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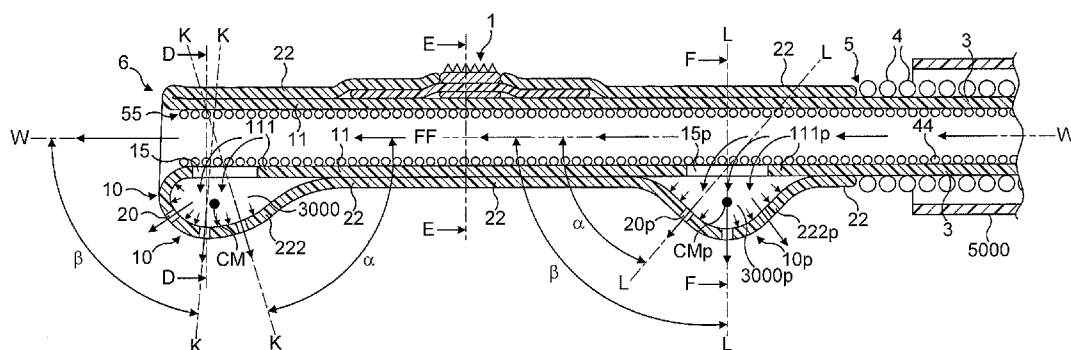
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(54) Title: ROTATIONAL ATHERECTOMY DEVICE WITH FLUID INFLATABLE SUPPORT ELEMENTS AND TWO
TORQUE TRANSMITTING COILS



(57) Abstract: A rotational atherectomy device for removing a stenotic tissue from a vessel of a patient is disclosed. The device comprises a rotatable, flexible, hollow drive shaft having a fluid impermeable wall defining a fluid impermeable lumen of the drive shaft and, an abrasive element mounted to a distal end portion of the drive shaft proximal to and spaced away from a distal support element formed at a distal end of the drive shaft, the distal support element being inflatable by pressurized fluid which flows in an antegrade direction through said lumen of the drive shaft and is at least partially re-directed into the distal fluid inflatable support element. The distal fluid inflatable support element has an outer wall comprising an outflow opening located such that said outflow opening faces an inner surface of a treated vessel during rotation of the drive shaft so that a flow of fluid through said outflow opening forms a layer of fluid between the outer wall of the rotating fluid inflated distal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel, the drive shaft being comprised of at least one fluid impermeable membrane and at least two torque transmitting coils, one of said coils extending distally beyond the distal end of the other coil and conveying torque to the abrasive element mounted to the drive shaft distal to and spaced away from a portion of the drive shaft formed from the fluid impermeable membrane and said torque transmitting coils.

ROTATIONAL ATHERECTOMY DEVICE WITH FLUID INFLATABLE SUPPORT ELEMENTS AND TWO TORQUE TRANSMITTING COILS

Description

5 The present invention relates to a rotational atherectomy device for removing or reducing stenotic lesions in blood vessels such as a human artery by rotating an abrasive element within the vessel to partially or completely ablate the unwanted material.

Atherosclerosis, the clogging of arteries, is a leading cause of coronary heart disease. Blood
10 flow through the peripheral arteries (e.g., carotid, femoral, renal etc.), is similarly affected by the development of atherosclerotic blockages. A conventional method of removing or reducing blockages in blood vessels is known as rotational atherectomy. Such a method and a device for performing the method are described in, for example, U.S. Patent No. 4,990,134 to Auth. According to Auth, a long guidewire is advanced into the diseased
15 blood vessel across the stenotic lesion. A hollow drive shaft formed from a single layer of torque transmitting coiled wire(s) is advanced over the guidewire. The distal end of the drive shaft terminates in a burr provided with an abrasive surface formed from diamond grit or diamond particles. The burr is positioned against the occlusion and the drive shaft rotated at extremely high speeds (e.g., 20,000-160,000 rpm). As the burr rotates, the
20 physician slowly advances it so that the abrasive surface of the burr scrapes against the occluding tissue and disintegrates it, reducing the occlusion and improving the blood flow through the vessel.

It is also known from U.S. Patent No. 6,132,444 to Shturman (the instant inventor) et al.,
25 to provide a drive shaft with an eccentric enlarged diameter segment positioned proximally to and spaced away from the distal end of the drive shaft. According to US Patent 6,132,444 to Shturman, abrasive particles are located around a maximum diameter of said eccentric enlarged diameter segment of the drive shaft thereby forming an eccentric abrasive element positioned proximally to and spaced away from the distal end of the drive
30 shaft. According to US Patent 6,132,444 to Shturman, the drive shaft is formed from a single layer of torque transmitting coiled wire(s).

