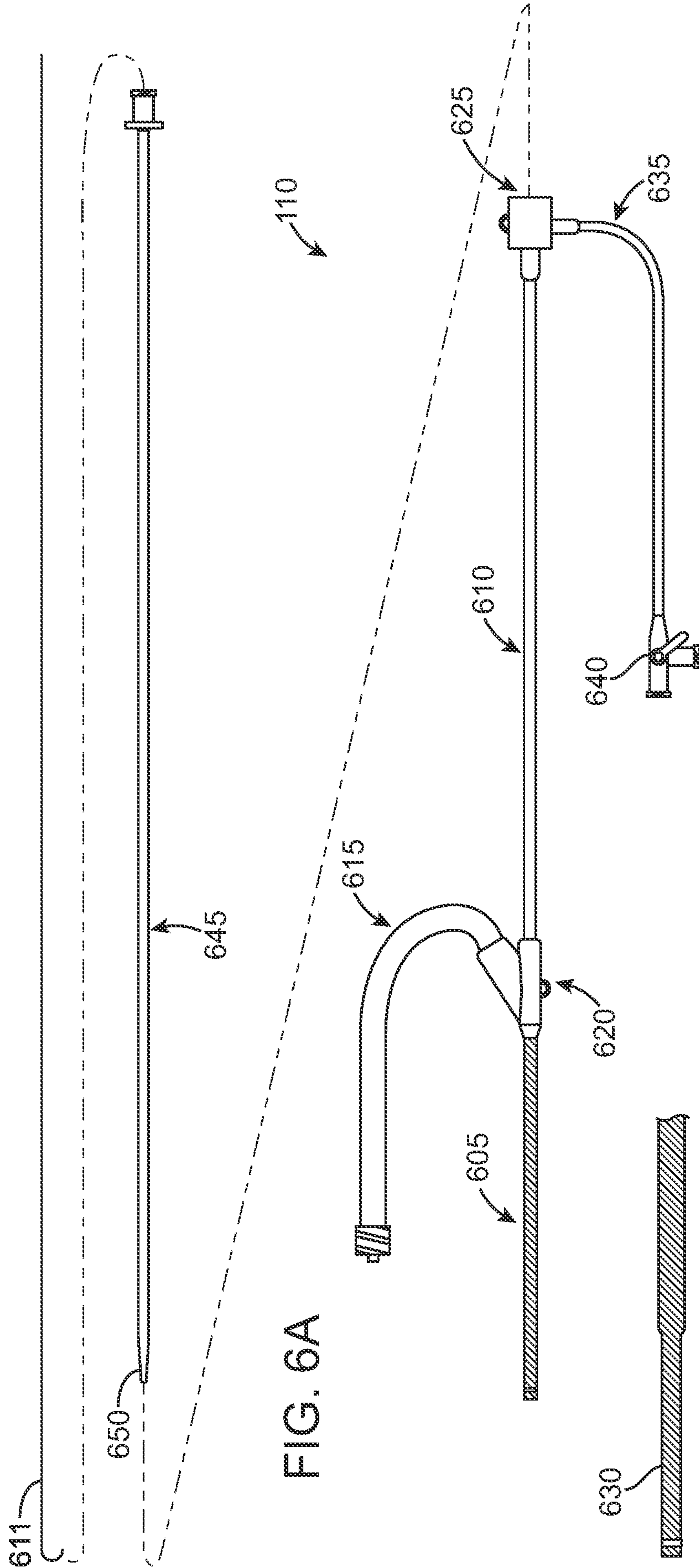
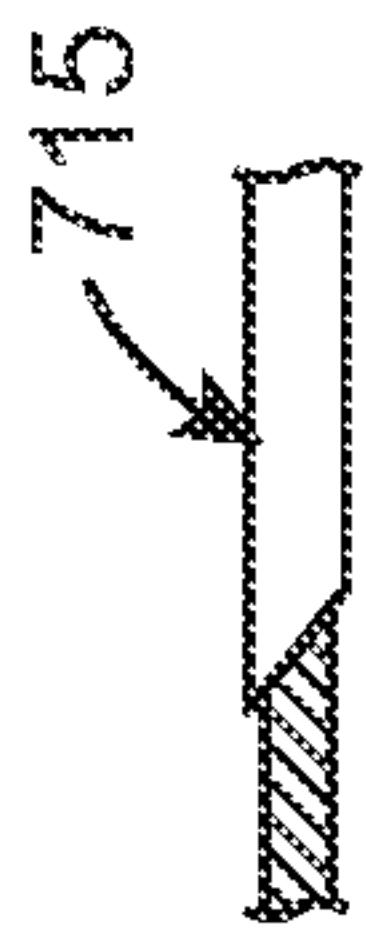
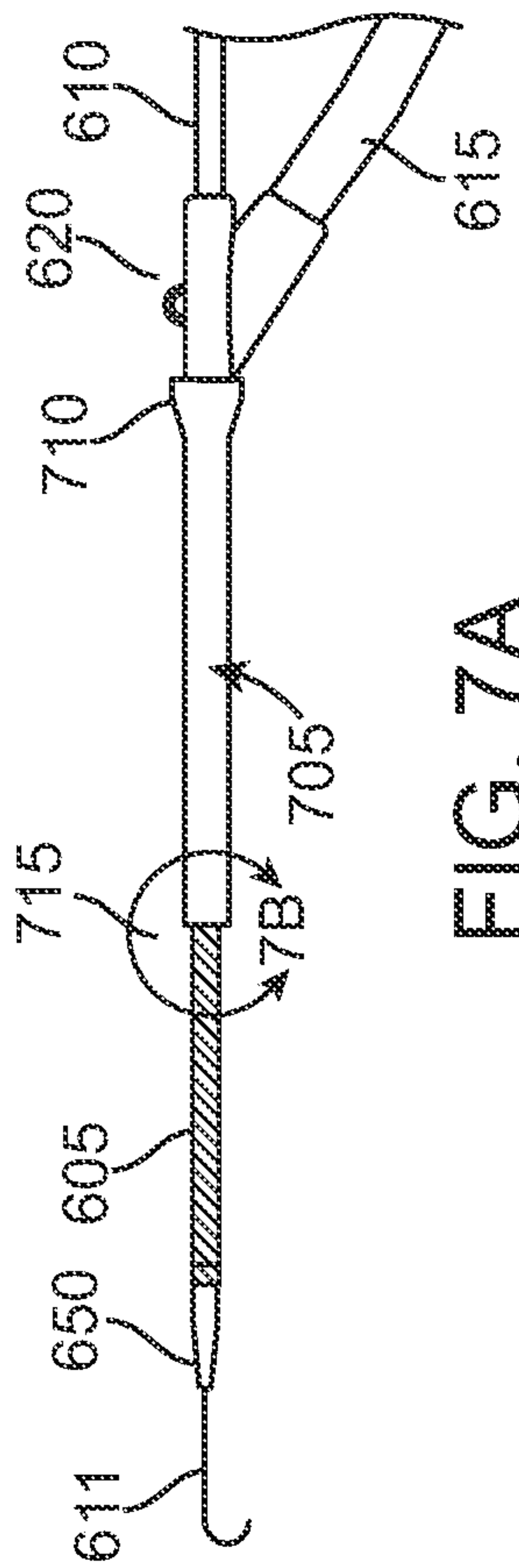


FIG. 6B



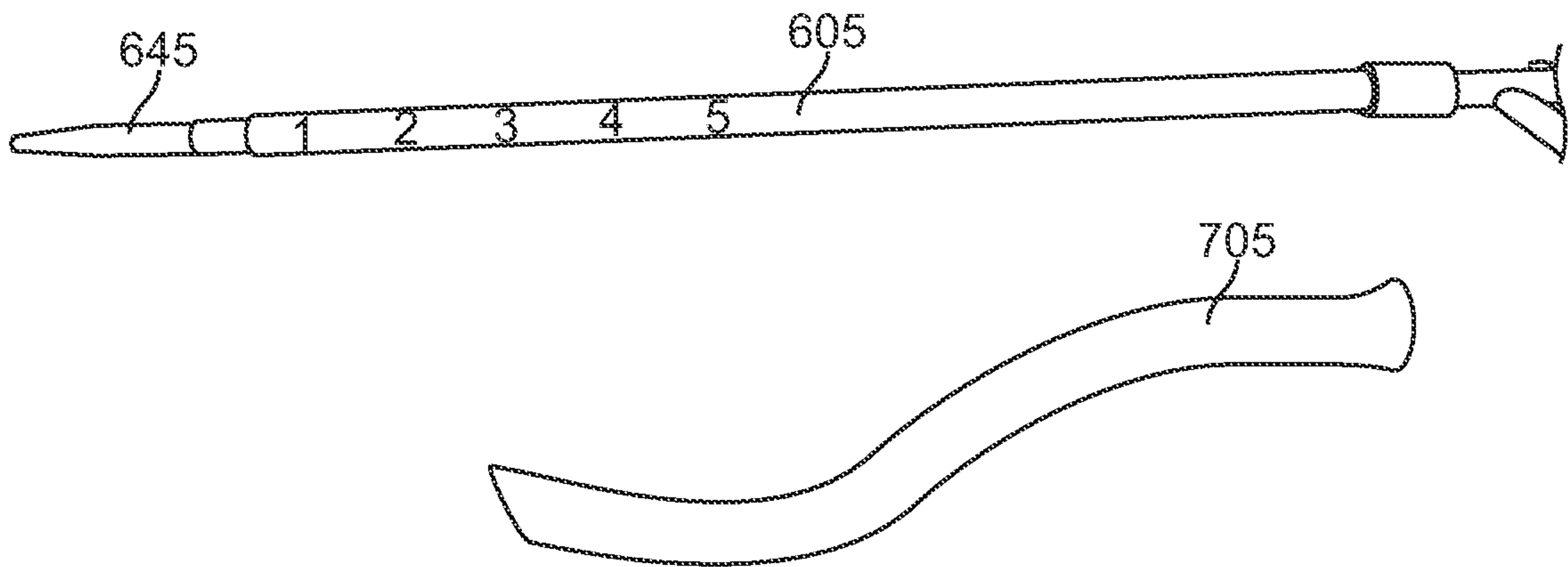


FIG. 7C

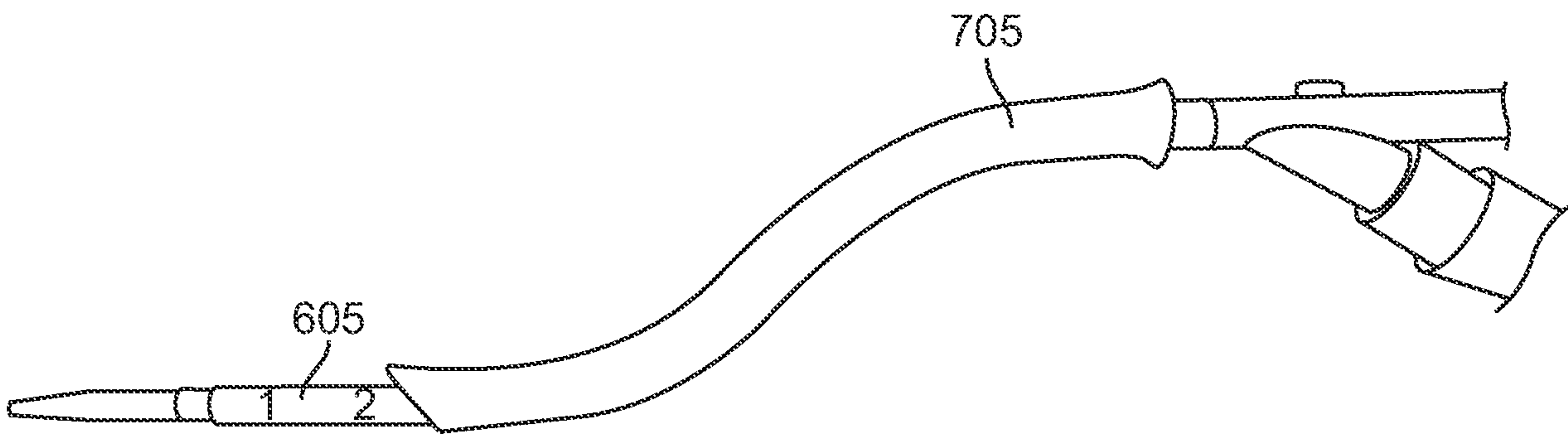


FIG. 7D

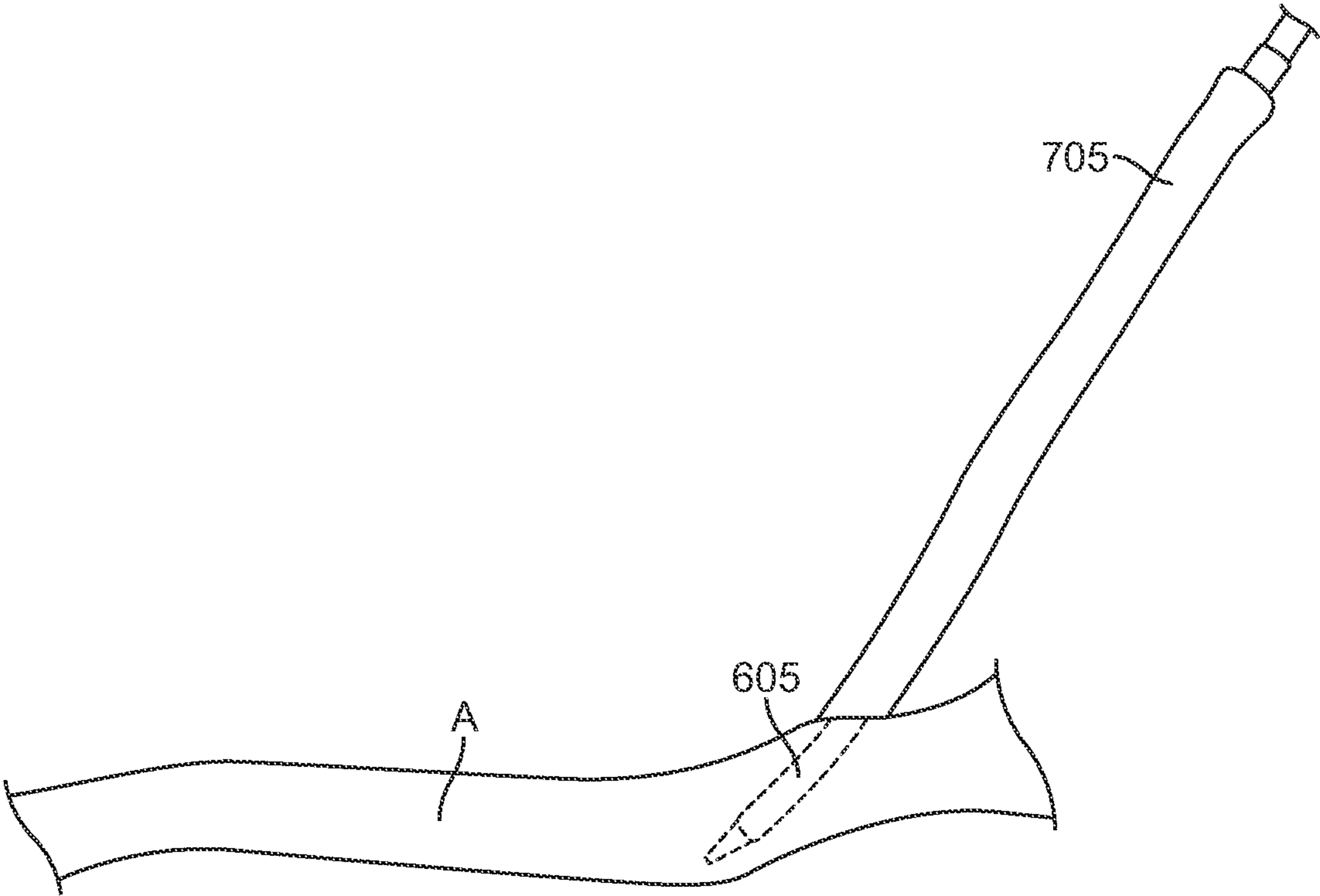


FIG. 7E

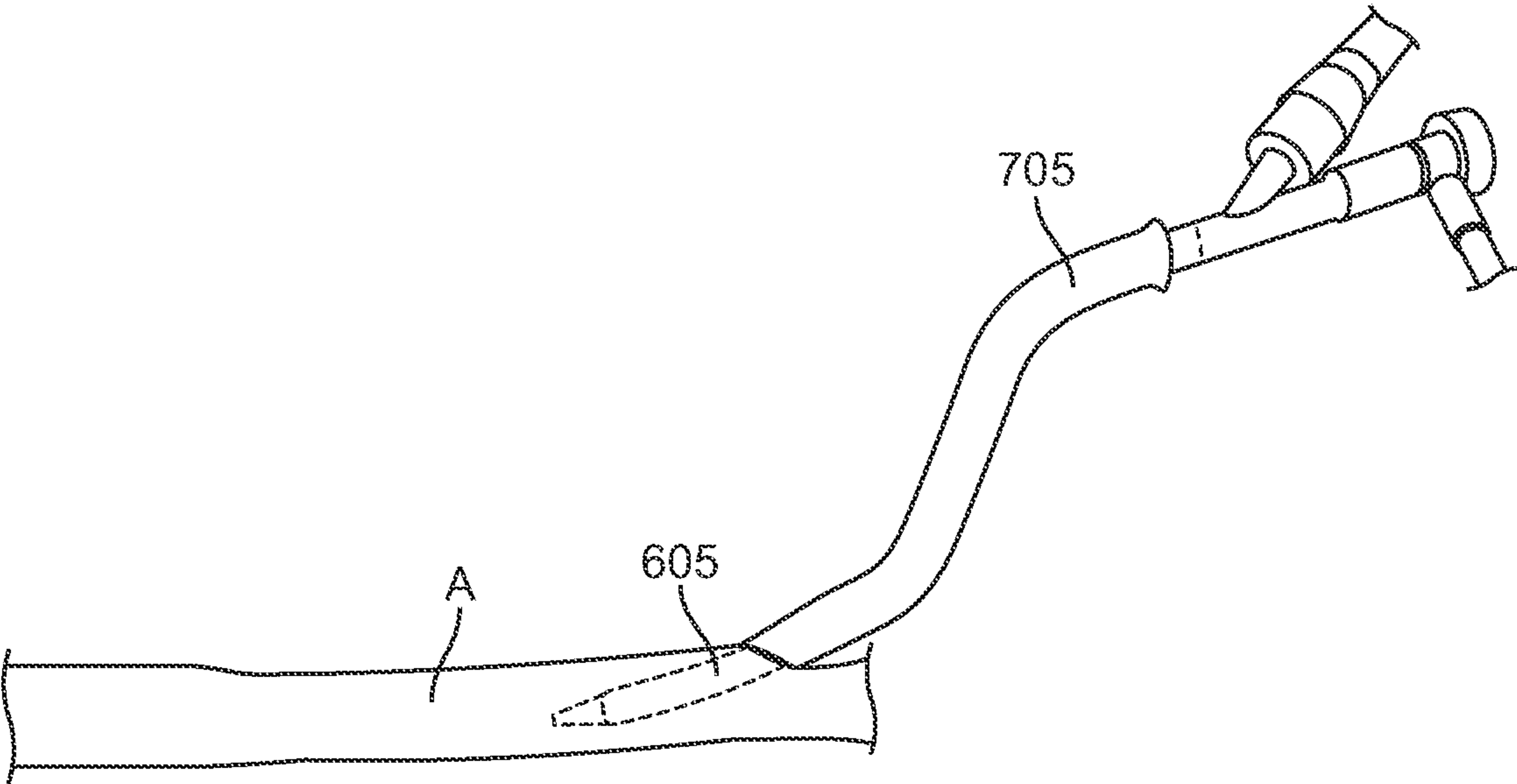


FIG. 7F

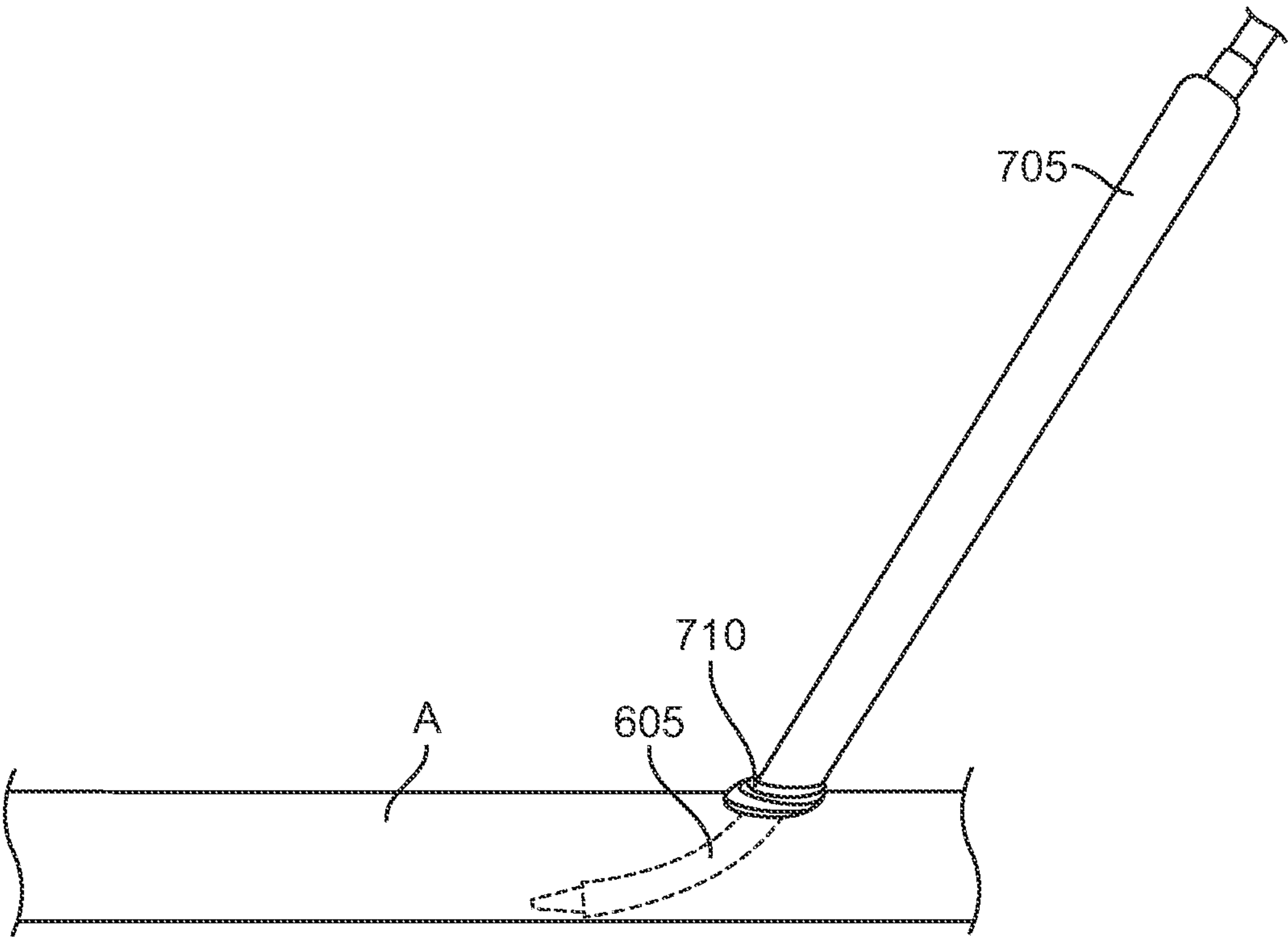


FIG. 7G

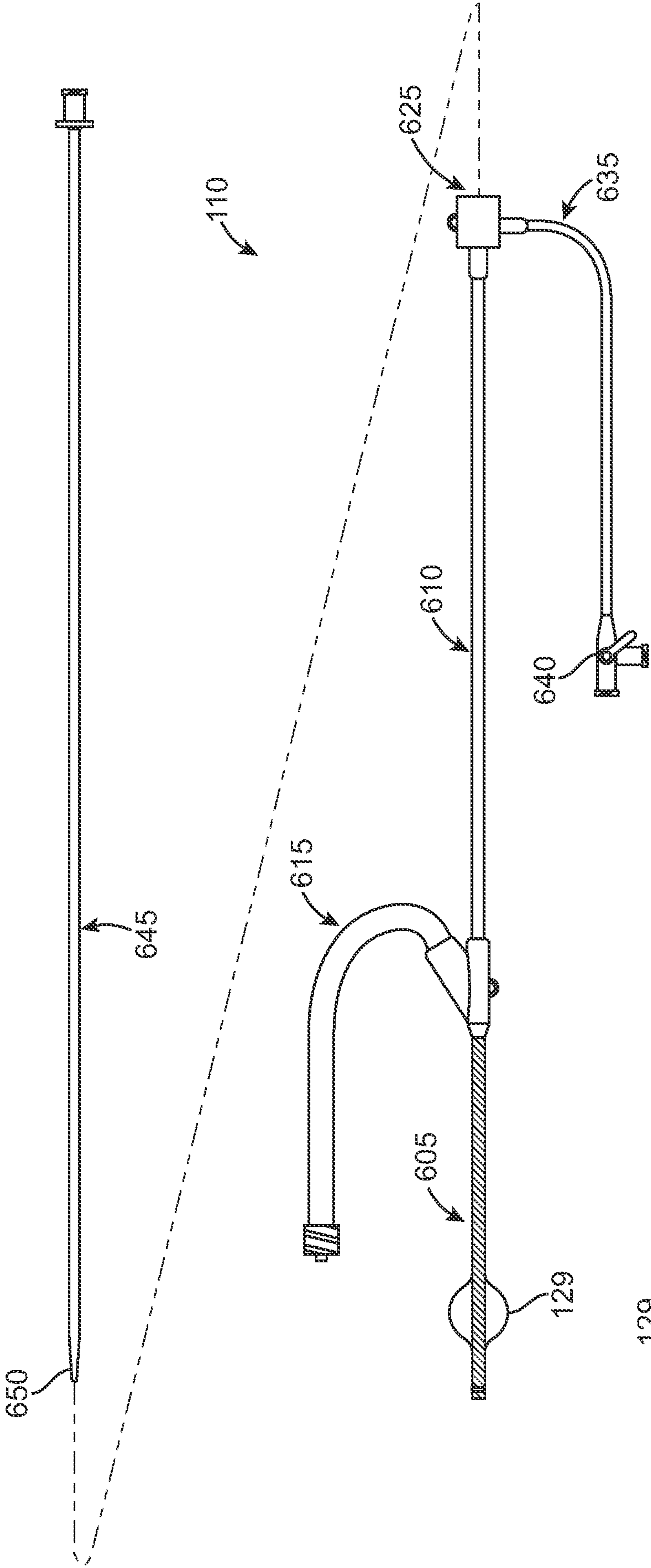


FIG. 8A

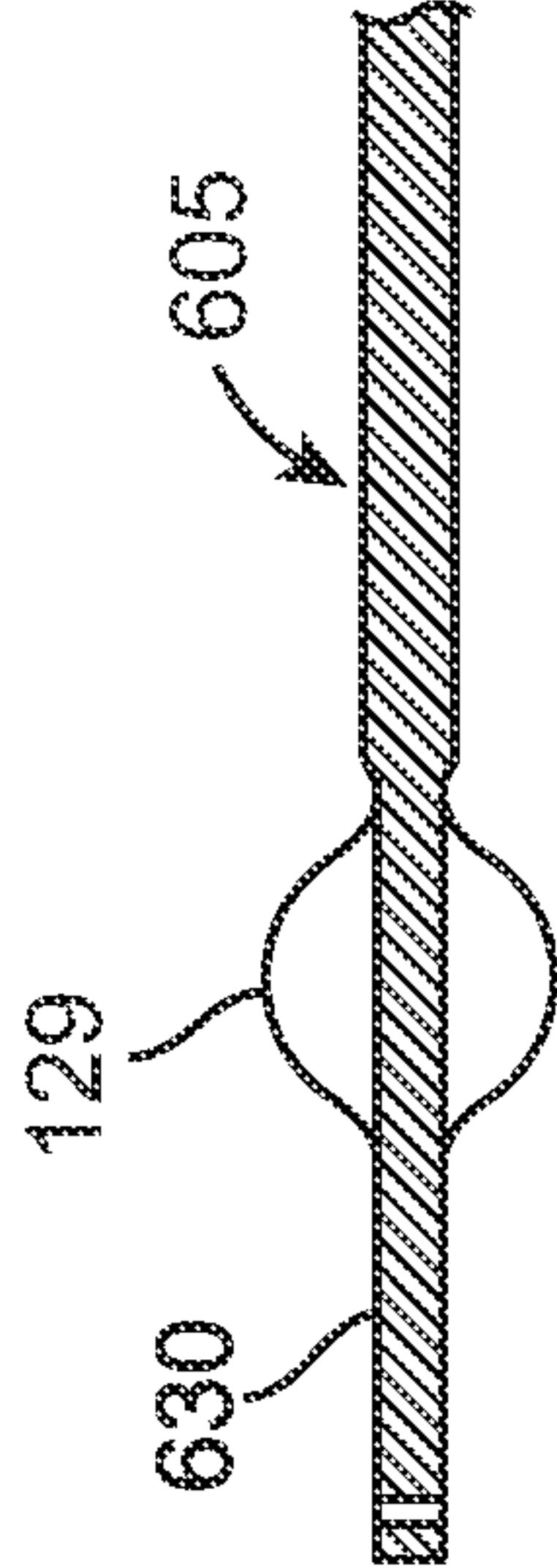
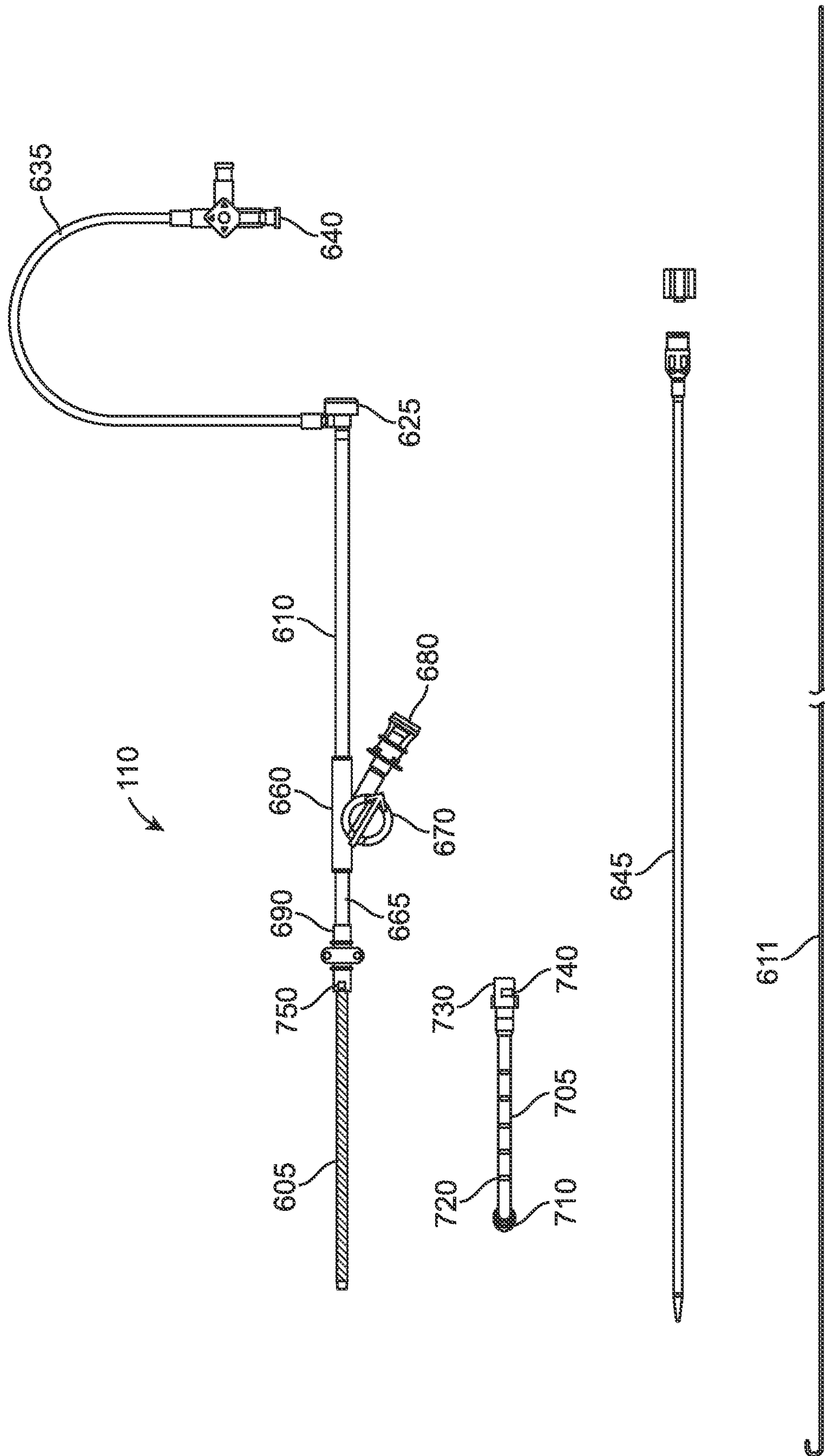