The prior art rotational atherectomy devices such as those referred to above comprise an elongated drive shaft rotatable around a stationary guidewire. A long proximal portion of the drive shaft is rotatable within an elongated stationary drive shaft sheath, said drive shaft sheath forming an annular lumen between the stationary sheath and the rotatable drive shaft. A saline solution or special lubricating fluid is pumped into the annular lumen between the stationary sheath and the rotatable drive shaft. A portion of said saline solution or special lubricating fluid is able to pass between adjacent wire turns of the drive shaft into a second annular lumen formed between the drive shaft and the guidewire thereby reducing friction between the drive shaft and the guidewire. In all of the prior art rotational atherectomy devices referred to above the antegrade flowing saline solution or special lubricating fluid enters the treated vessel from distal end of the stationary drive shaft sheath and thereby entrains and propels distally in an antegrade direction along the treated vessel abraded particles (debris) removed by the abrasive element. The distal migration of the abraded particles (debris) in an antegrade direction and embolisation of very small diameter arteries or capillaries by said abraded particles is of major concern to physicians who practice in this field. Clearly, the existence of particulate matter in the blood stream is undesirable and can cause potentially life-threatening complications, especially if the particles are over a certain size.

Although the potentially detrimental effect caused by the presence of abraded particles in the blood vessels is reduced if they are very small microparticles, it is much more preferable to remove from the treated blood vessel any debris abraded or otherwise released from the stenotic lesion during treatment and thereby prevent migration of debris to other locations along the treated blood vessel.

A rotational atherectomy device, described in US Patent No. 5,681,336 (to Clement et al.), has been proposed. This device attempts to prevent migration of abraded particles distally along the treated blood vessel by removing the ablated material from the blood vessel whilst the device is in use. The rotational atherectomy device known from US Patent No. 5,681,336 (to Clement et al.) has a complicated construction and is difficult to manufacture on a commercial scale.

A number of disadvantages associated with the known rotational atherectomy devices have been addressed in WO 2006/126076 to Shturman (the instant inventor). All of the the embodiments described in WO 2006/126076 comprise a rotatable fluid impermeable drive shaft and allow delivery of pressurized fluid from a lumen of the rotatable fluid

5 impermeable drive shaft into the treated vessel distal to the abrasive element so that at least a portion of said fluid flows in a retrograde direction along the treated vessel between the stenotic lesion and the vessel wall and entrains the abraded particles removed by the abrasive element. The retrograde flowing fluid and entrained abraded particles are aspirated from the treated vessel and out of the patient's body.

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All embodiments shown in WO 2006/126076 illustrate a torque transmitting element of the fluid impermeable drive shaft being formed by a single multifilament metal torque transmitting coil which extends distally through and distal to the abrasive element. An atherectomy device having this design allows excellent transmission of torque to the

15 abrasive element by the torque transmitting coil, but does not enable the device to have a sufficiently small transverse cross-sectional dimension to cross very tight stenotic lesions.

The present invention seeks to provide a rotational atherectomy device with transverse cross-sectional dimensions sufficiently small to cross very tight stenotic lesions.

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According to the present invention, there is provided a rotational atherectomy device for removing a stenotic tissue from a vessel of a patient, the device comprising a rotatable, flexible, hollow drive shaft having a fluid impermeable wall defining a fluid impermeable lumen of the drive shaft and, an abrasive element mounted to a distal end portion of the

25 drive shaft proximal to and spaced away from a distal support element formed at a distal end of the drive shaft, the distal support element being inflatable by pressurized fluid which flows in an antegrade direction through said lumen of the drive shaft and is at least partially re-directed into the distal fluid inflatable support element, wherein the distal fluid inflatable support element has an outer wall comprising an outflow opening located such that said

30 outflow opening faces an inner surface of a treated vessel during rotation of the drive shaft so that a flow of fluid through said outflow opening forms a layer of fluid between the outer wall of the rotating fluid inflated distal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated distal

support element and the wall of the treated vessel, the drive shaft being comprised of at least one fluid impermeable membrane and at least two torque transmitting coils, one of said coils extending distally beyond the distal end of the other coil and conveying torque to the abrasive element mounted to the drive shaft distal to and spaced away from a portion
5 of the drive shaft formed from the fluid impermeable membrane and said torque transmitting coils.

In a preferred embodiment, the outer wall of the distal fluid inflatable support element has a plurality of outflow openings located such that at least one of said outflow openings,
10 during rotation of the drive shaft, faces an inner surface of a treated vessel so that fluid flowing through the outflow openings forms a layer of fluid between the outer wall of the rotating fluid inflated distal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel.

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In one embodiment of the invention, the abrasive element has a slot and is mounted to the drive shaft such that said slot extends in a longitudinal direction and is attached to the drive shaft by a flexible strap which extends through said slot and is connected to the drive shaft distal and proximal to the abrasive element.

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In another embodiment, the abrasive element has a slot and is mounted to the drive shaft by a flexible strap which extends through said slot and is wrapped circumferentially around the drive shaft. Preferably, the abrasive element has a slot and is mounted to the drive shaft by a flexible strap which extends through said slot and is wrapped circumferentially around
25 the drive shaft distal to and spaced away from the distal end of the torque transmitting coil.