FIG. 8B



AGL

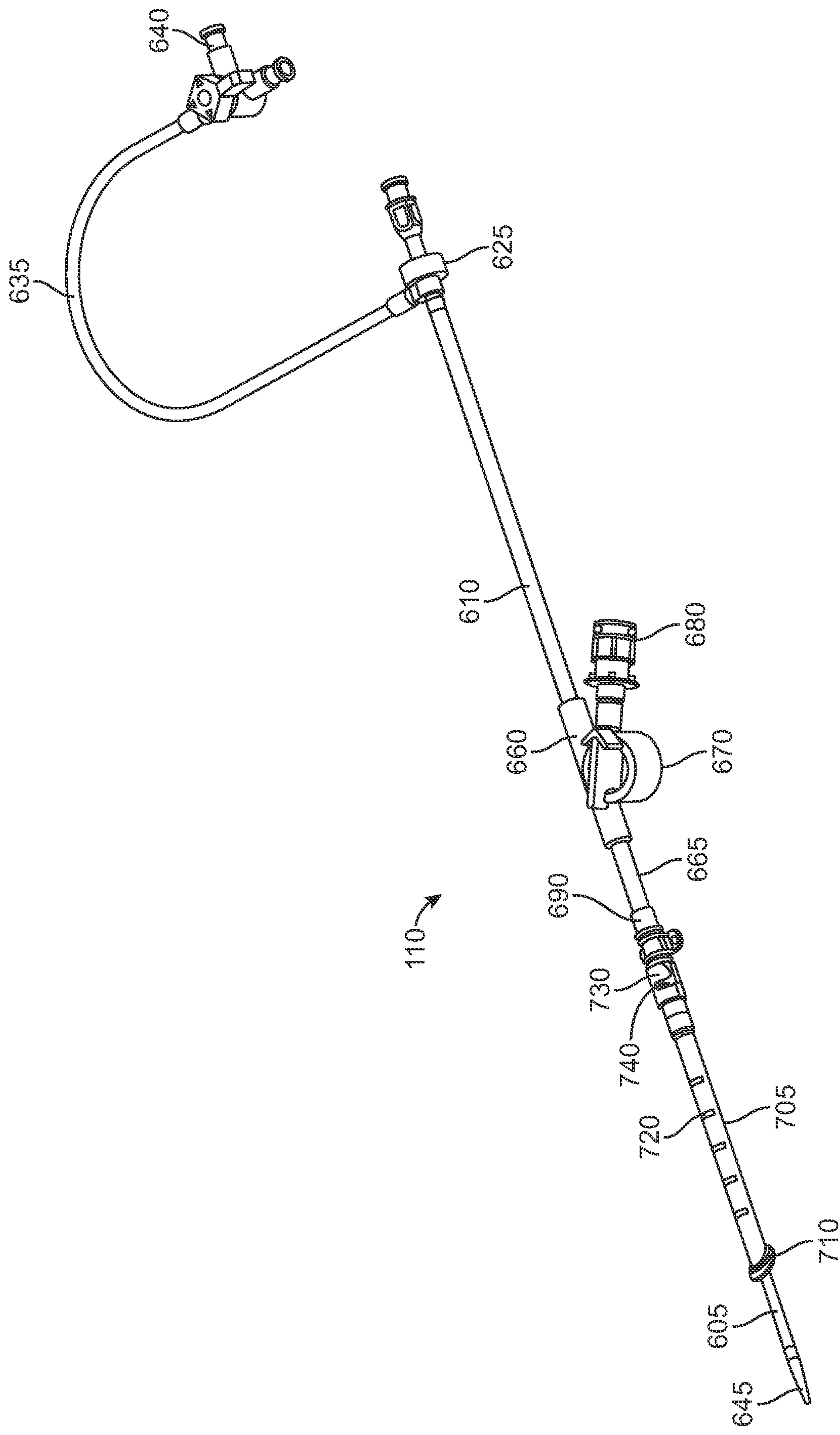


FIG. 9B

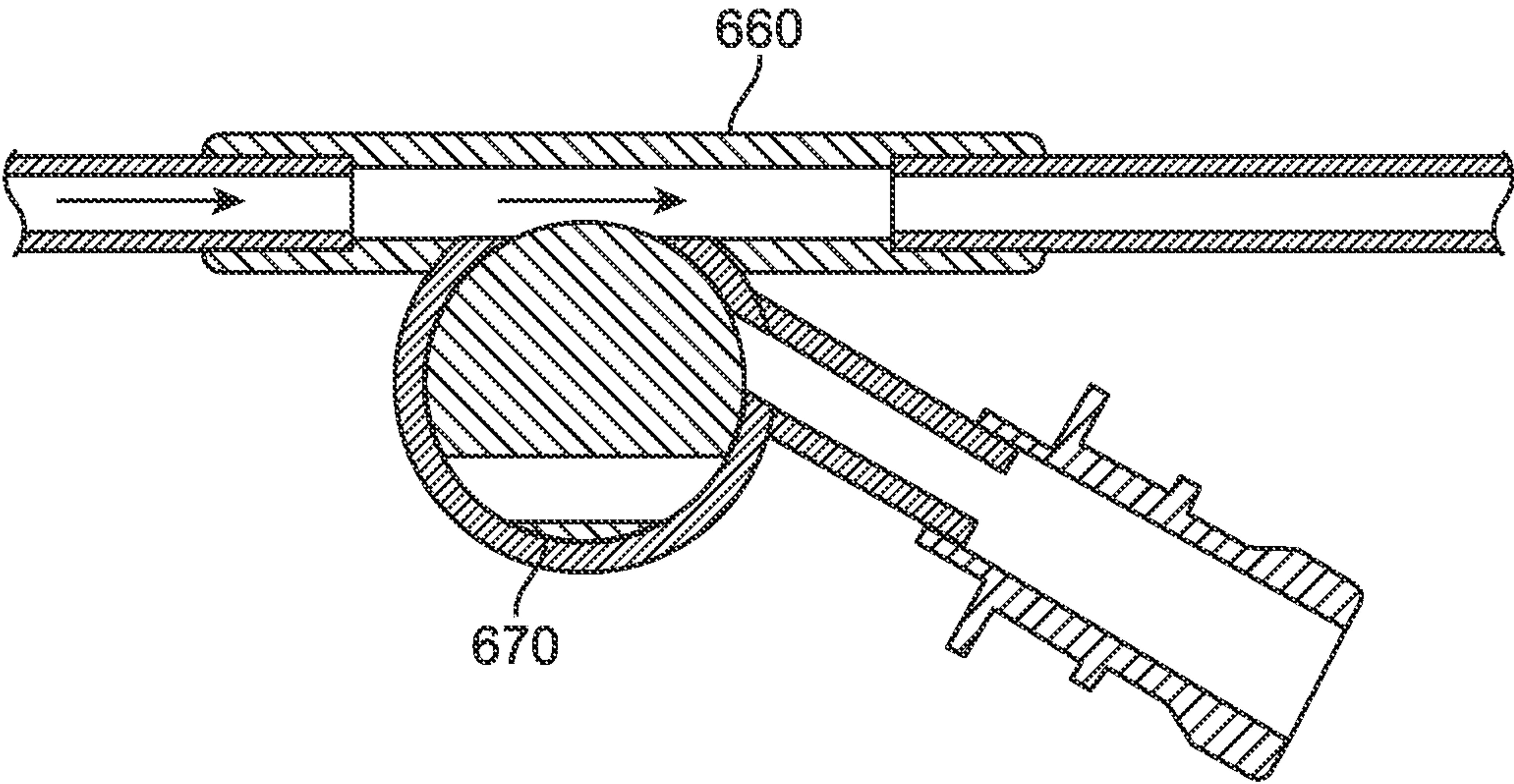


FIG. 9C

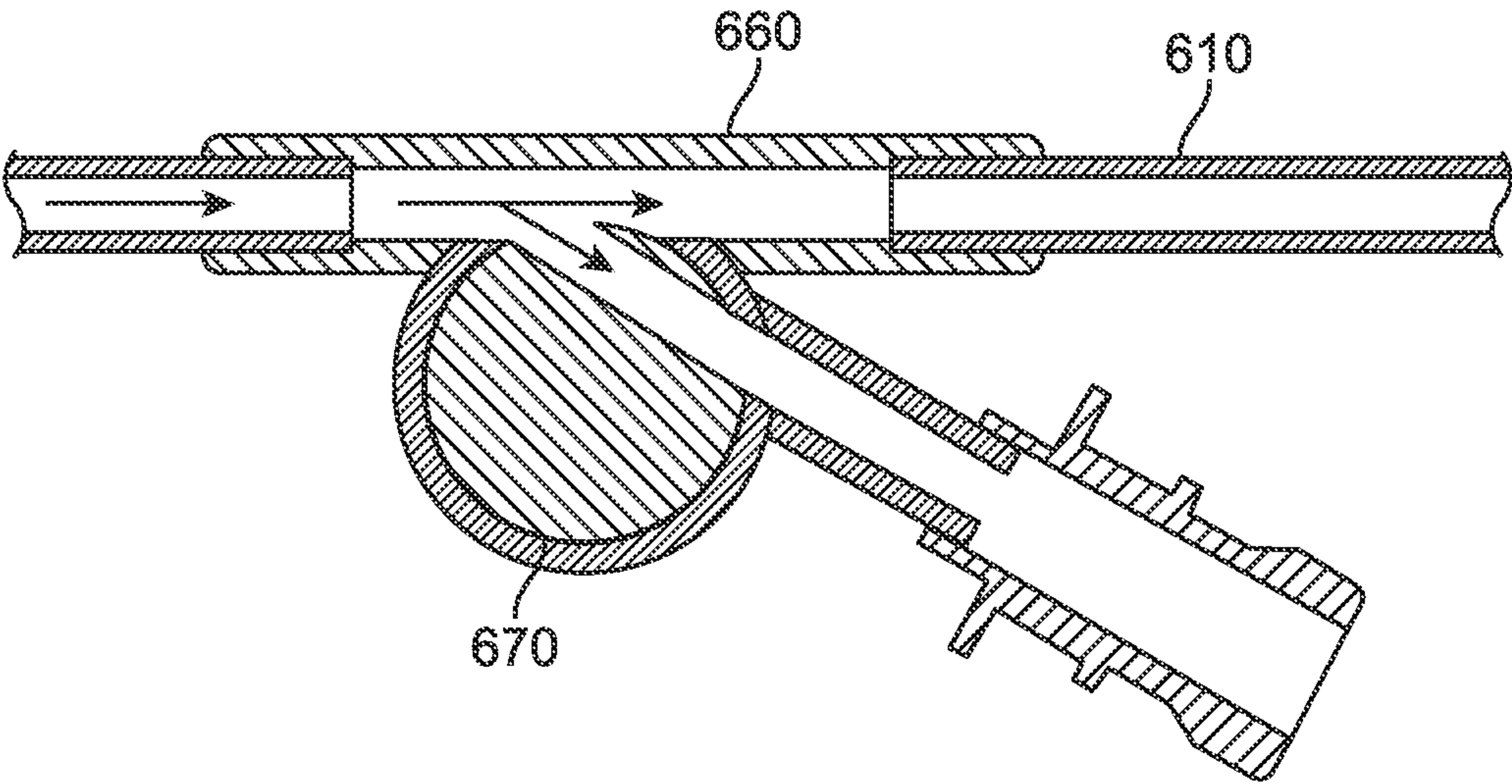


FIG. 9D

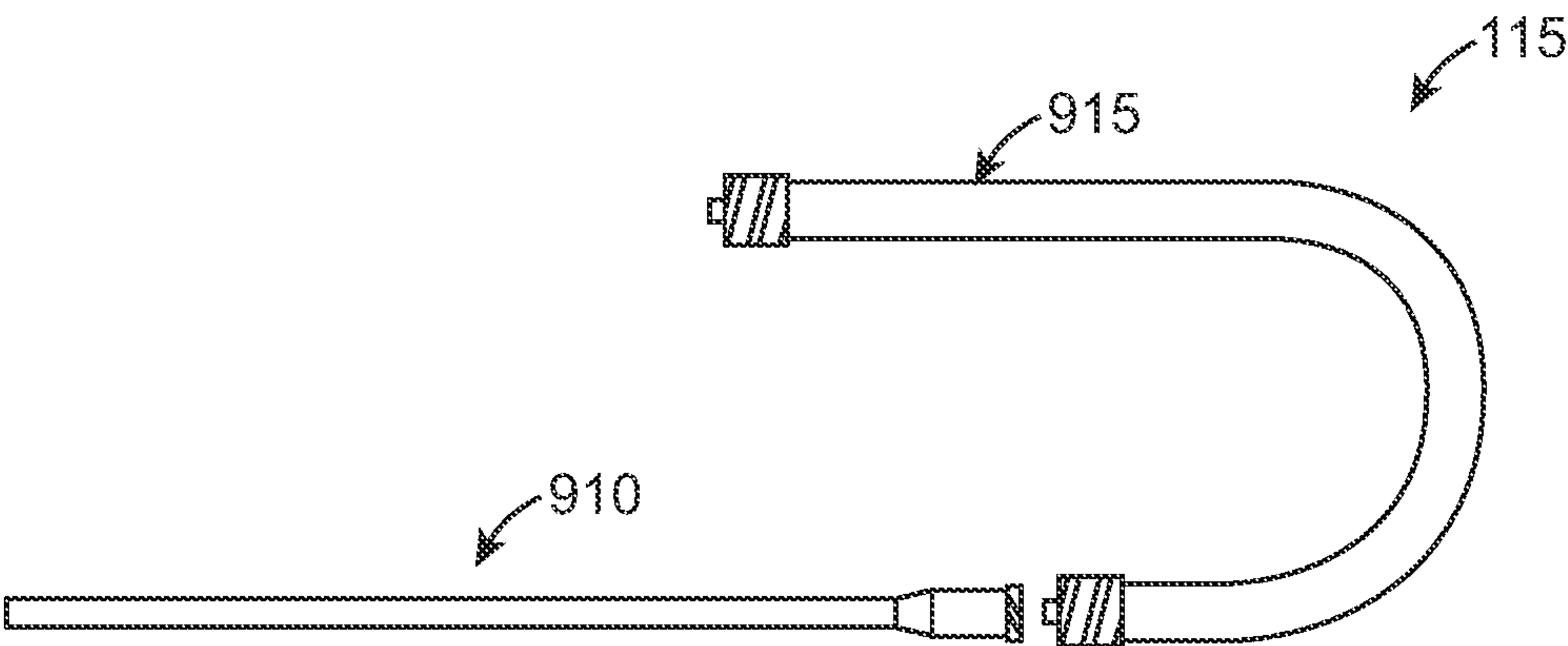


FIG. 10A

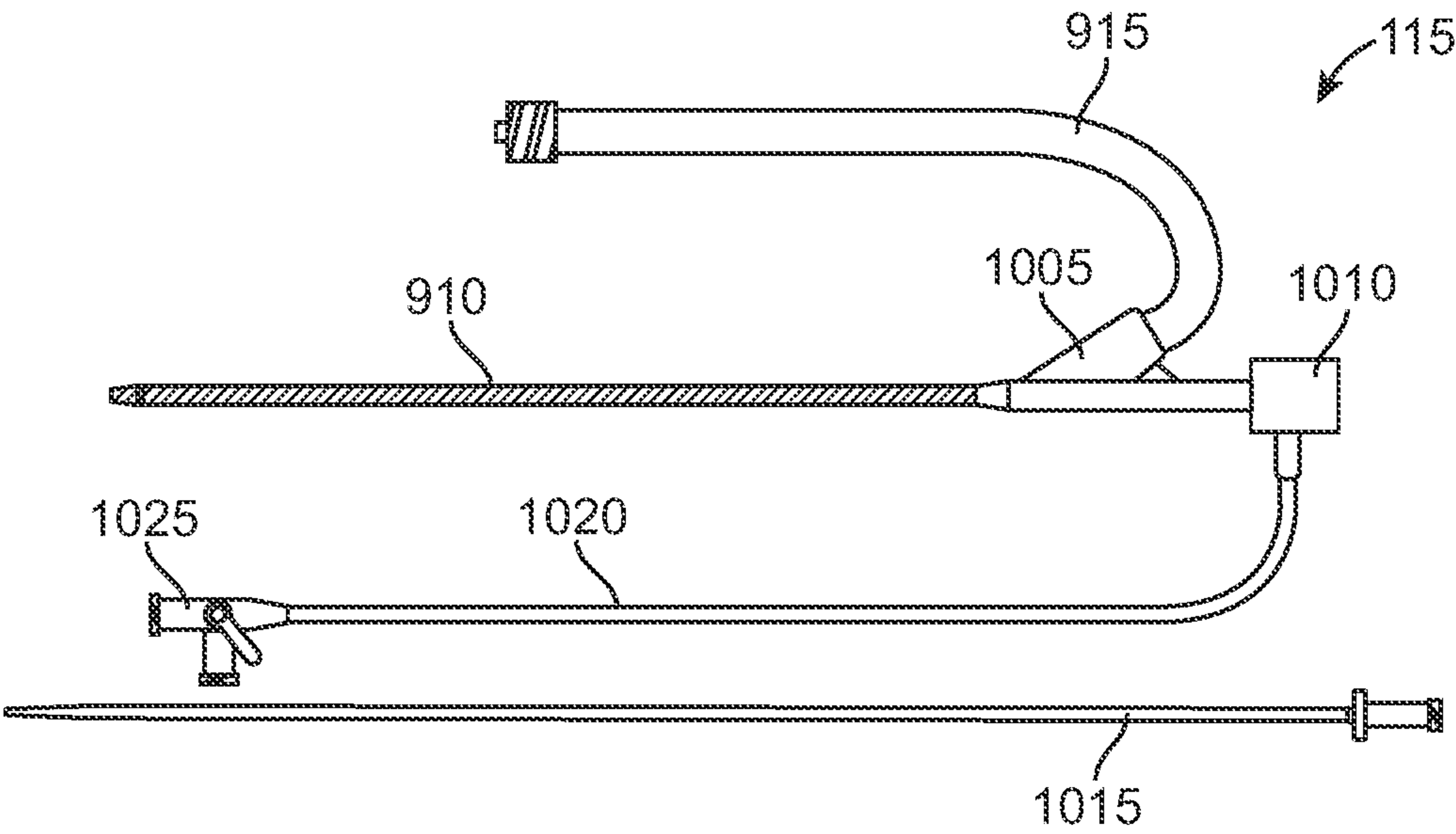


FIG. 10B

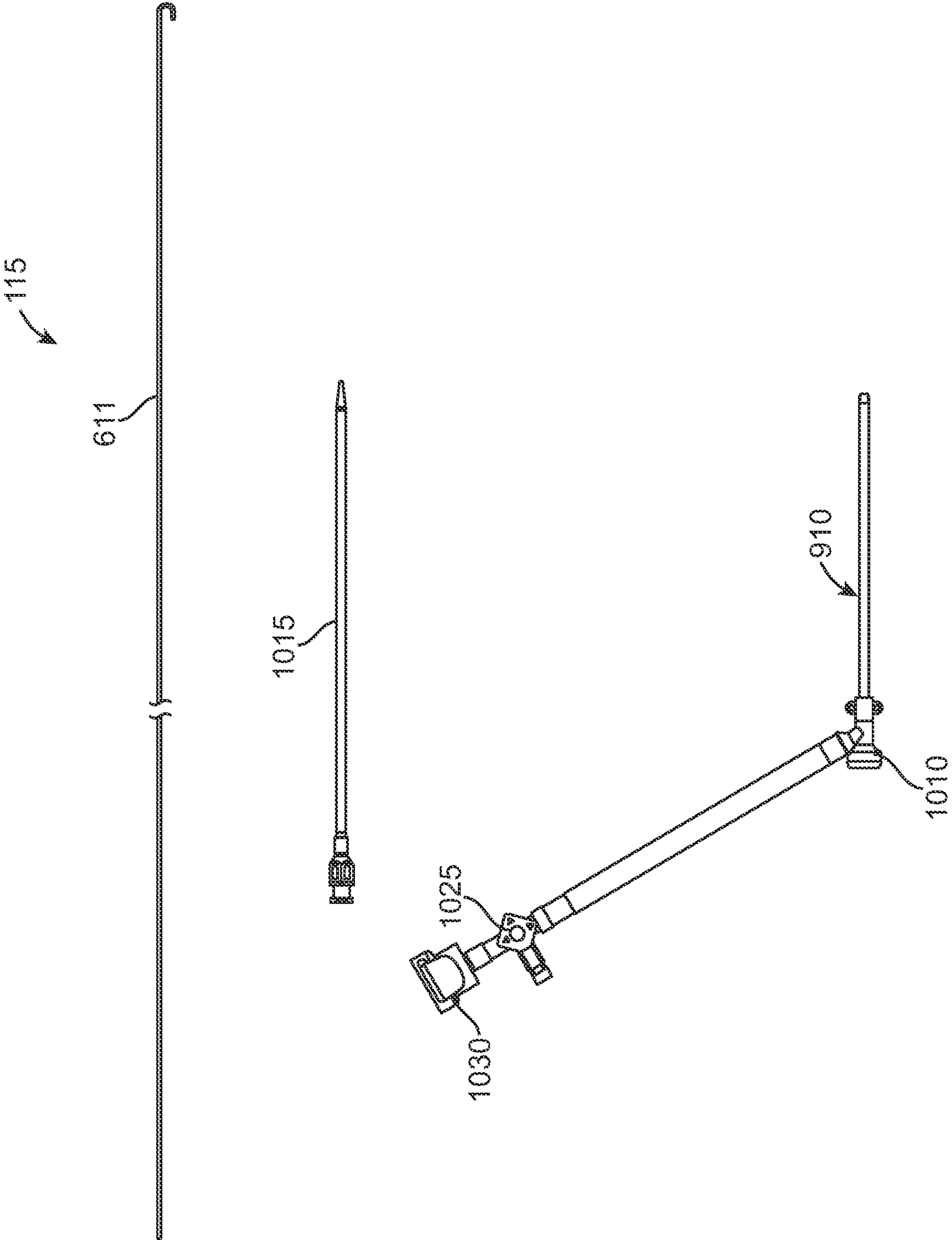


FIG. 10C

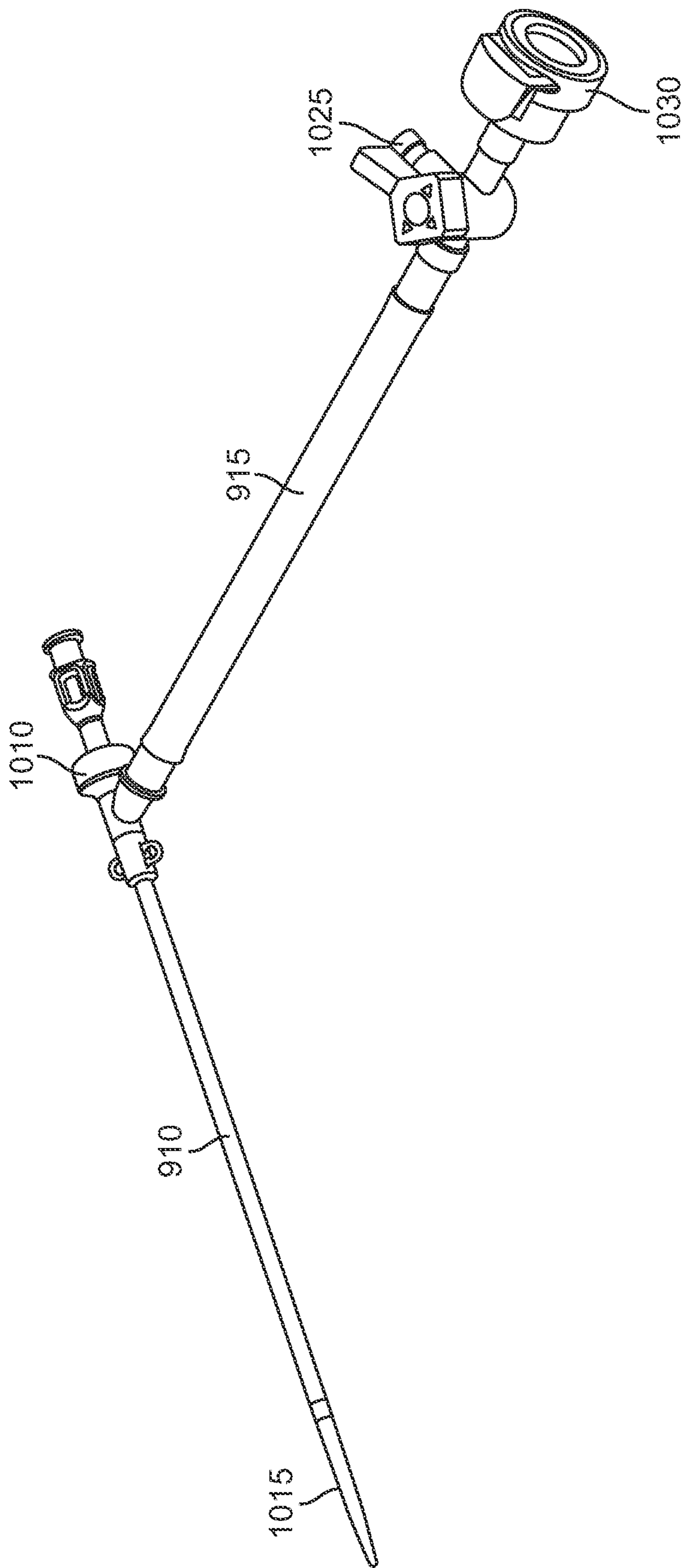
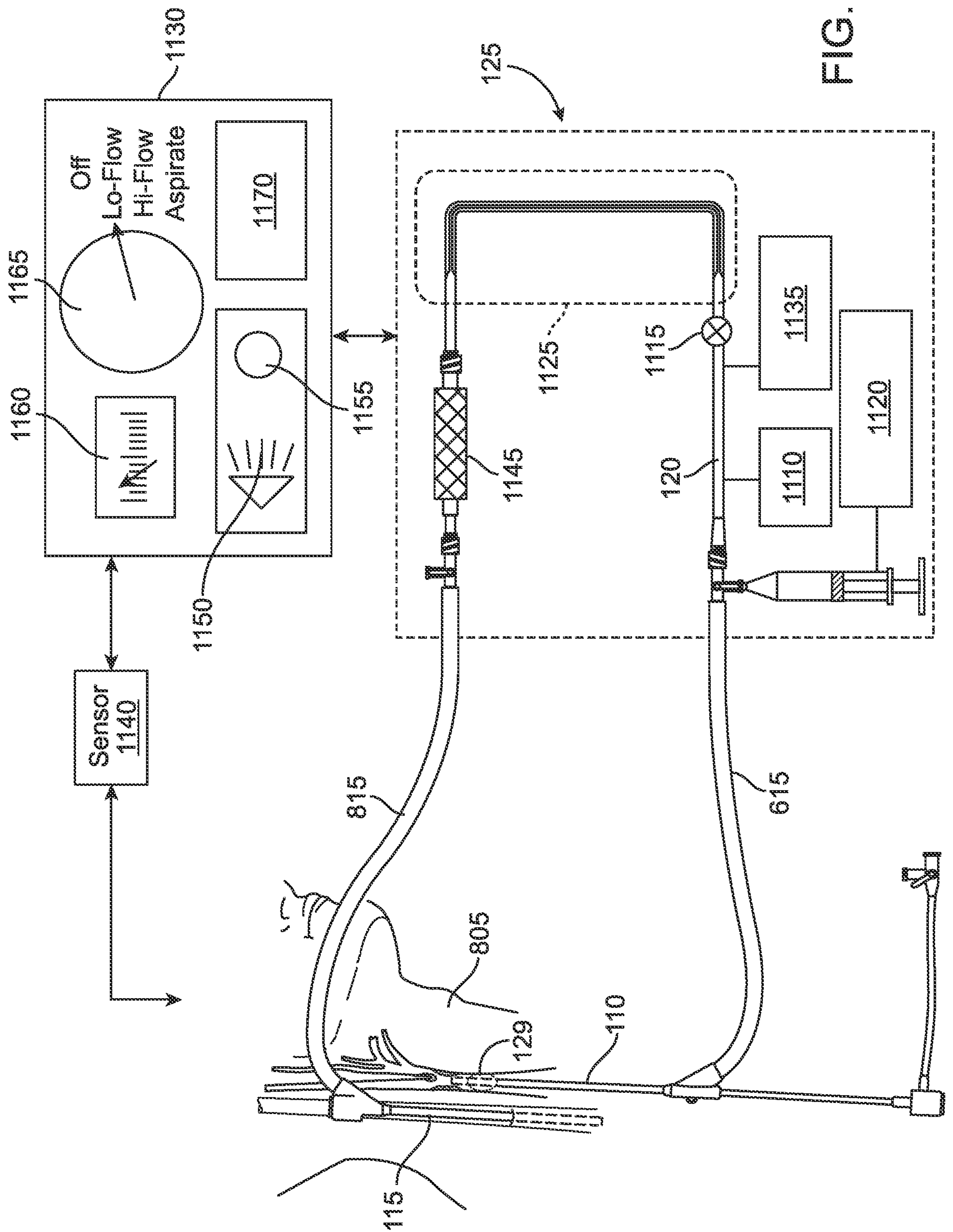


FIG. 10D



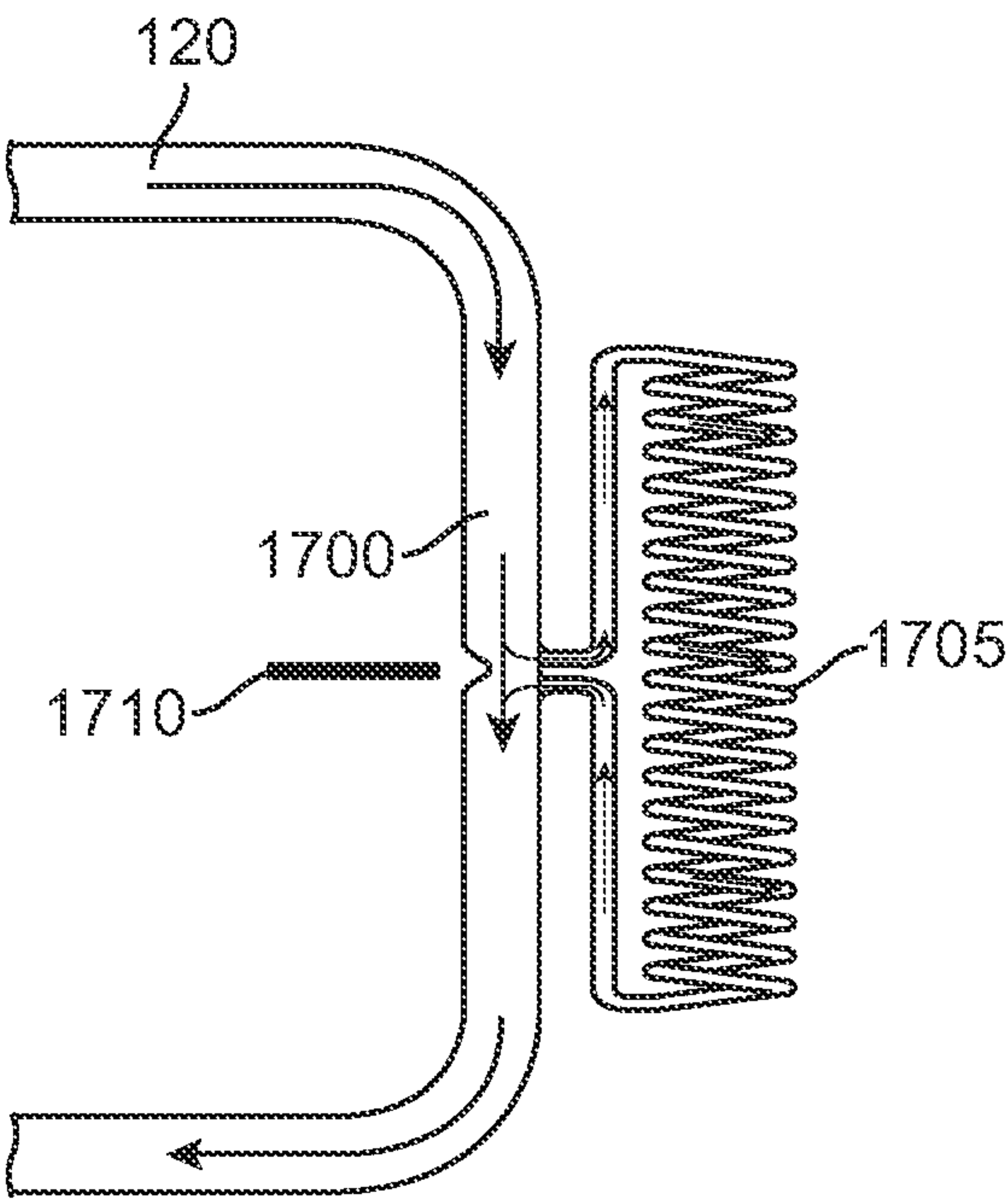


FIG. 12A

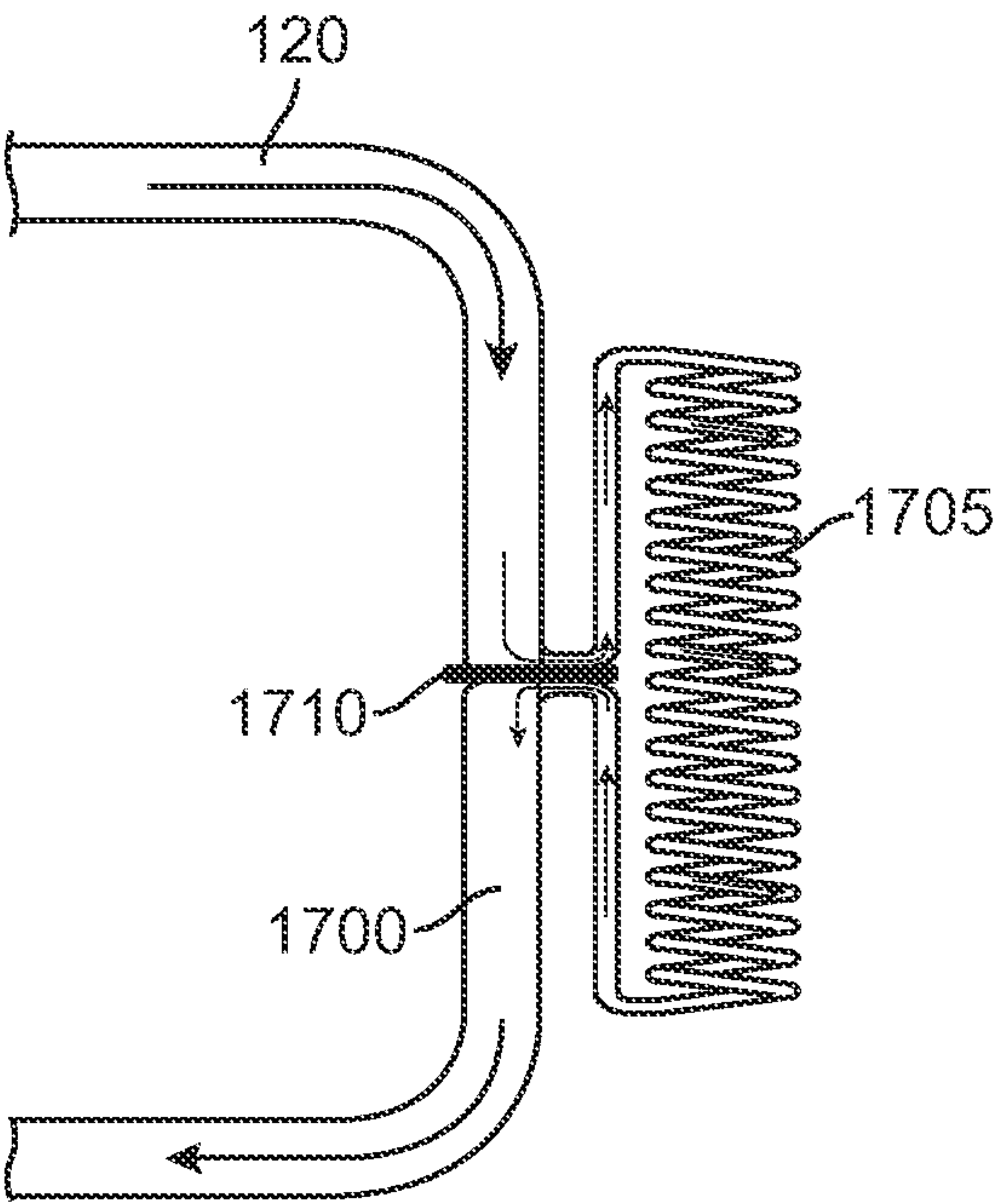


FIG. 12B

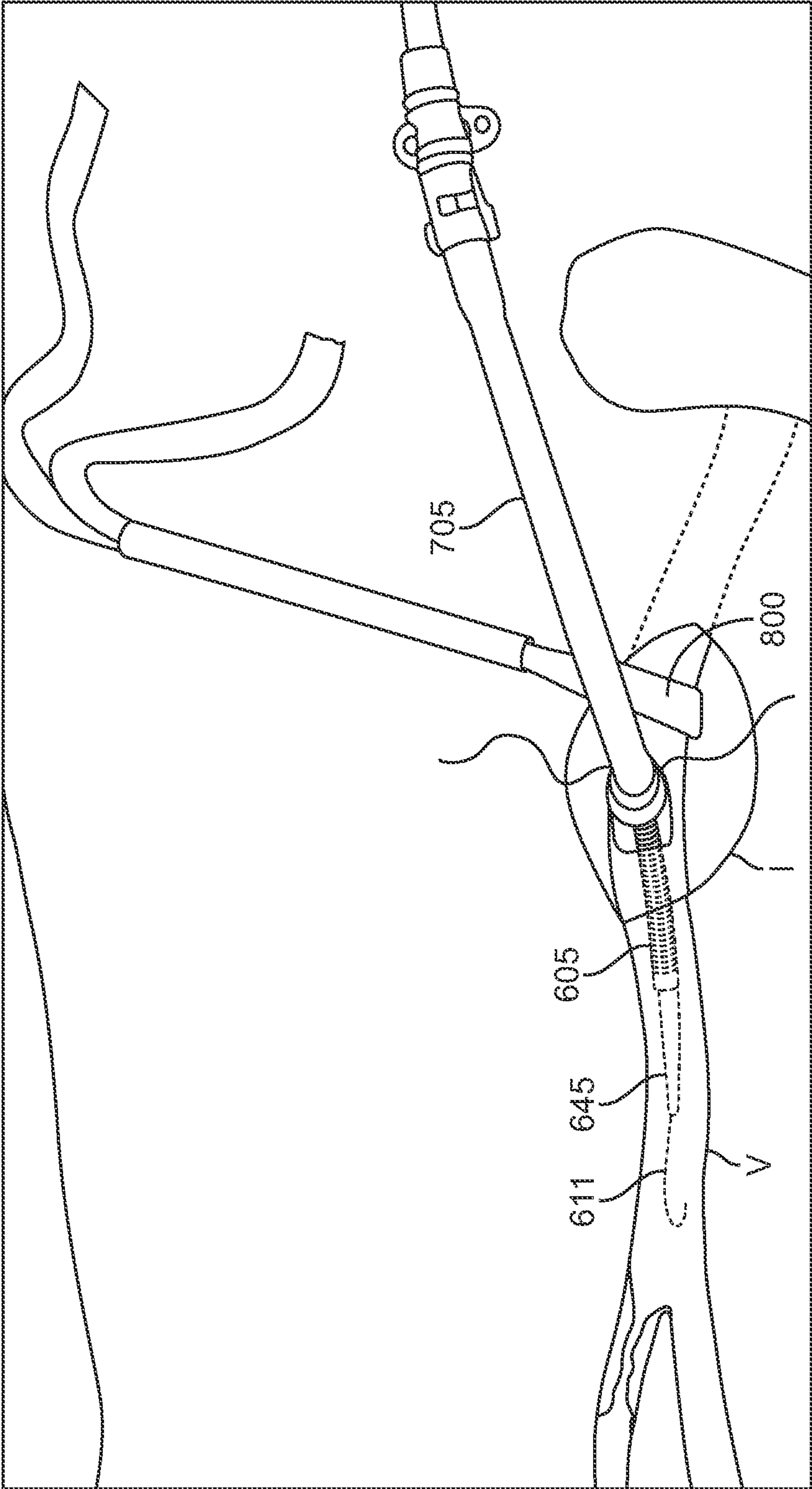


FIG. 13A

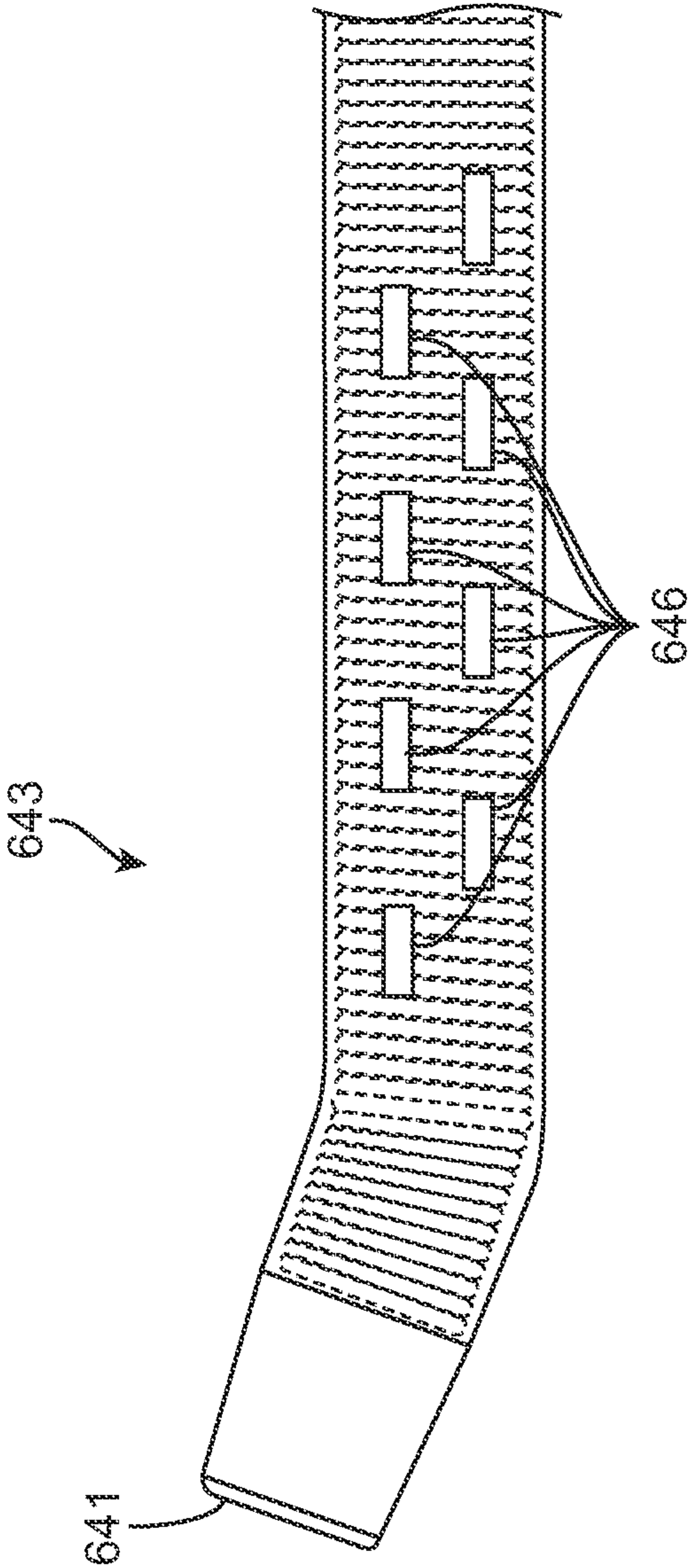


FIG. 13C

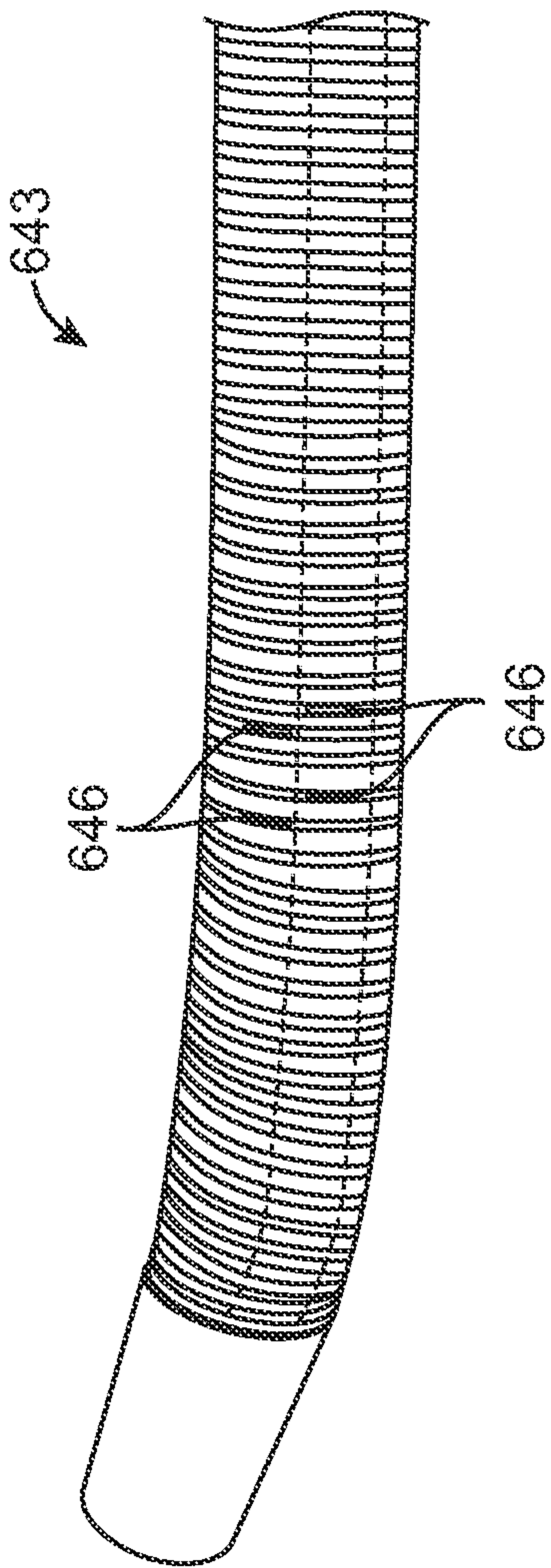


FIG. 13D

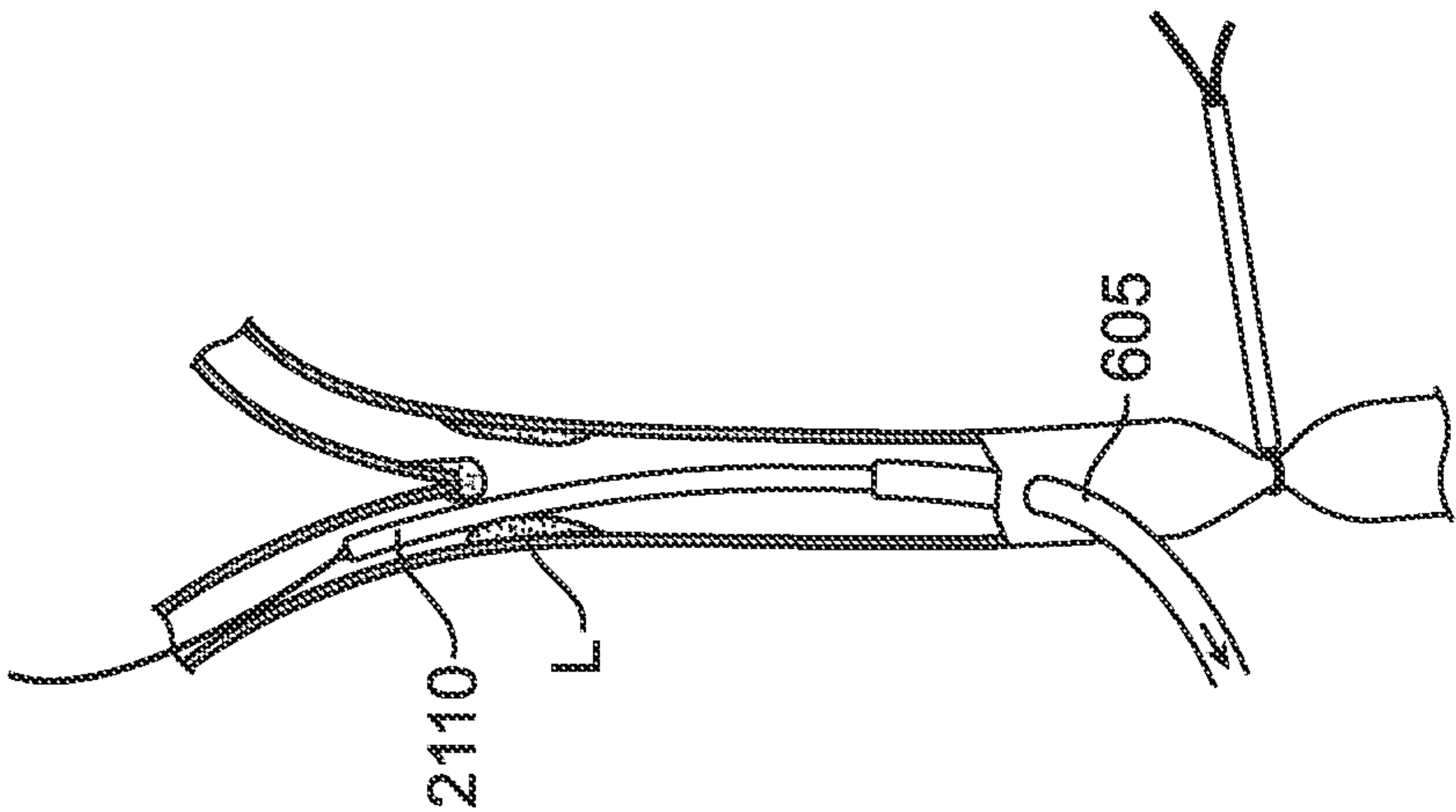


FIG. 14C

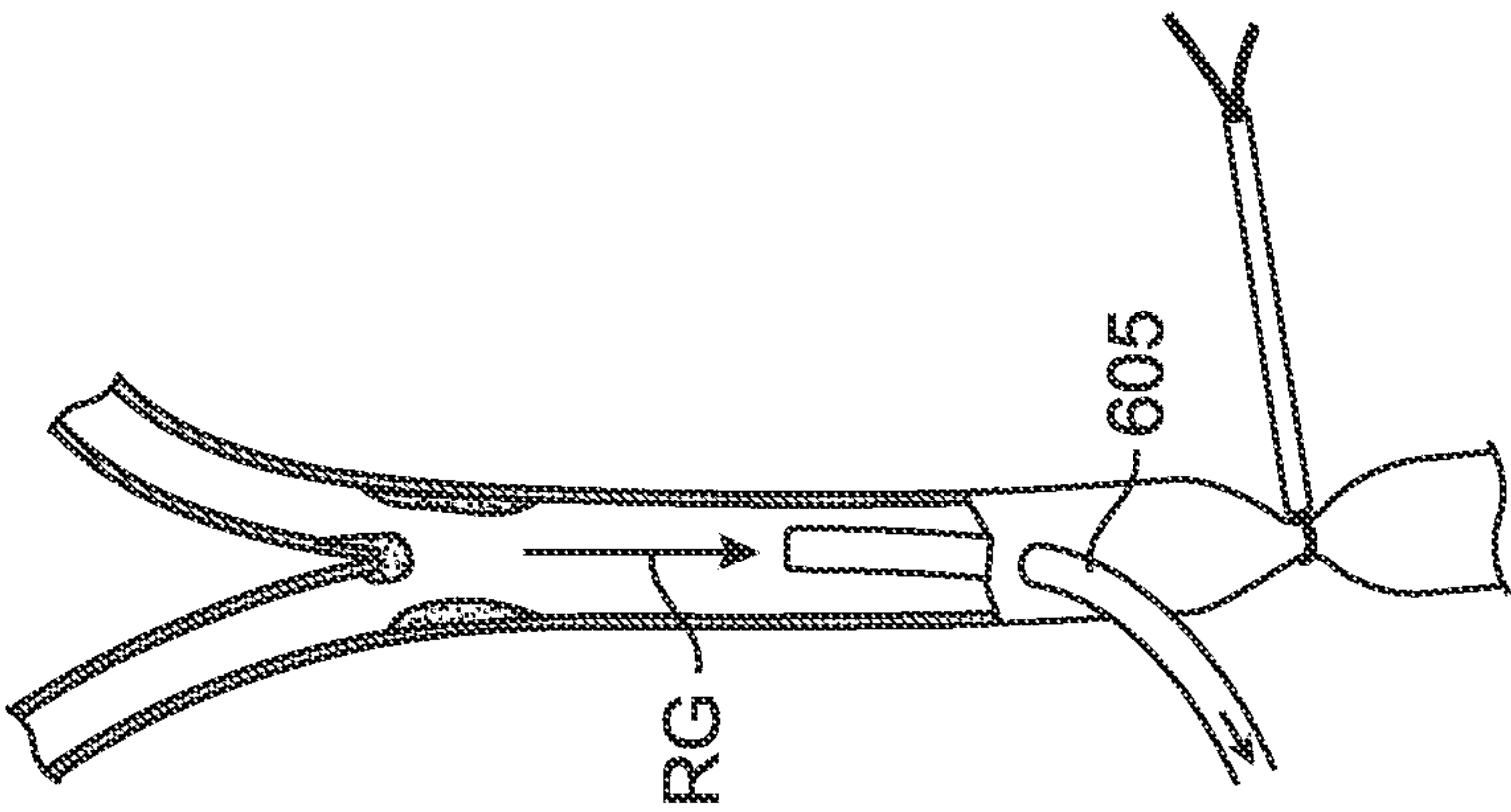


FIG. 14B

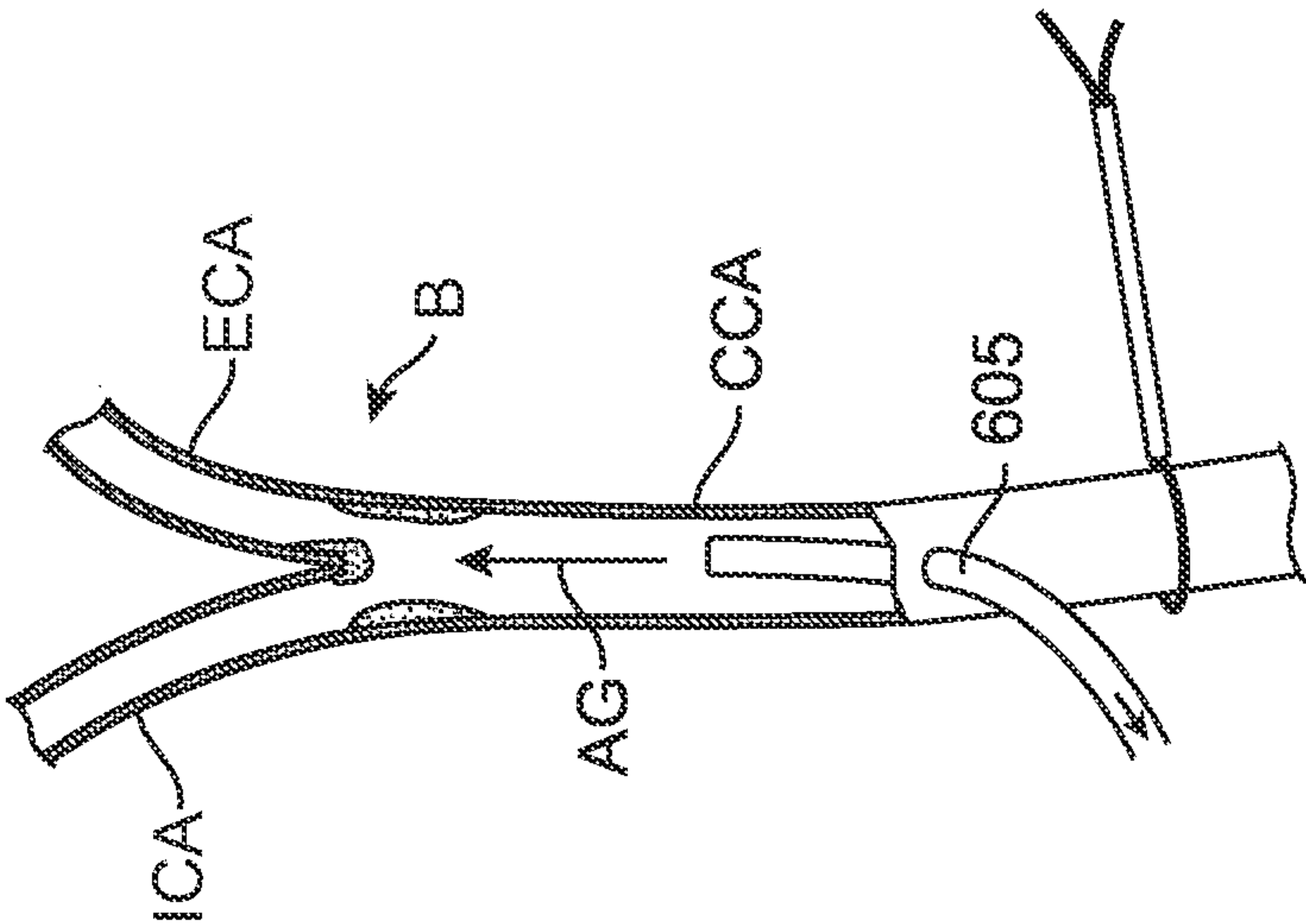


FIG. 14A

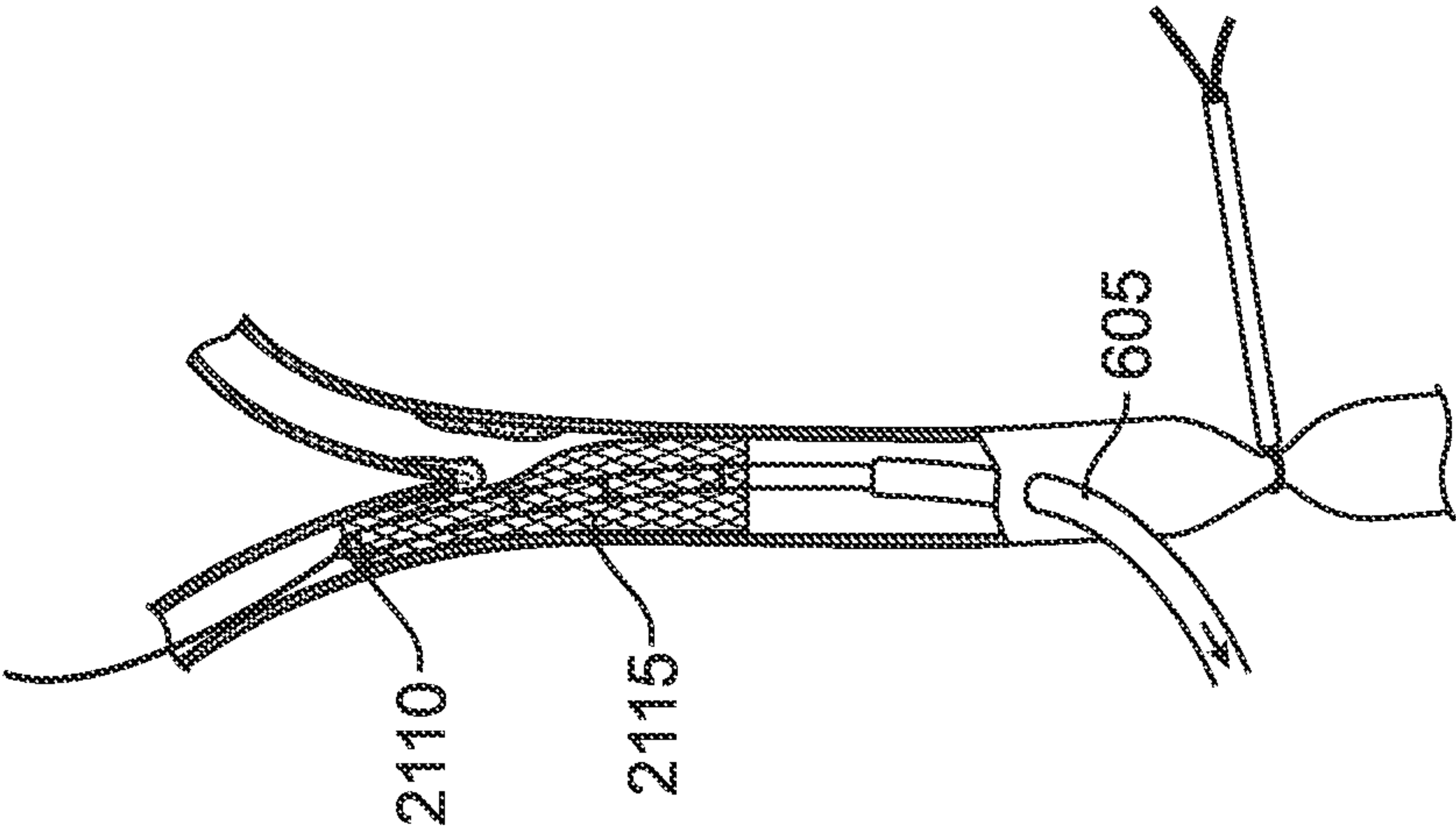


FIG. 14D

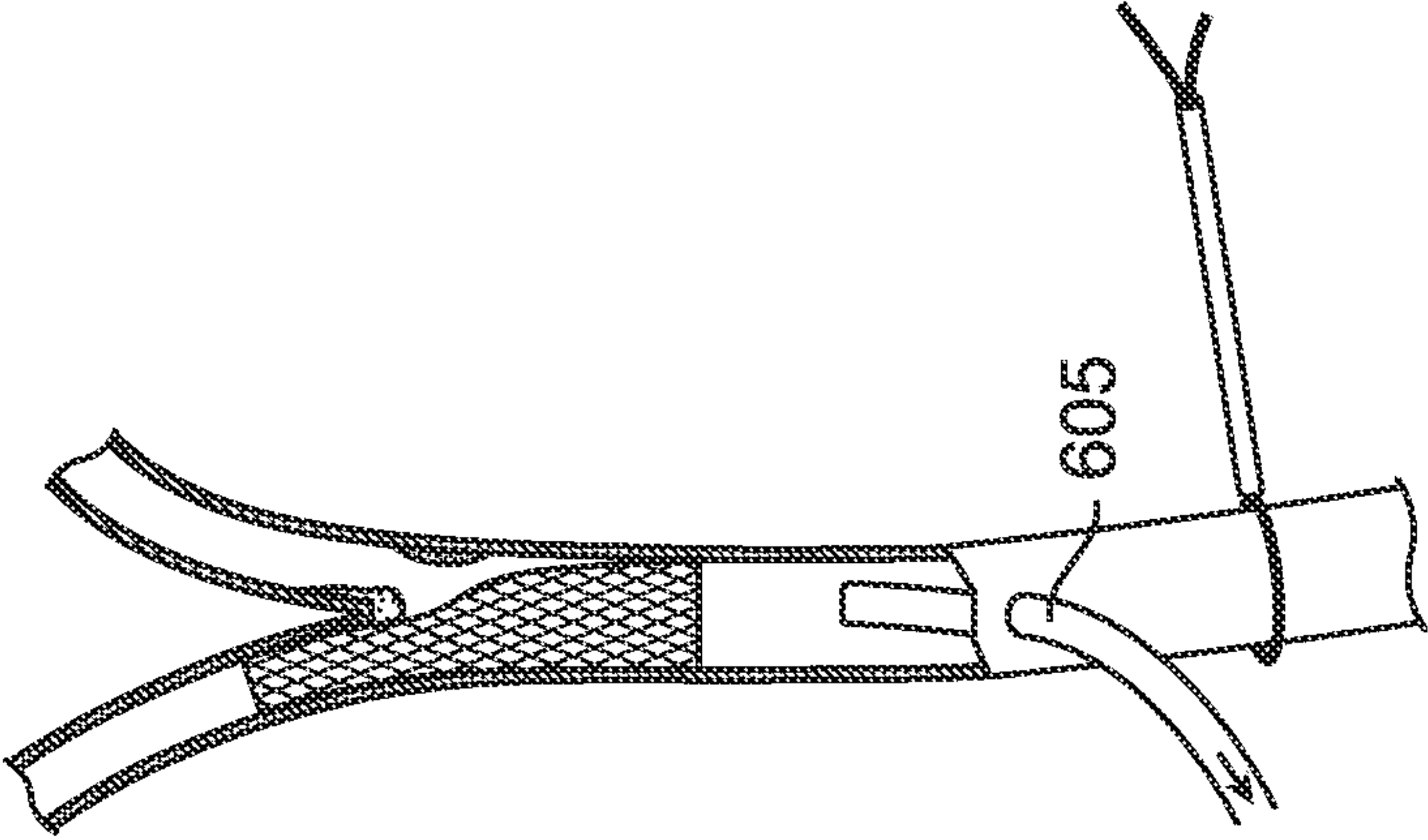


FIG. 14E

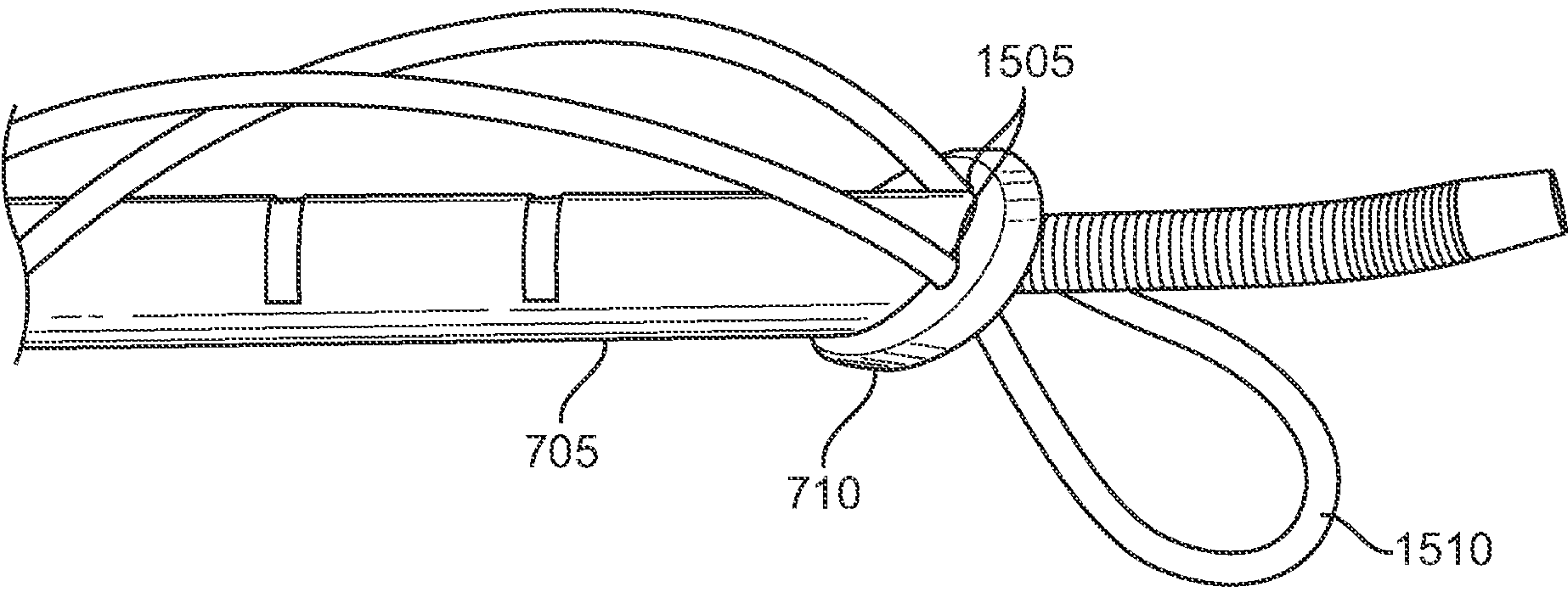


FIG. 15

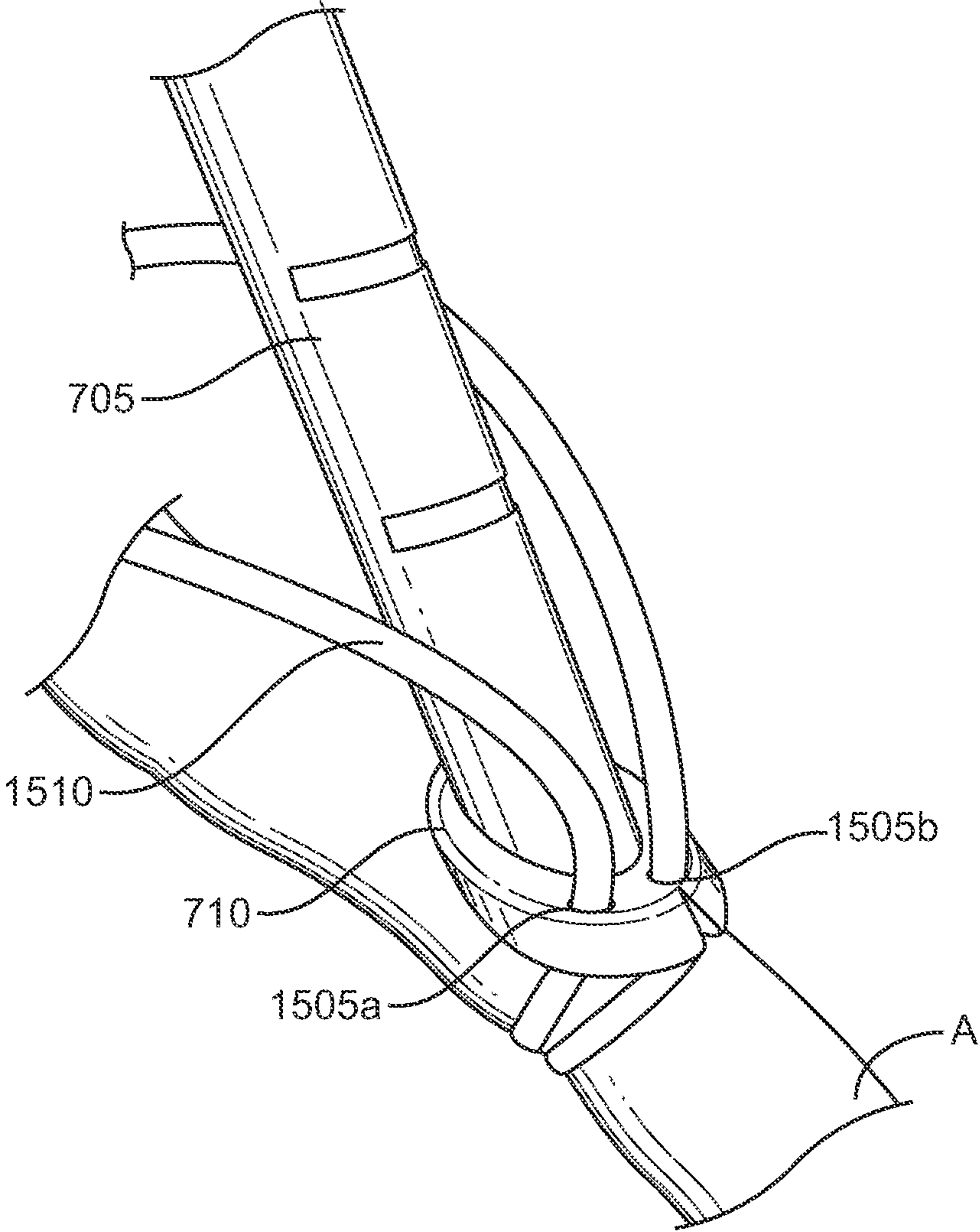


FIG. 16

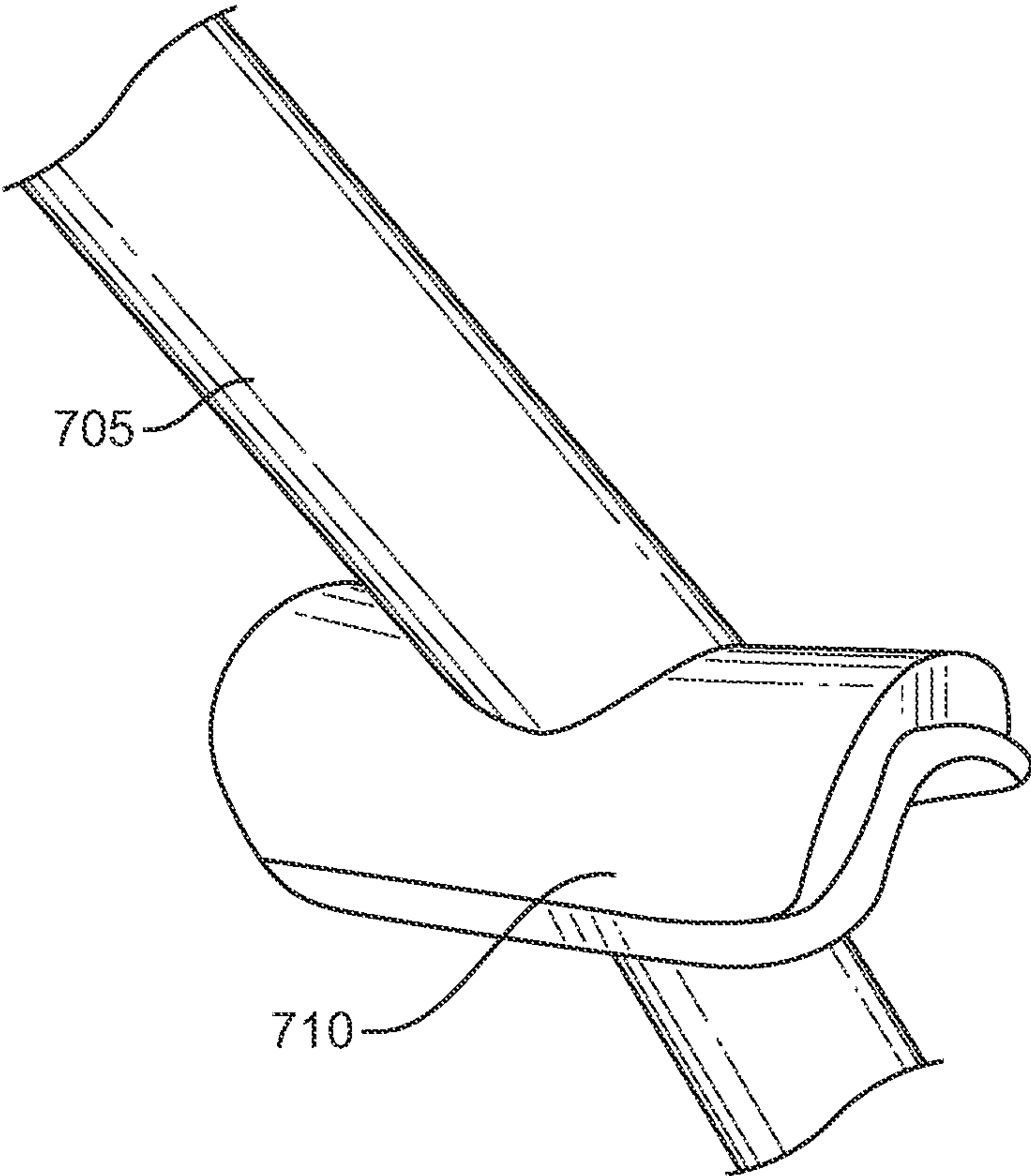


FIG. 17

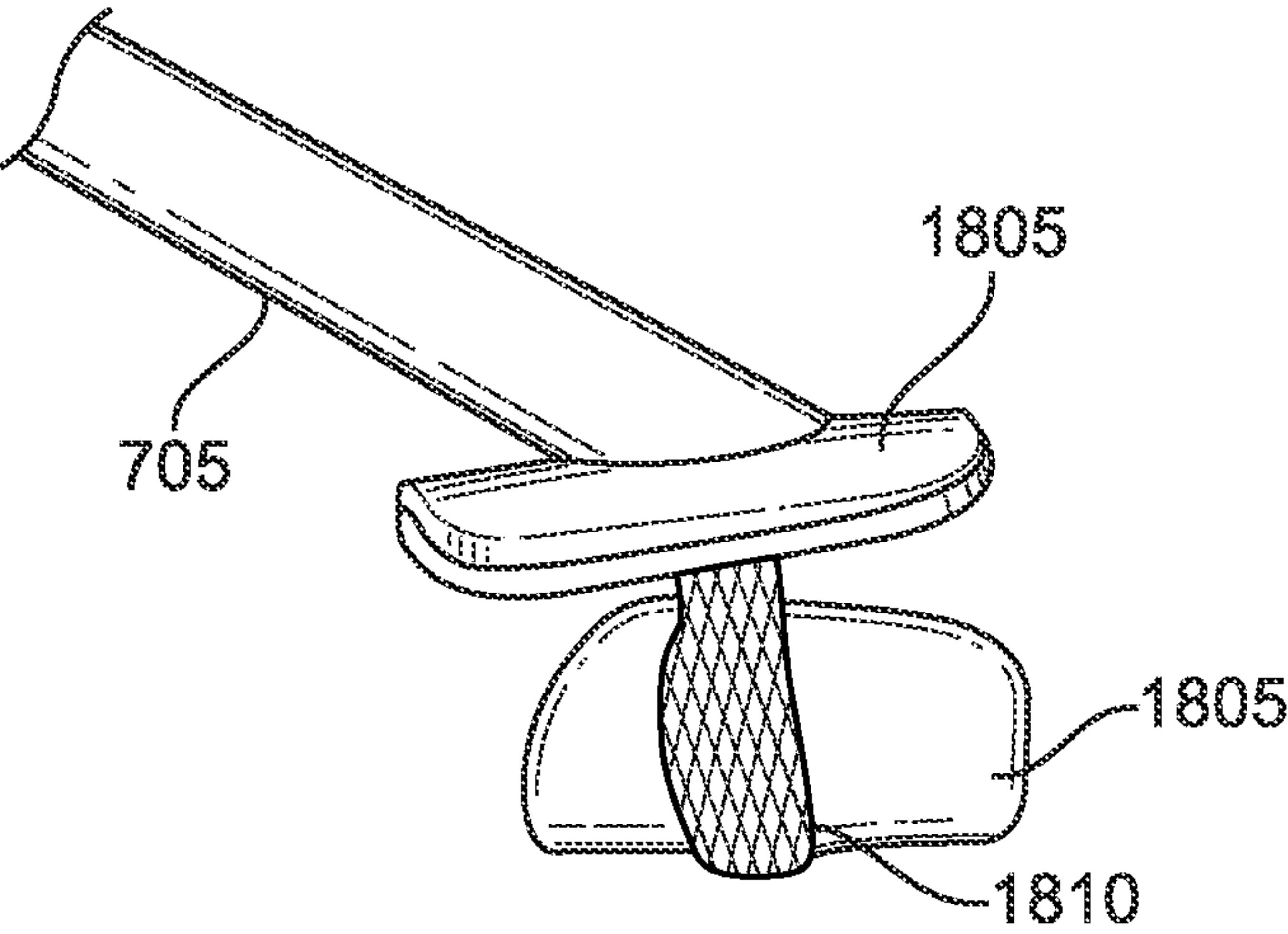


FIG. 18A

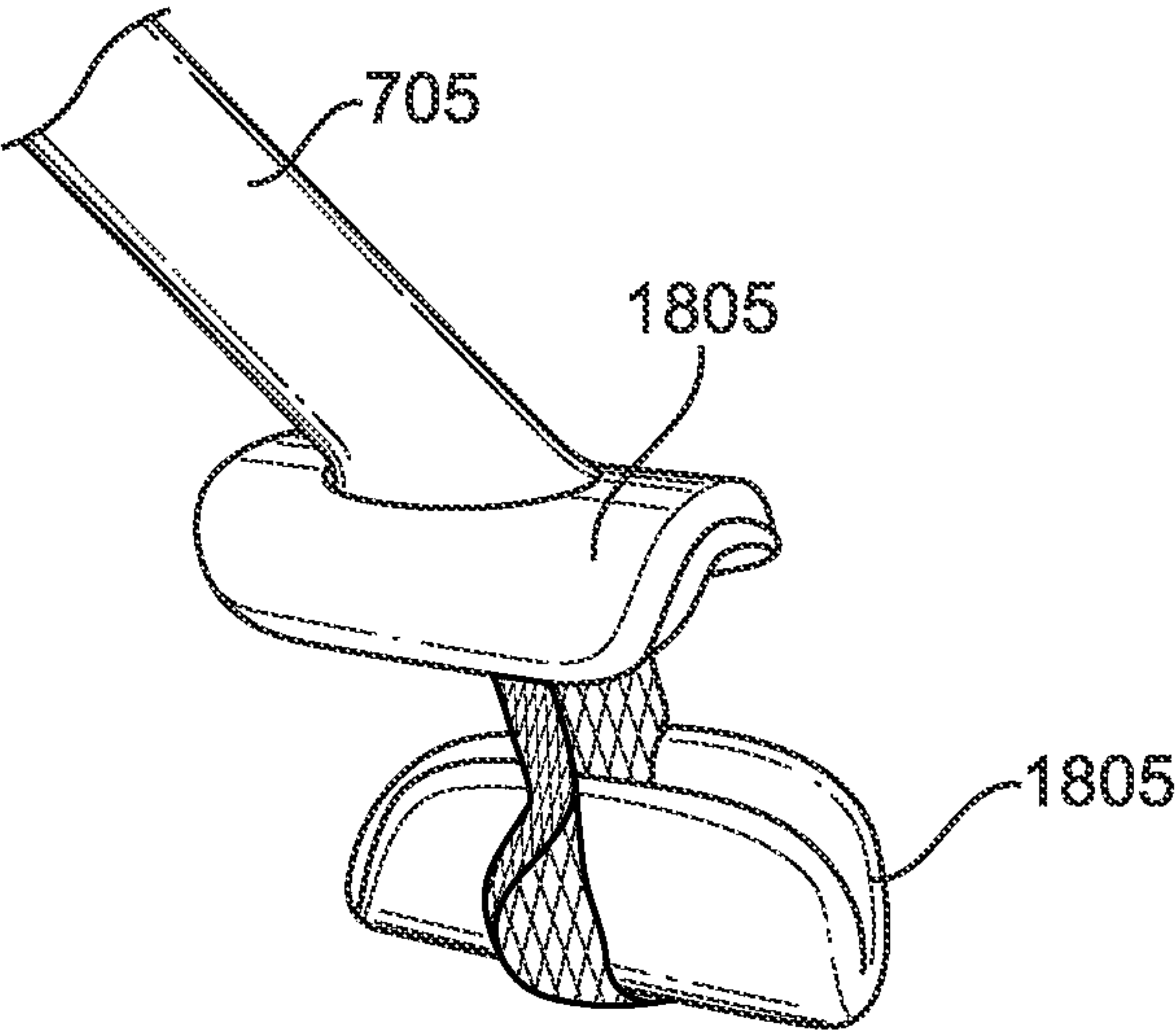


FIG. 18B

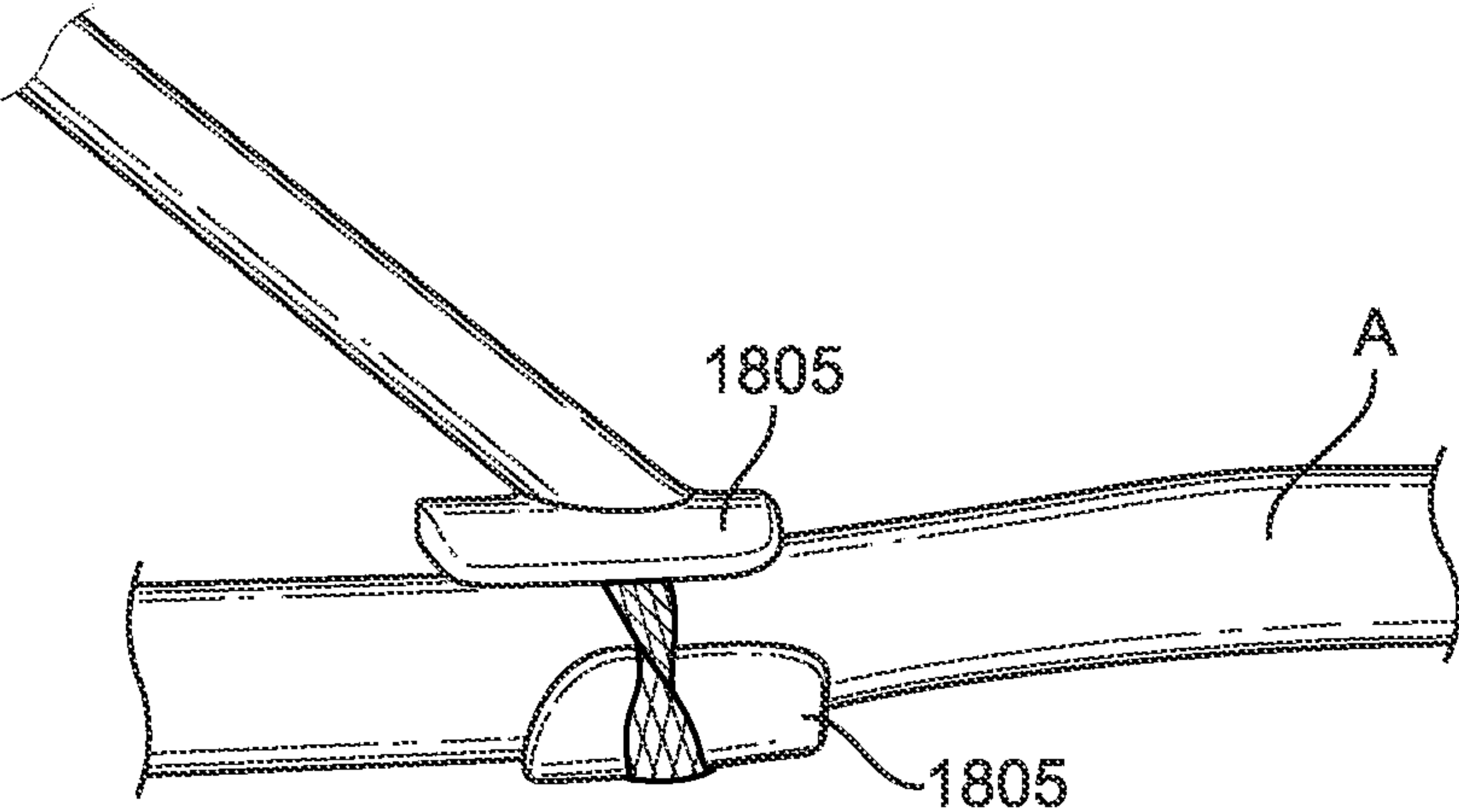


FIG. 18C

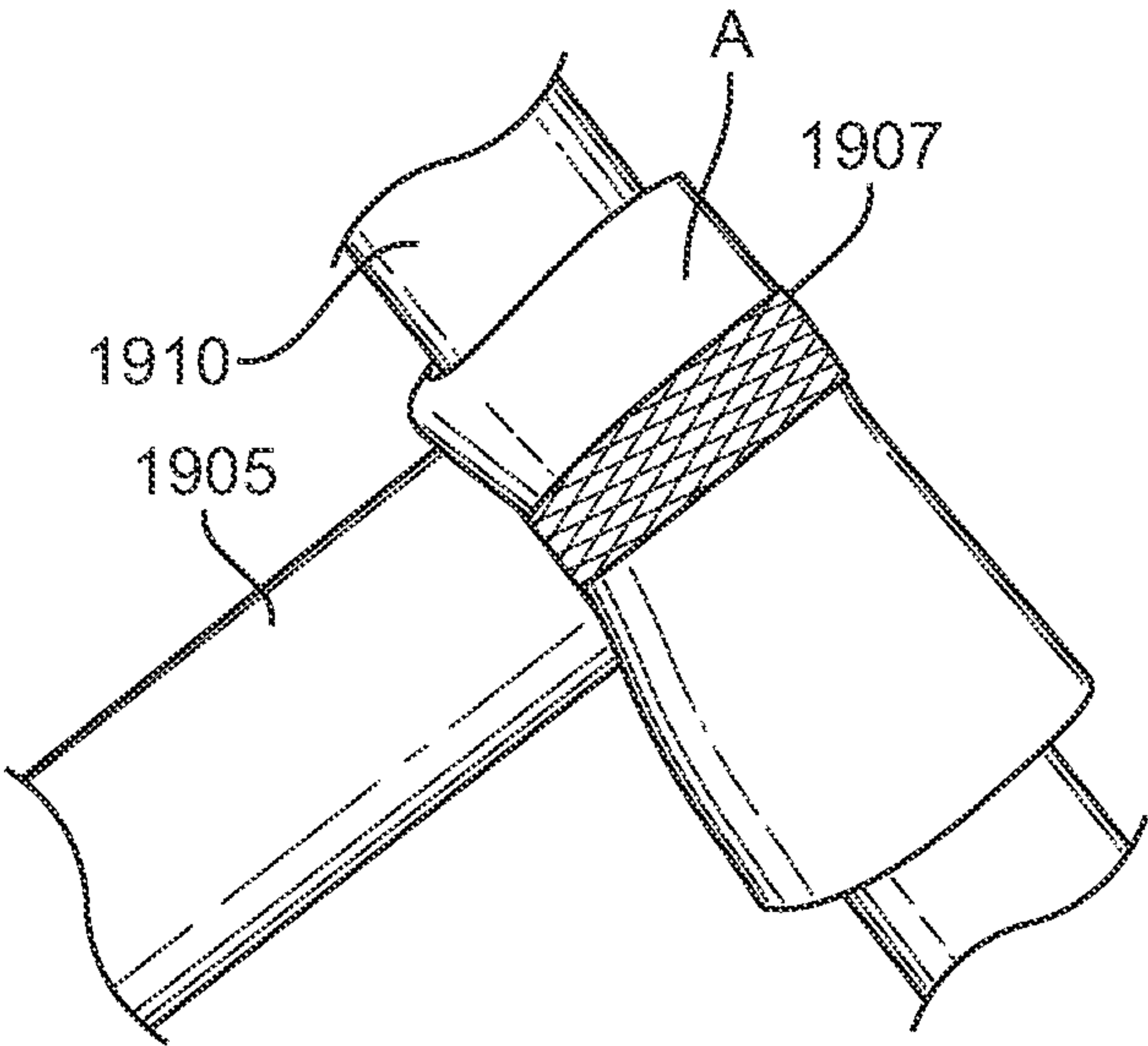


FIG. 19A

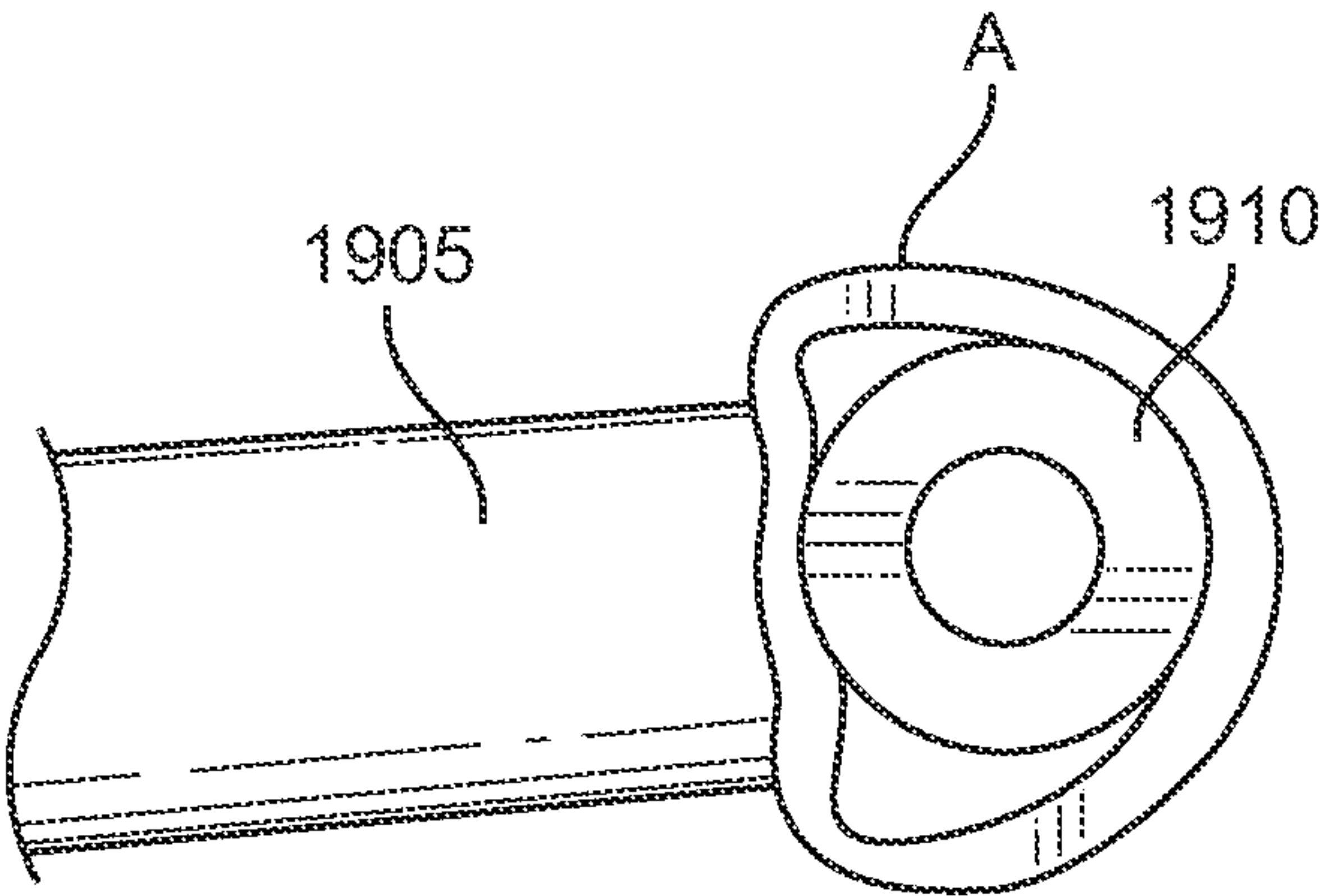


FIG. 19B

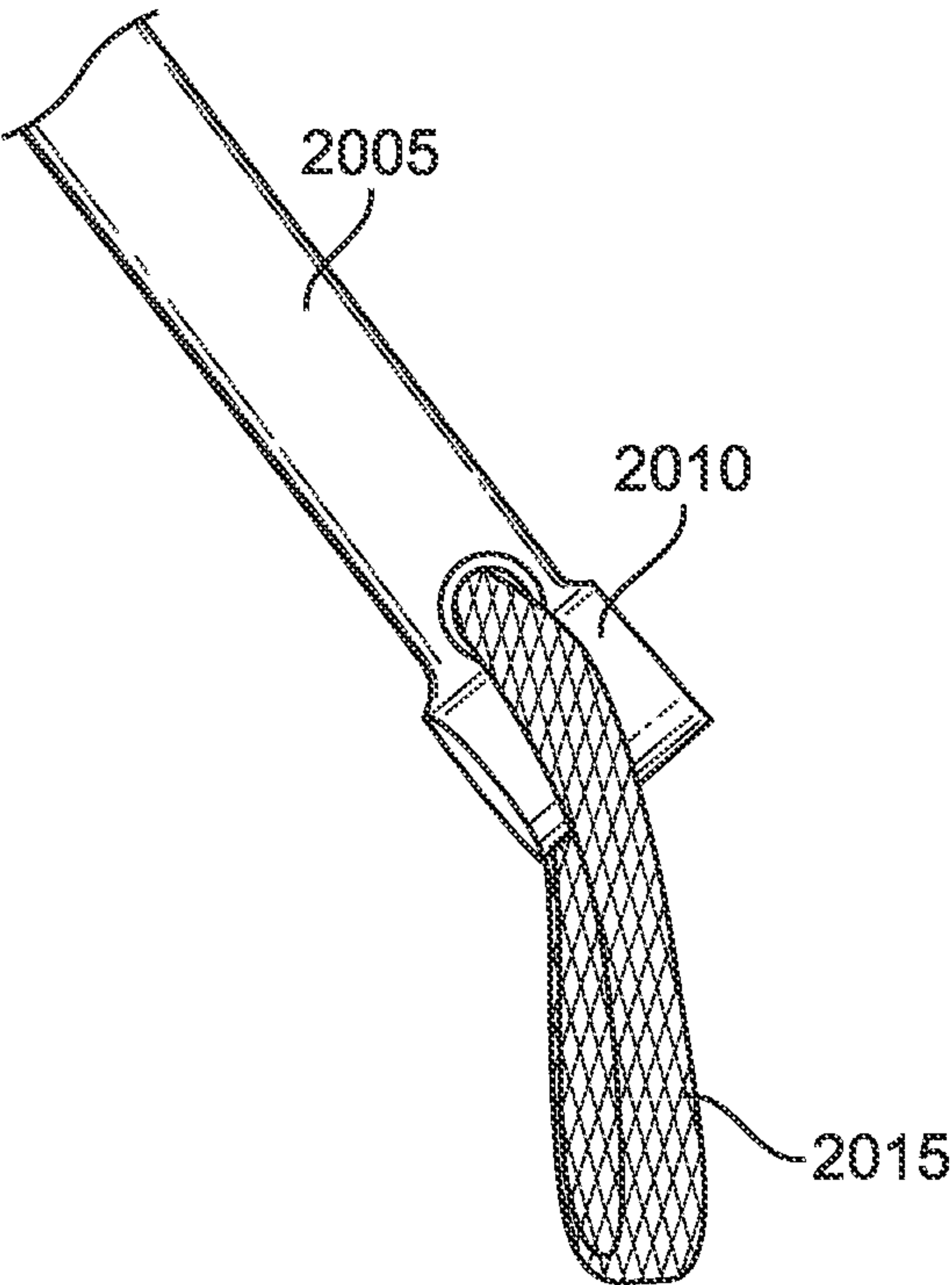


FIG. 20

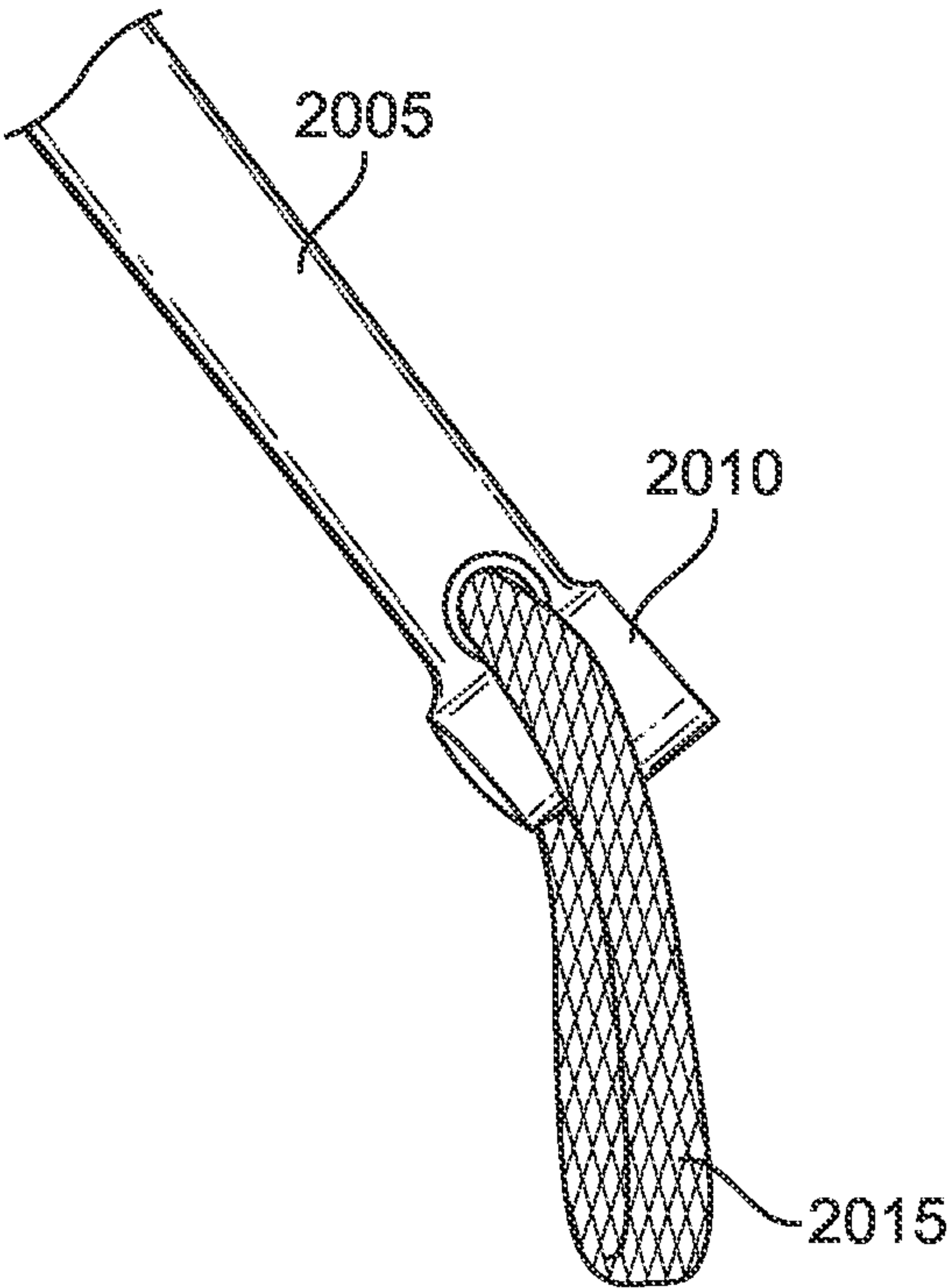


FIG. 21

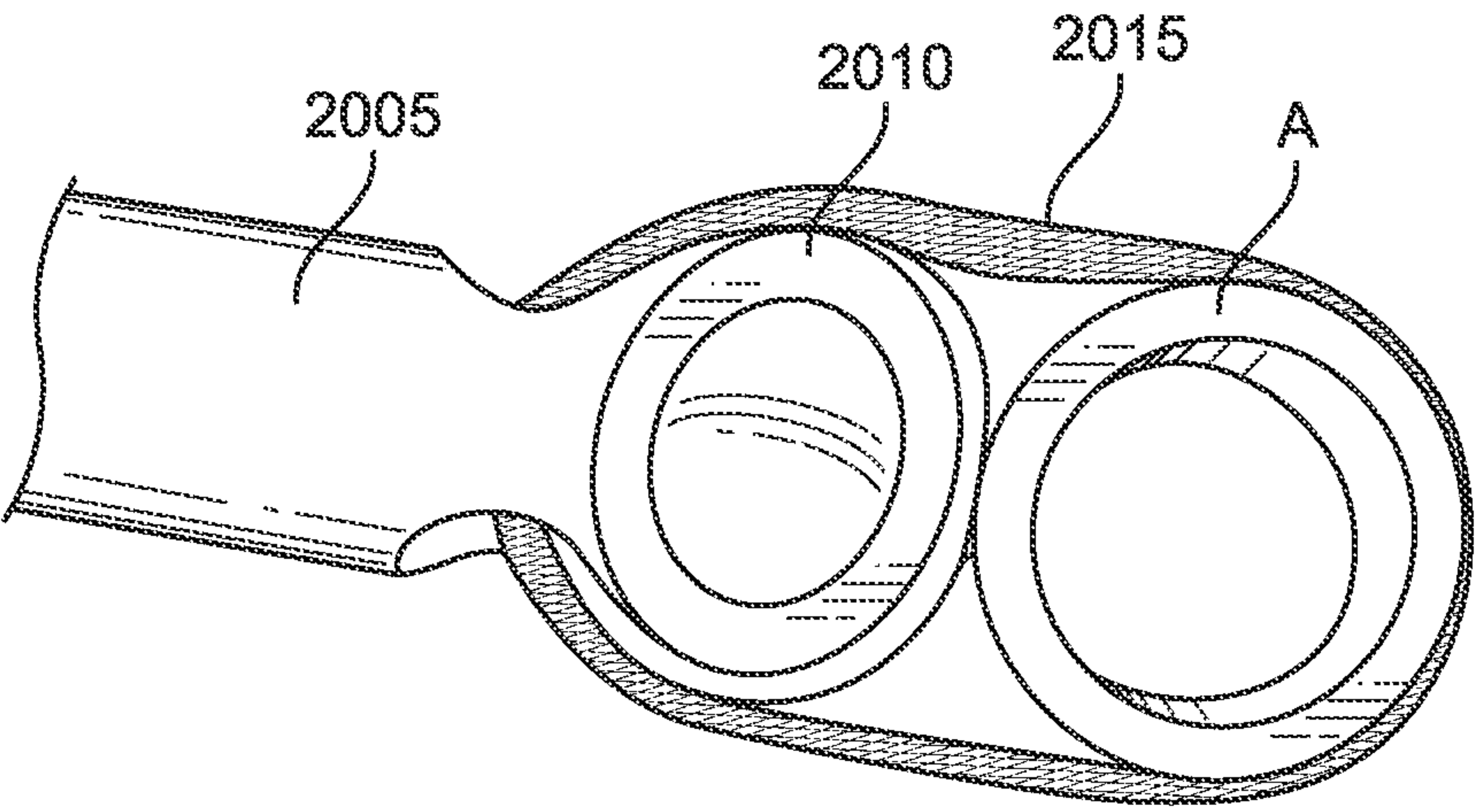


FIG. 22

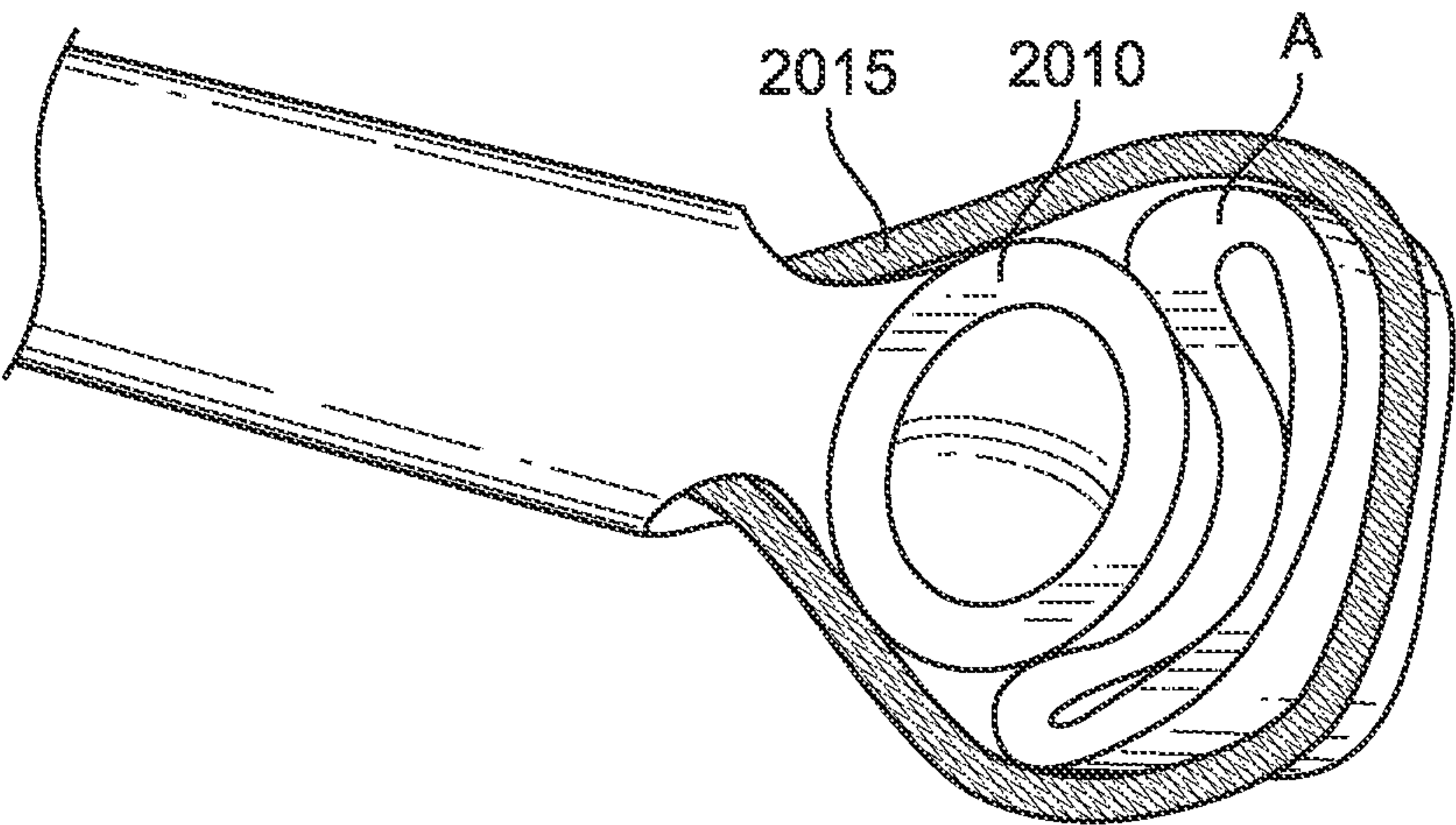


FIG. 23

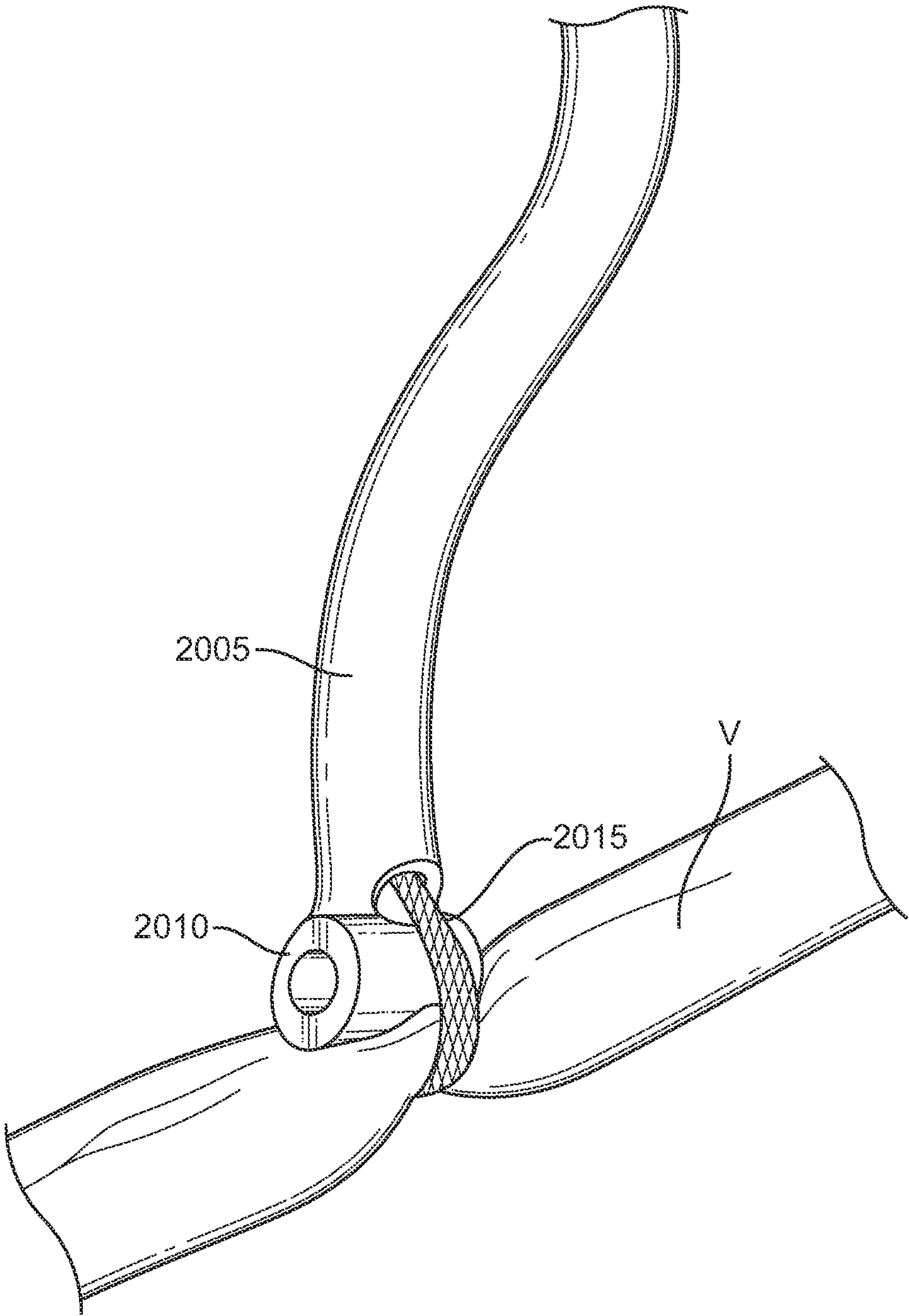


FIG. 24

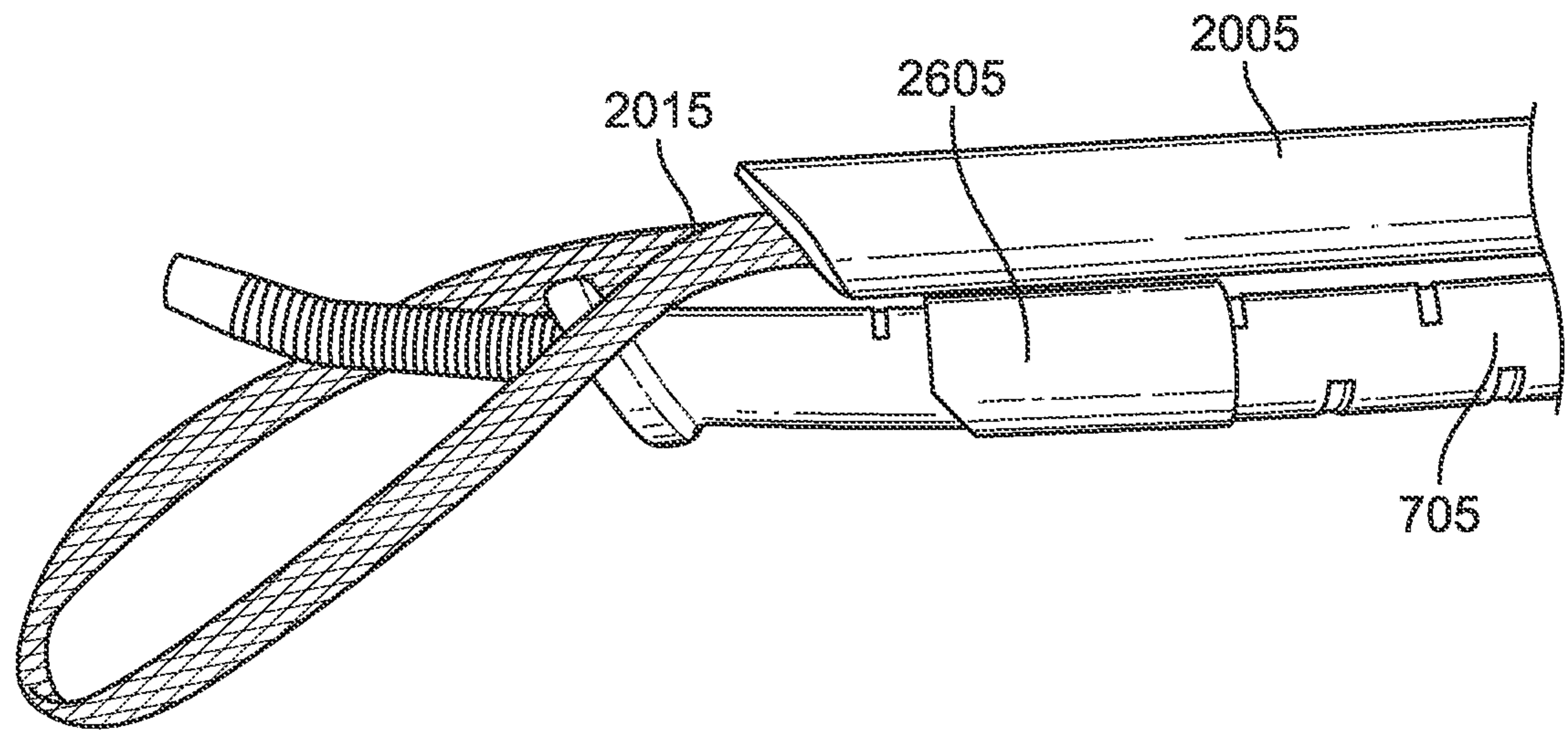


FIG. 25

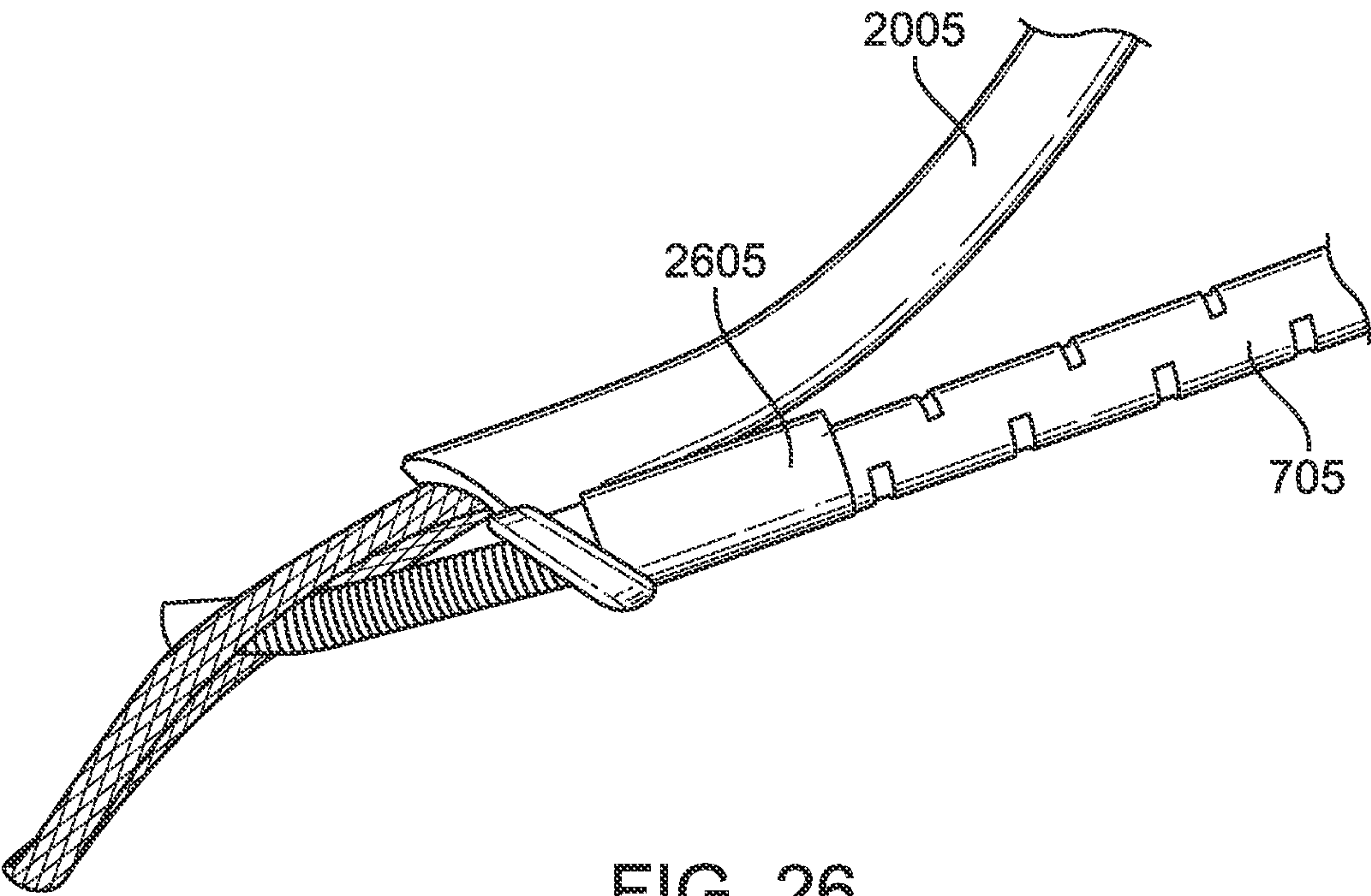


FIG. 26

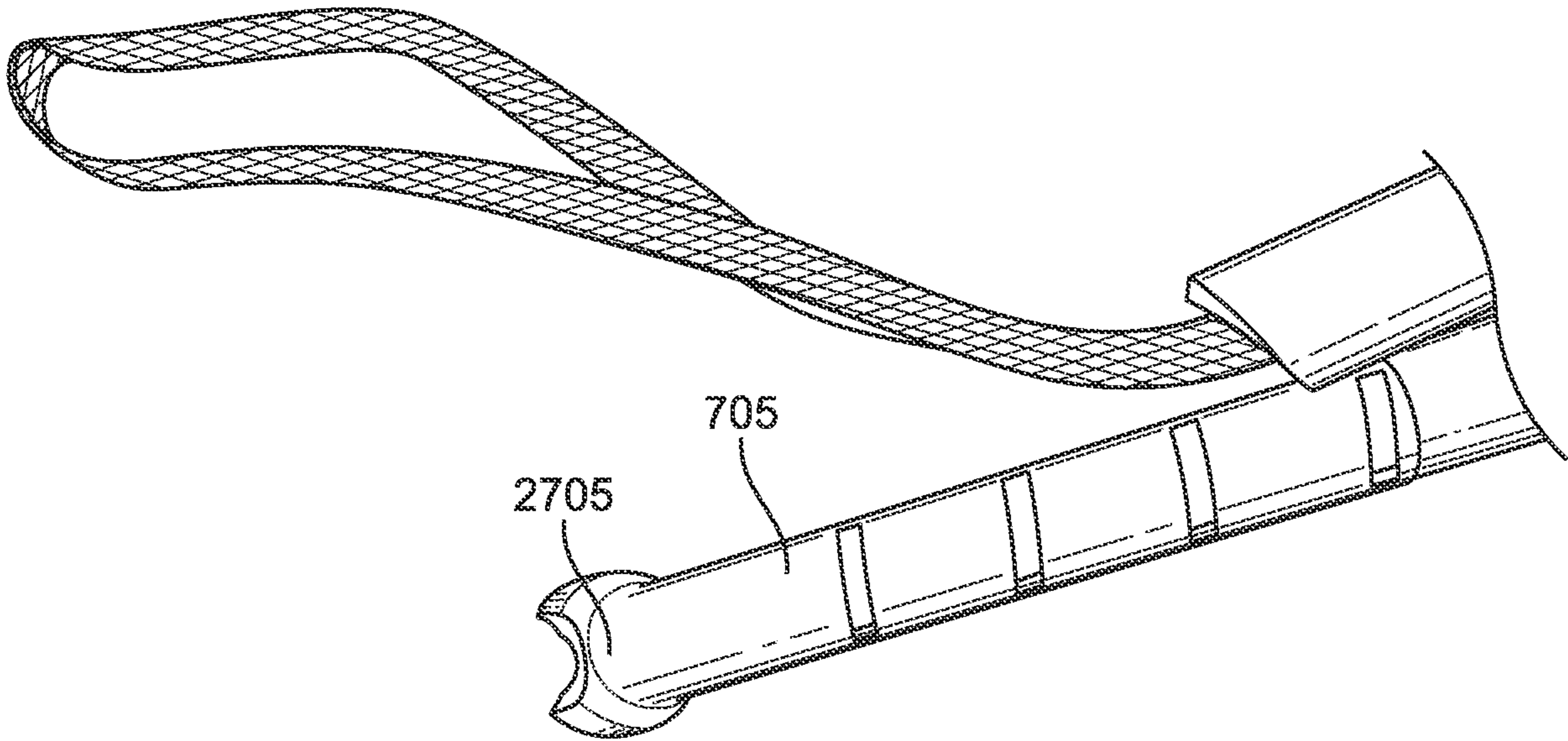


FIG. 27

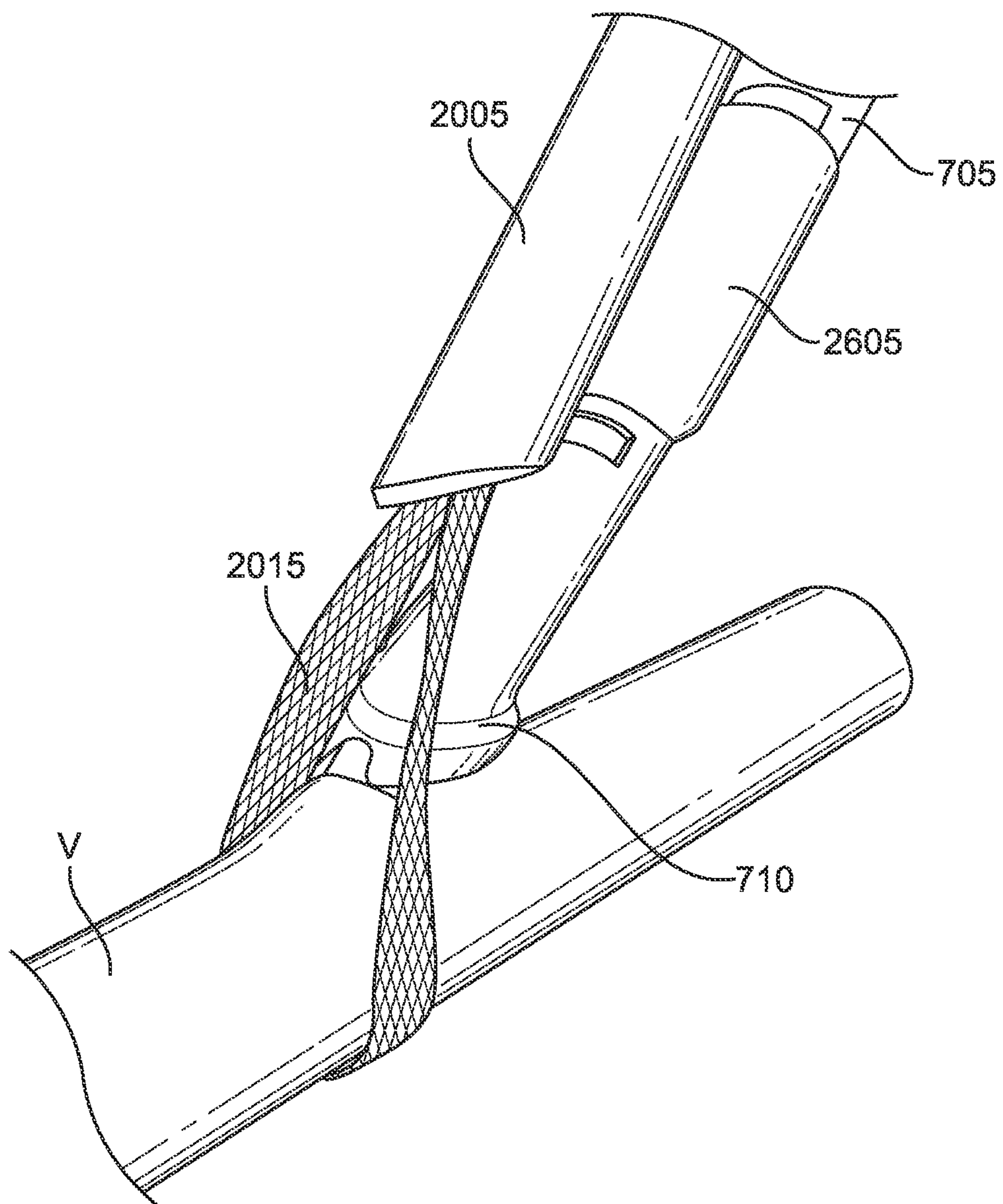


FIG. 28

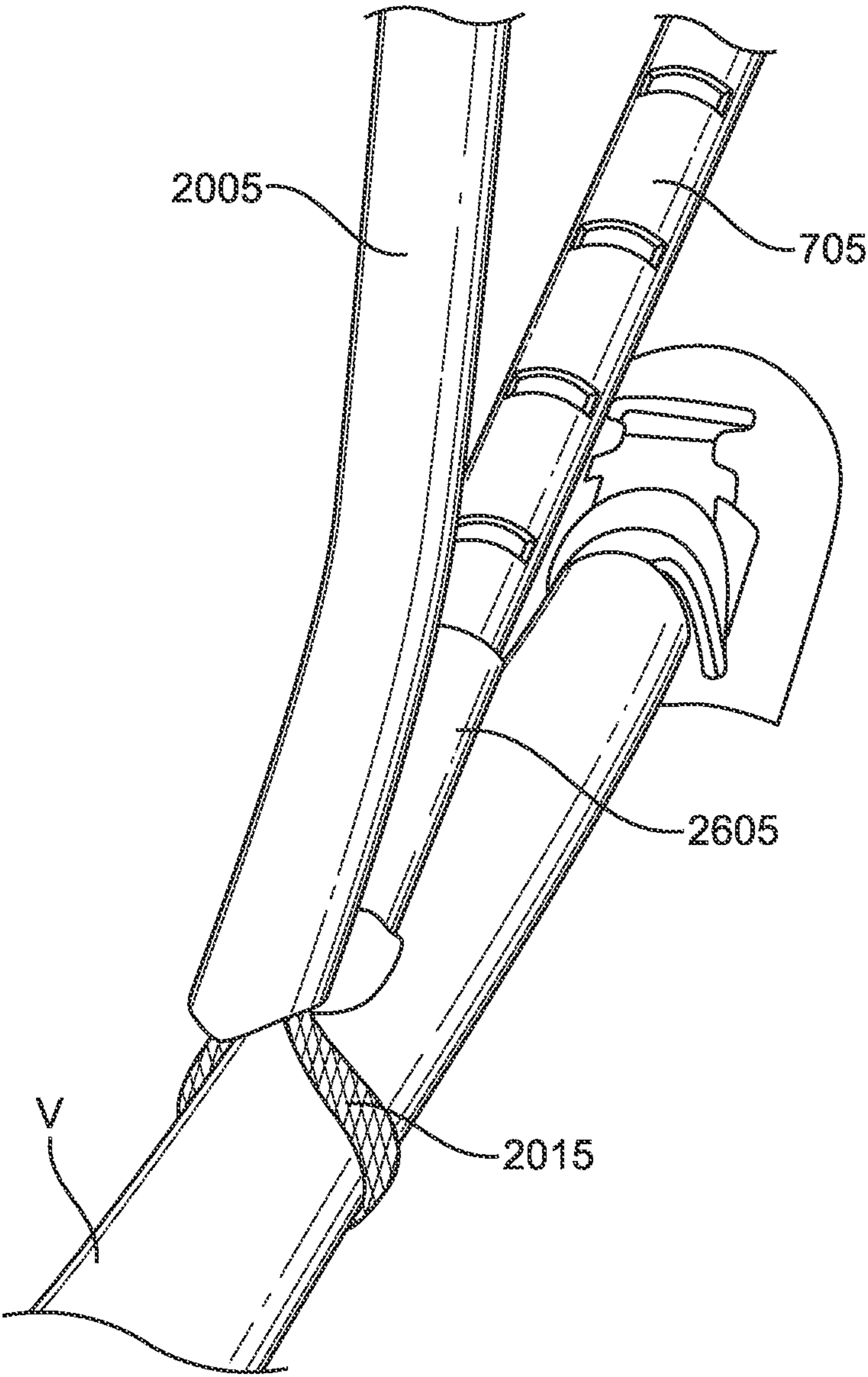


FIG. 29

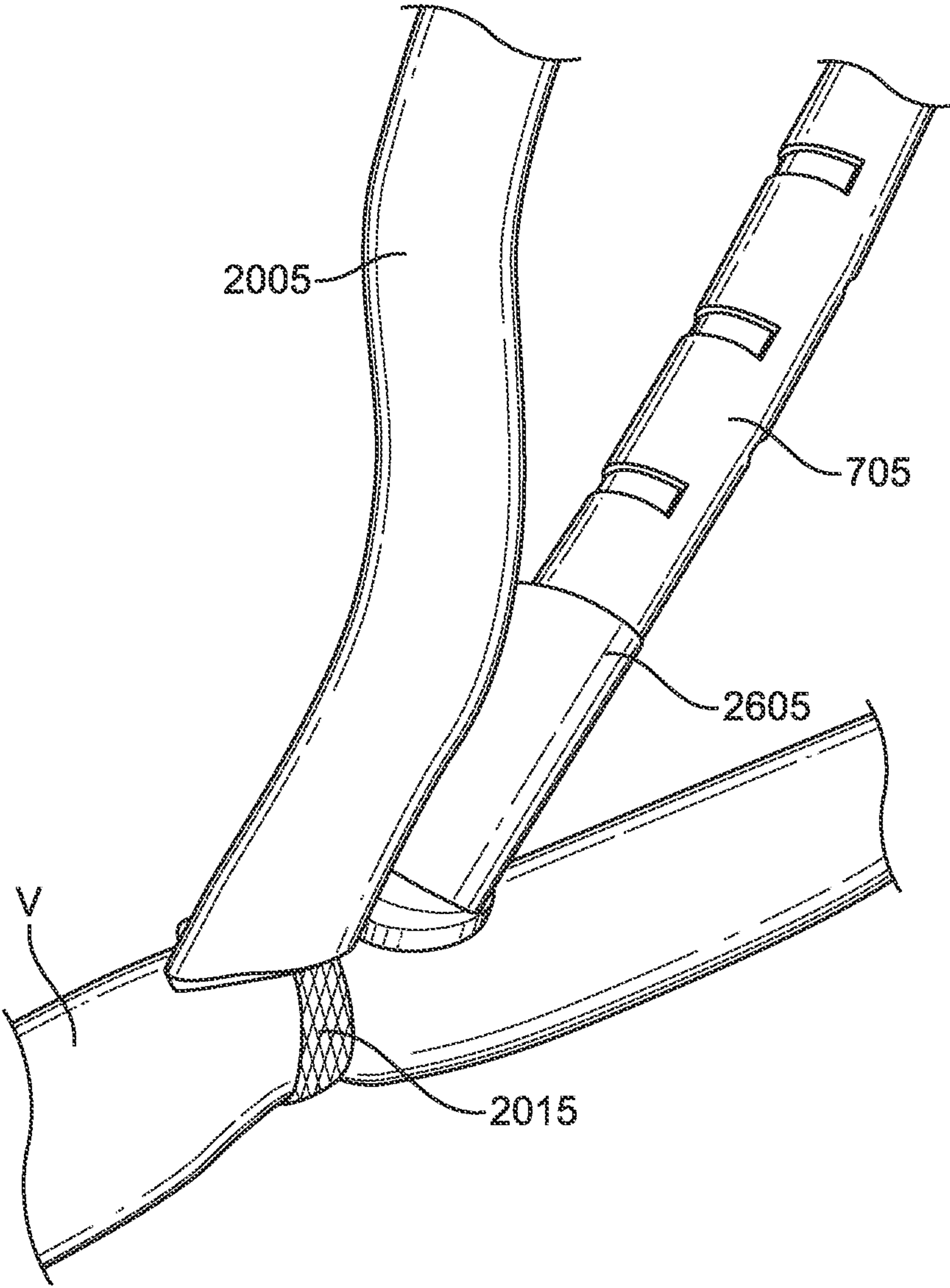


FIG. 30

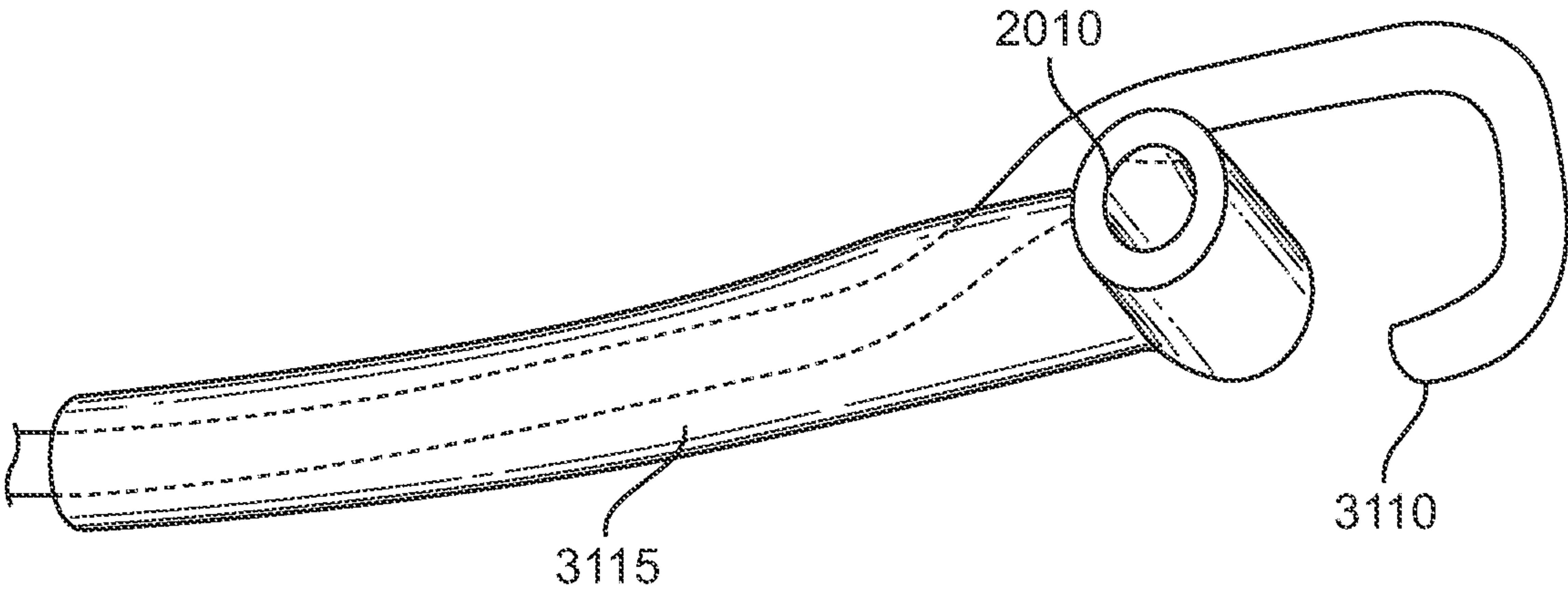


FIG. 31

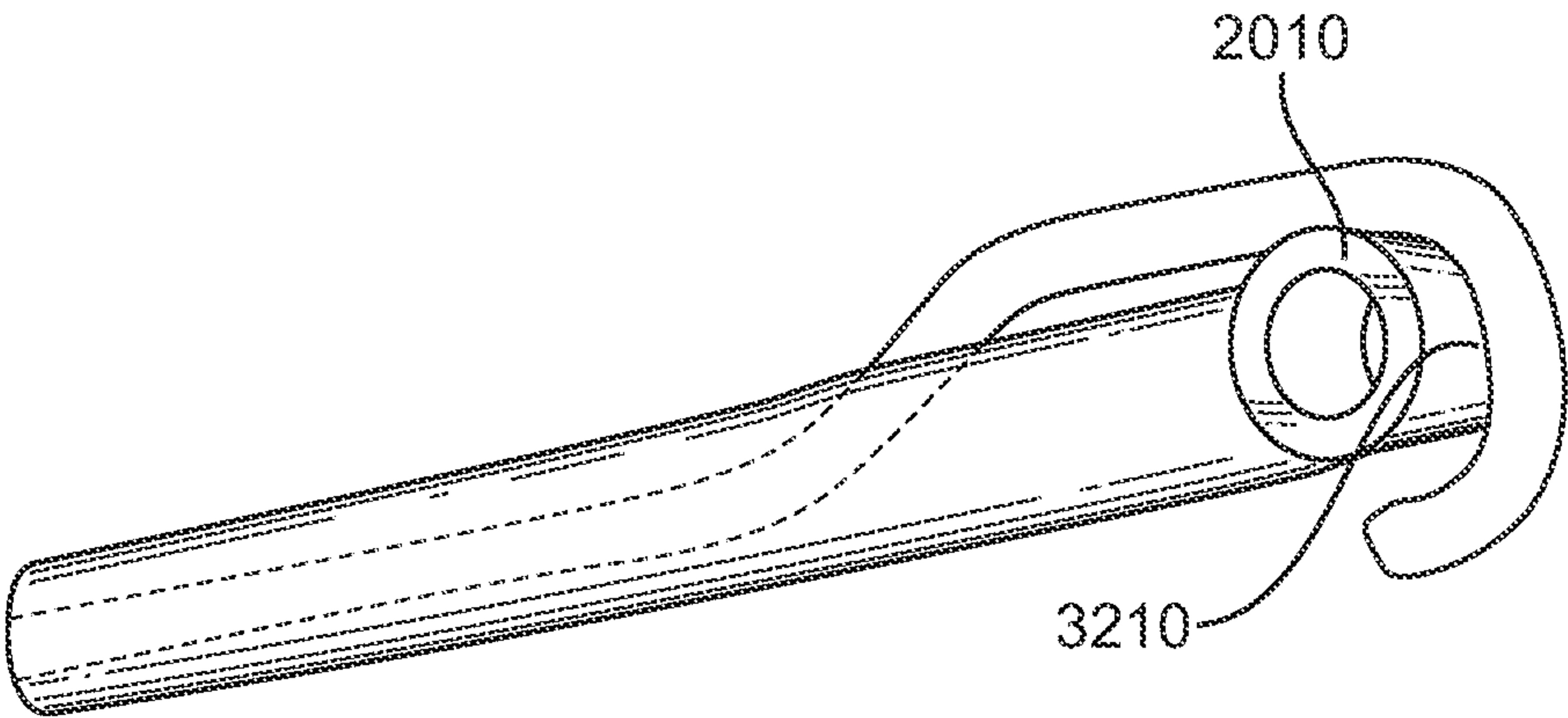


FIG. 32

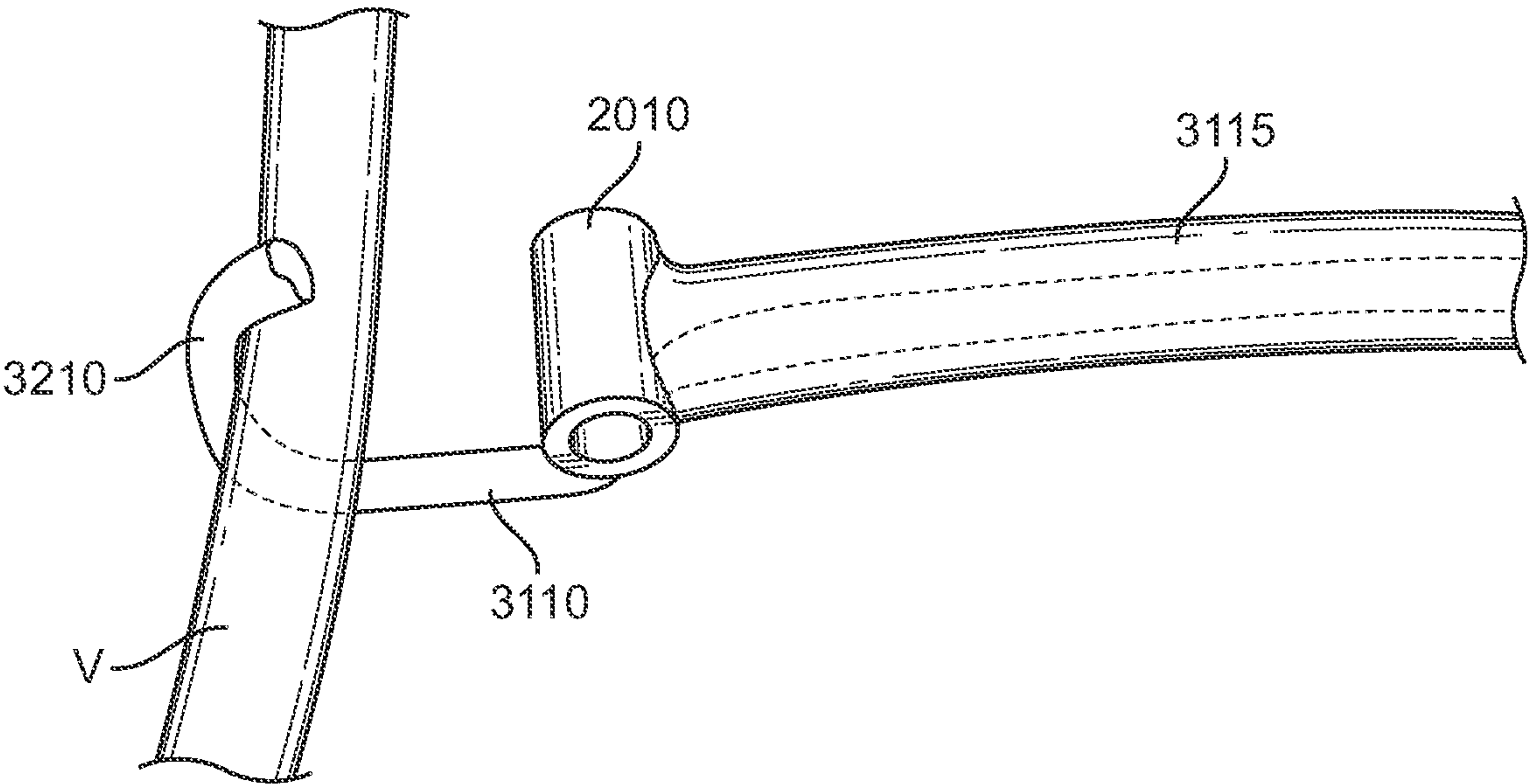


FIG. 33

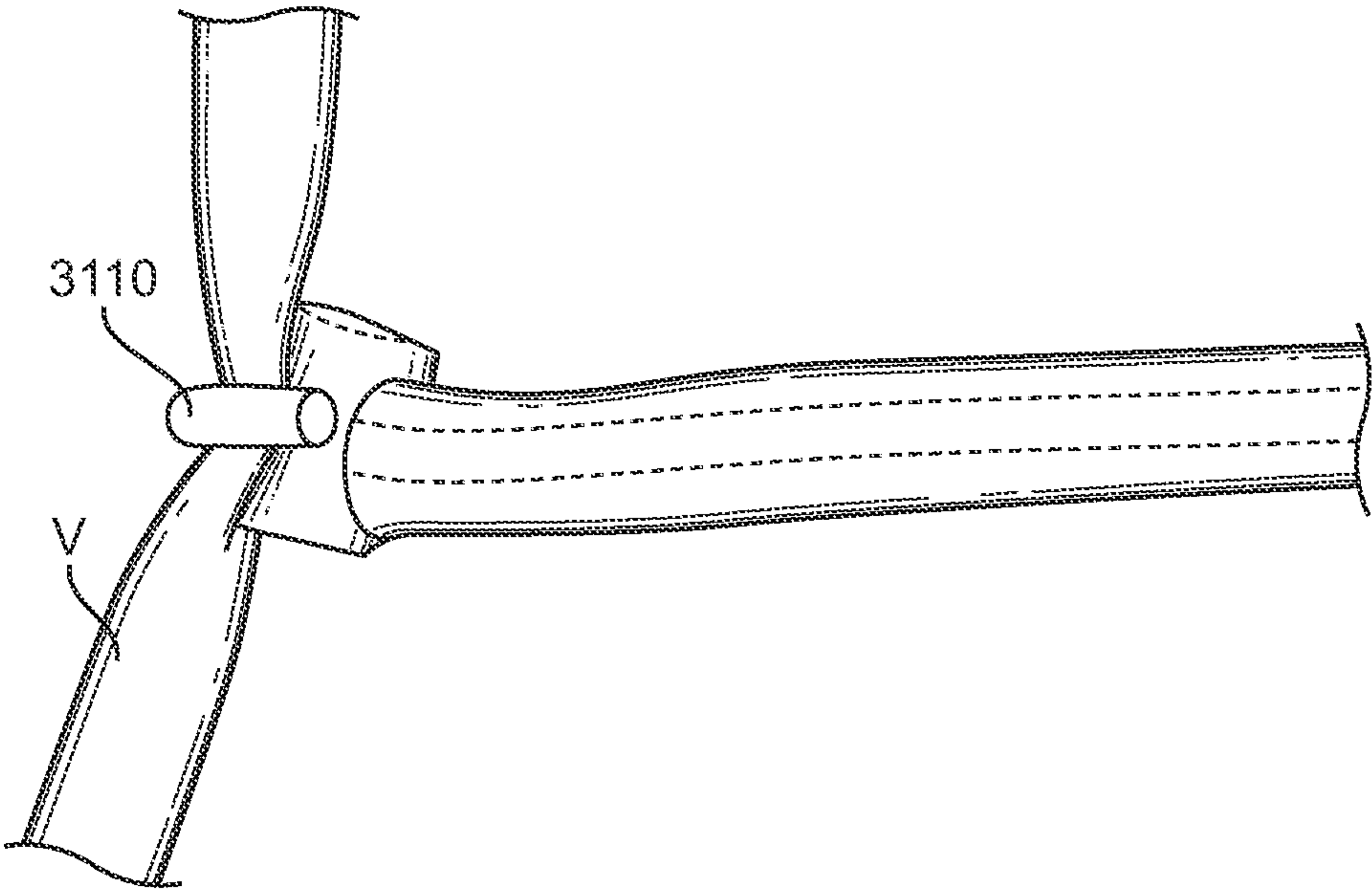


FIG. 34

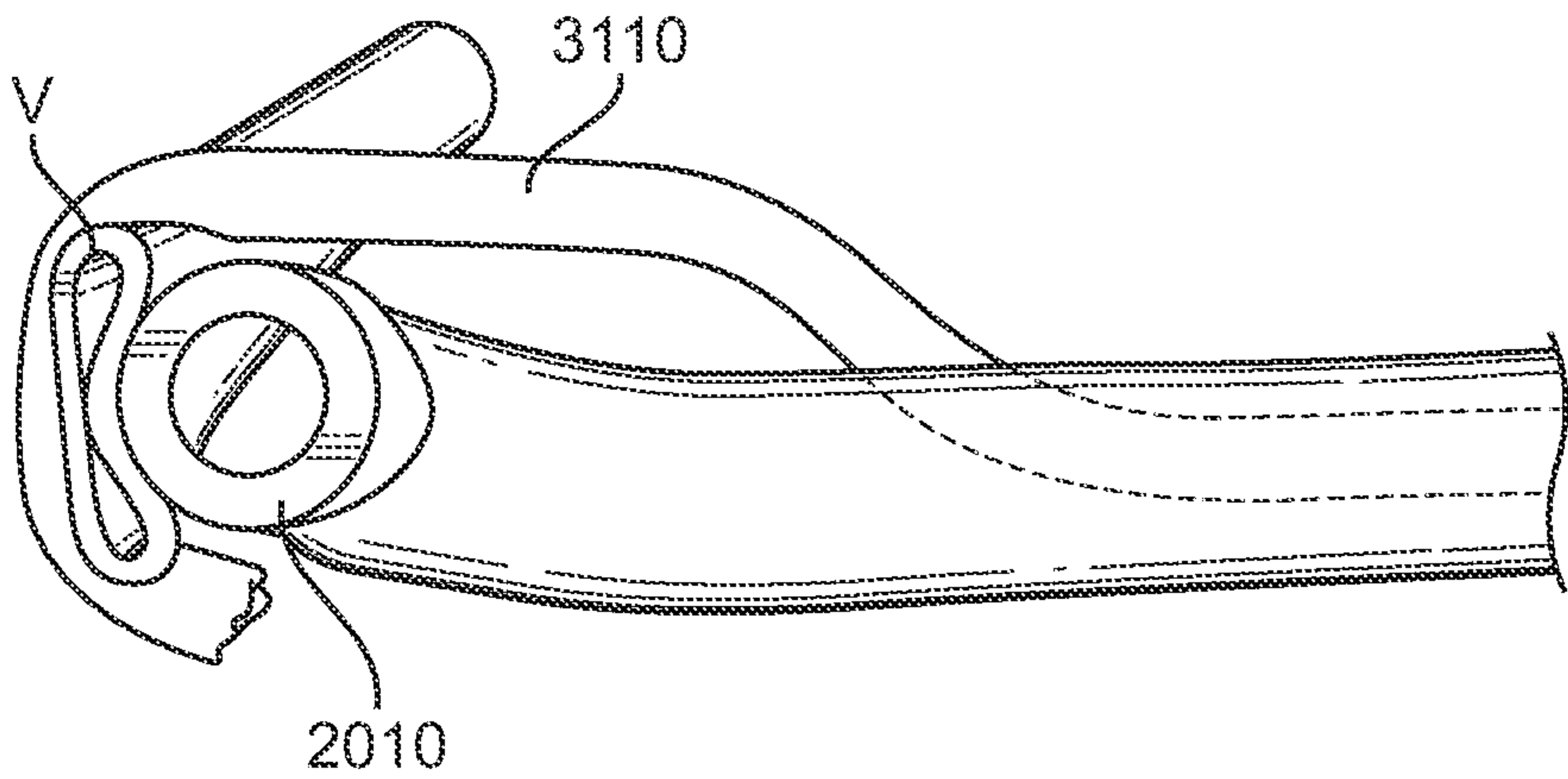


FIG. 35

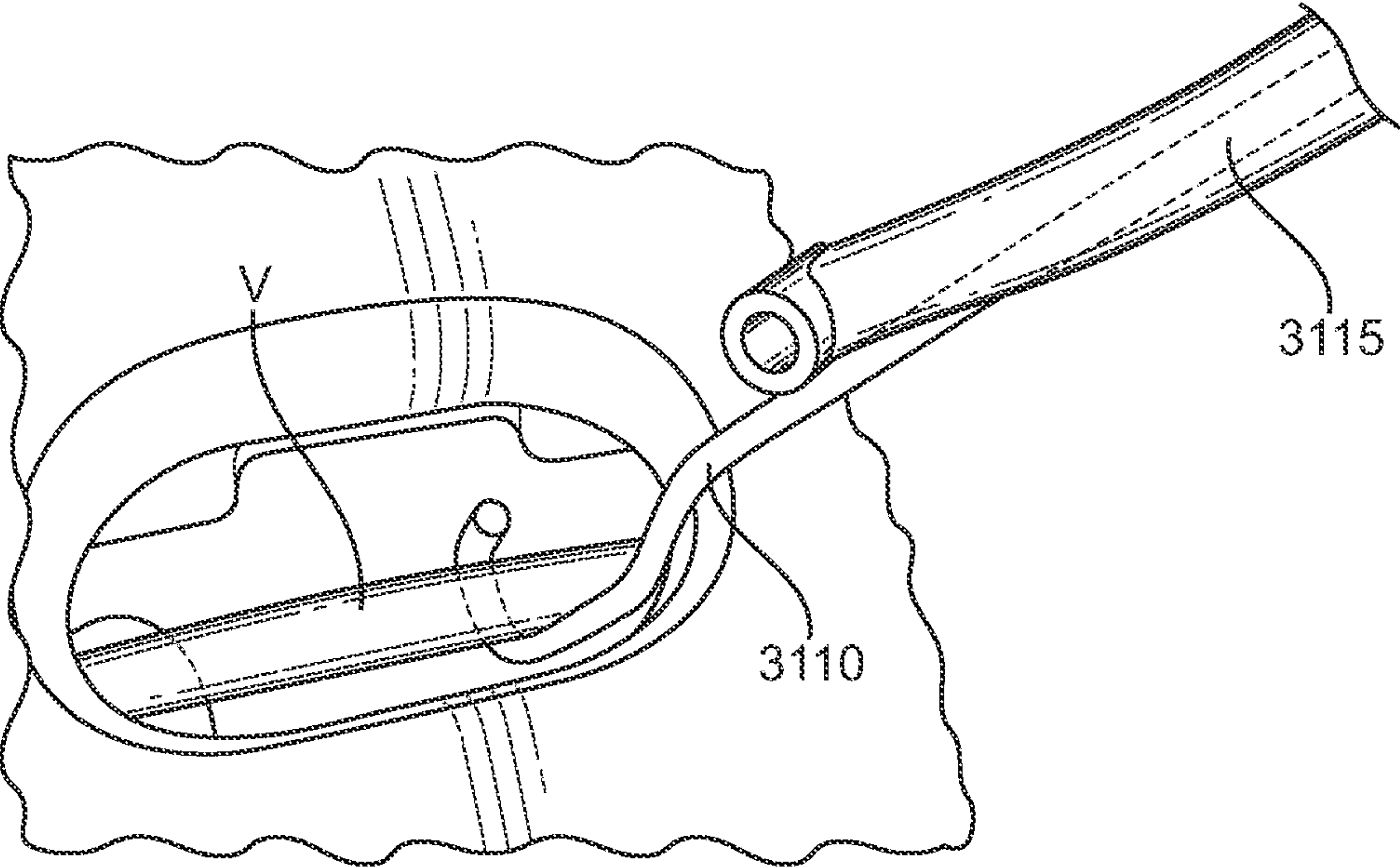


FIG. 36

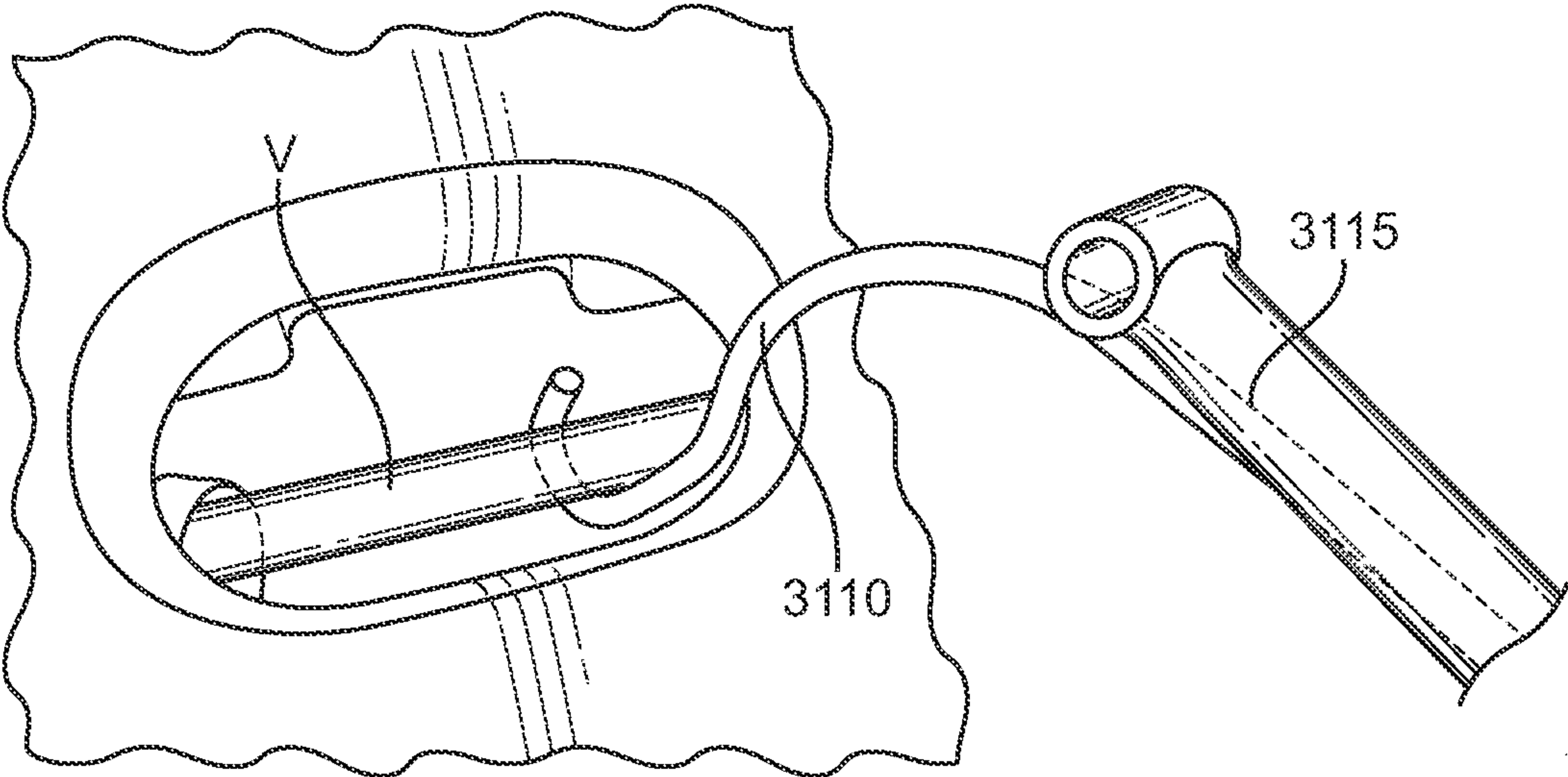


FIG. 37

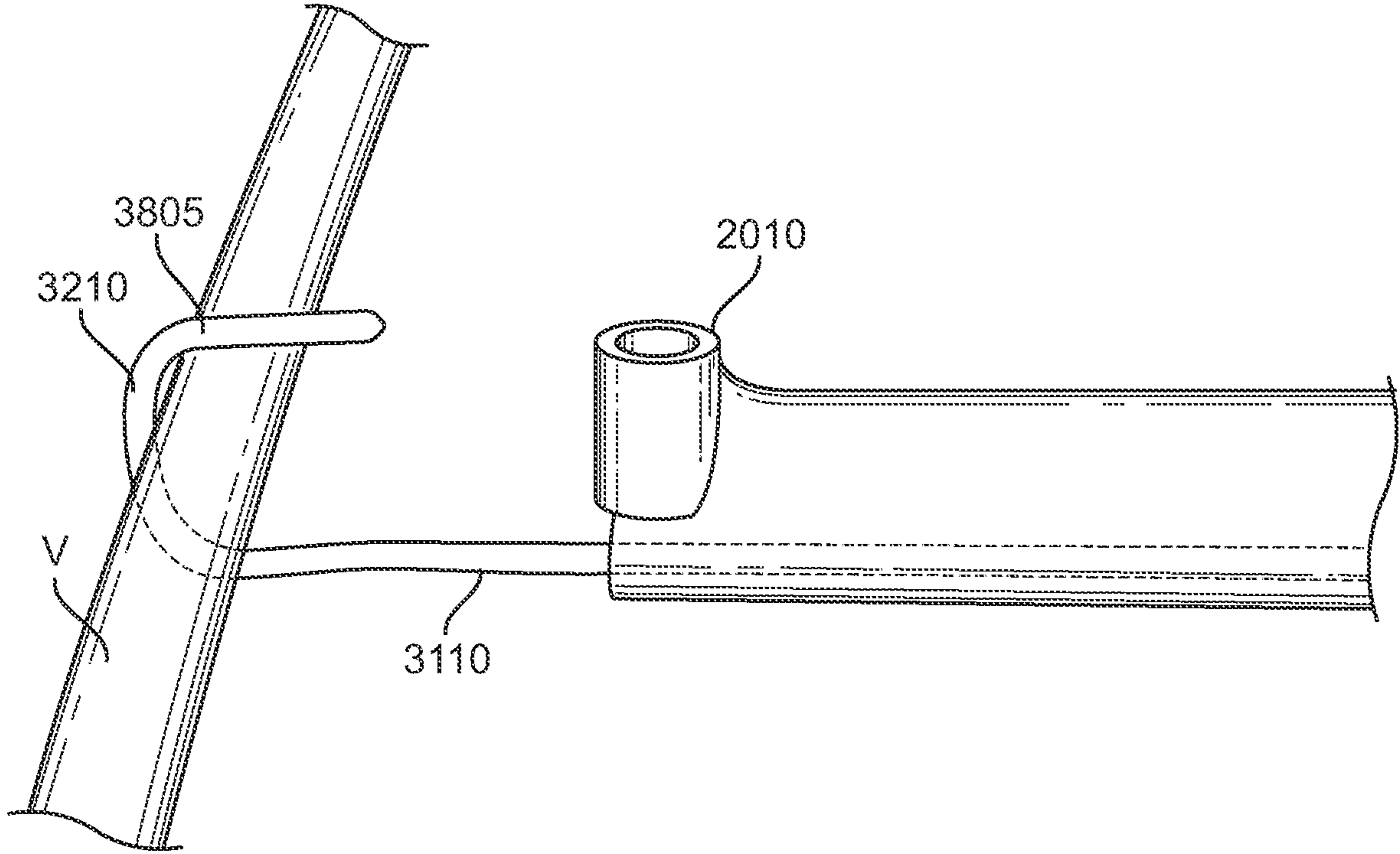


FIG. 38

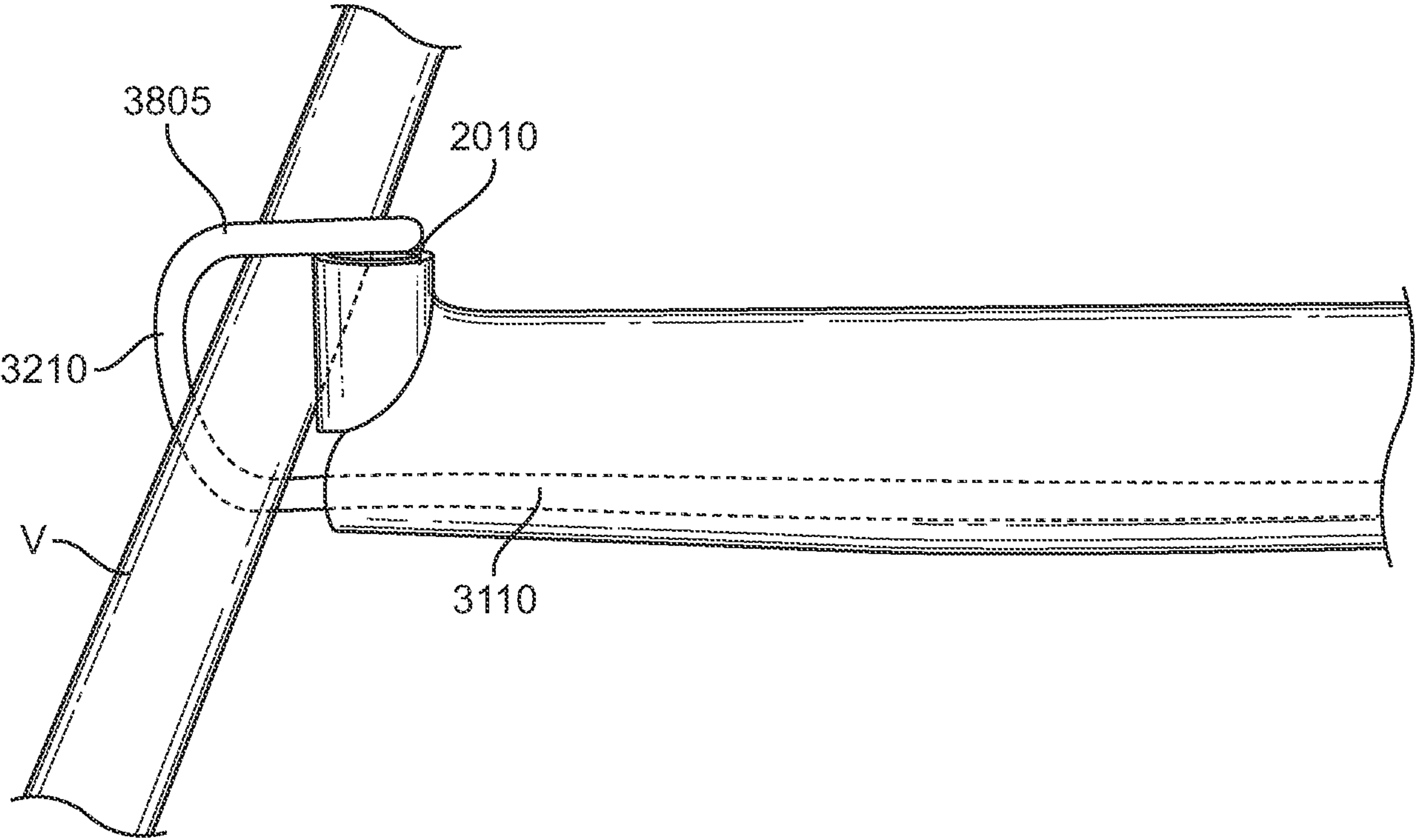


FIG. 39

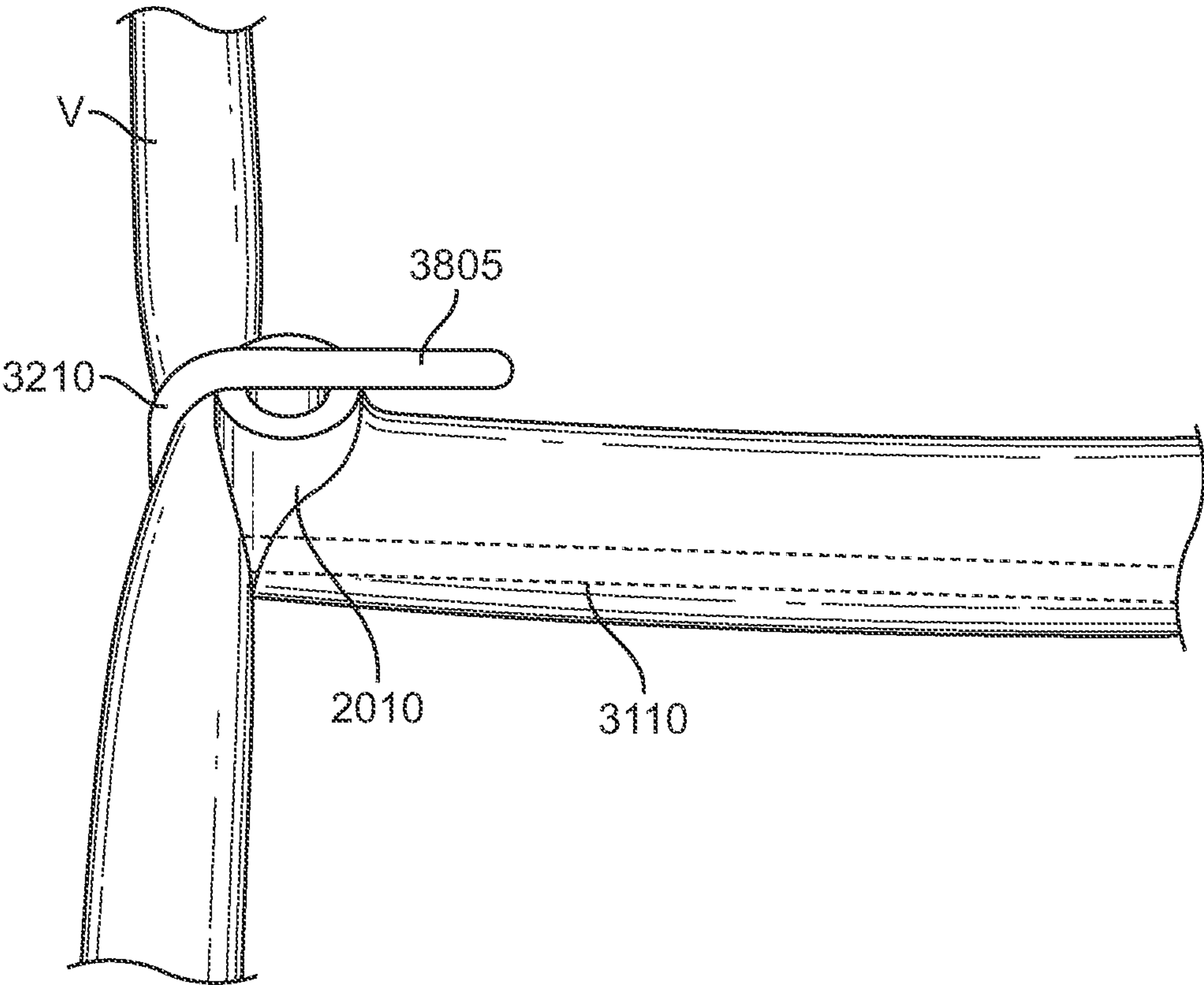


FIG. 40

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 20/61073

A. CLASSIFICATION OF SUBJECT MATTER

IPC - A61B 17/00, A61B 17/12, A61B 17/122 (2021.01)

CPC - A61B 17/12, A61B 2017/2944, A61B 17/122, A61B 17/12009, A61B 17/12013

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 2001/0016750 A1 (Malecki et al.) 23 August 2001 (23.10.2001), entire document	1-2, 5-7, 9-13, 15 — 17-22
X	US 3,868,957 A (Doddington) 4 March 1975 (03.04.1975), entire document	1, 3-4, 8, 13-14, 16
Y	US 2017/0296769 A1 (Silk Road Medical, Inc.) 2 October 2014 (02.10.2014), entire document	17-22
A	GB 2,161,708 A (Williams) 22 January 1986 (22.01.1986), entire document	1-22
A	US 5,897,565 A (Foster) 27 April 1999 (27.04.1999), entire document	1-22
A	US 2016/0066917 A1 (Cook Medical Technologies LLC) 10 March 2016 (10.03.2016), entire document	1-22



Further documents are listed in the continuation of Box C.



See patent family annex.

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"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

18 JANUARY 2021

Date of mailing of the international search report

10 FEB 2021

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