The flexible strap may have leading and trailing edge portions relative to the direction of rotation of the drive shaft, wherein the trailing edge portion of the flexible strap at least partially overlaps the leading edge portion when wrapped around the drive shaft. The
30 leading and trailing edge portions of the flexible strap can be bonded to each other in their overlapping region.

In one embodiment, the abrasive element has a leading edge and a trailing edge relative to the direction of rotation of the drive shaft, the leading edge of the abrasive element being thinner than the trailing edge so that, during rotation of the drive shaft, an abrasive surface of the abrasive element engages and abrades stenotic tissue only by a thicker portion of the
5 abrasive element, said thicker portion of the abrasive element being spaced away from the leading edge of the abrasive element.

In another embodiment, the abrasive element has a rotationally leading edge and a rotationally trailing edge relative to the direction of rotation of the drive shaft, the
10 rotationally leading edge of the abrasive element being thinner than the trailing edge so that the degree of engagement of the abrasive element with the stenotic tissue gradually increases during a revolution of the drive shaft. The abrasive element may extend around less than a half of the circumference of the drive shaft. Alternatively, the abrasive element extends around less than a third of a circumference of the drive shaft or, it may extend
15 around the entire circumference of the drive shaft.

In one embodiment, the fluid impermeable drive shaft has a longitudinal axis and the distal fluid inflatable support element has a centre of mass offset from the longitudinal axis of the drive shaft when the distal inflatable support element is fluid inflated. Preferably, the outer
20 wall of the distal fluid inflatable support element defines a fluid inflatable space that extends only partially around a circumference of the drive shaft so that, when the distal inflatable support element is fluid inflated, its centre of mass is offset from a longitudinal axis of the drive shaft in one direction, the distal fluid inflated support element acting, during rotation of the drive shaft, as a counterweight to the abrasive element which has its
25 centre of mass offset from the longitudinal axis of the drive shaft in the opposite direction.

In one preferred embodiment, the fluid impermeable drive shaft is provided with a proximal fluid inflatable support element located proximal to and spaced away from the abrasive element, the proximal fluid inflatable support element having an outer wall. The
30 proximal fluid inflatable support element may comprise an inner wall having an inflow aperture therein so that a portion of fluid flowing in an antegrade direction through the drive shaft is re-directed through the inflow aperture into the inflatable support element to inflate said proximal fluid inflatable support element.

In one embodiment, the proximal fluid inflatable support element has a centre of mass offset from the longitudinal axis of the drive shaft when the proximal inflatable support element is fluid inflated.

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In one preferred embodiment, the outer wall of the proximal fluid inflatable support element comprises an outflow opening located such that said outflow opening faces an inner surface of a treated vessel during rotation of the drive shaft so that a flow of fluid through said outflow opening forms a layer of fluid between the outer wall of the rotating fluid inflated proximal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated proximal support element and the wall of the treated vessel.

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The outer wall of the proximal fluid inflatable support element preferably has a plurality of outflow openings located such that at least one of said outflow openings, during rotation of the drive shaft, faces an inner surface of a treated vessel so that fluid flowing through the outflow openings forms a layer of fluid between the outer wall of the rotating fluid inflated proximal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated proximal support element and the wall of the treated vessel.

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The outer wall of the proximal fluid inflatable support element preferably defines a fluid inflatable space that extends only partially around a circumference of the drive shaft so that, when the proximal inflatable support element is fluid inflated, its centre of mass is offset from a longitudinal axis of the drive shaft in one direction, the proximal fluid inflated support element acting, during rotation of the drive shaft, as a counterweight to the abrasive element which has its centre of mass offset from the longitudinal axis of the drive shaft in the opposite direction.

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Preferably, in the first embodiment, the fluid inflatable space within both the distal and proximal fluid inflatable support elements extends circumferentially only partially around circumferential segments of the drive shaft which are spaced away in one direction with respect to the longitudinal axis of the drive shaft so that, when both the distal and proximal

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fluid inflatable support elements are inflated by fluid, their centers of mass become offset from a longitudinal axis of the drive shaft in said one direction and the distal and proximal fluid inflatable support elements act as counterweights to the abrasive element which is located on the drive shaft between the support elements and has its centre of mass offset
5 from the longitudinal axis of the drive shaft in the opposite direction.

Conveniently, a fluid inflatable space within the distal fluid inflatable support element extends uniformly around an entire circumference of the drive shaft to provide the distal support element with a centre of mass which is coaxial with a longitudinal axis of the drive
10 shaft when said distal support element is fluid inflated.

In one embodiment, there is a plurality of openings in the outer wall of the fluid inflatable distal support element, said openings being located around the circumference of the outer wall of the fluid inflatable distal support element such that, during rotation of the drive
15 shaft, flows of fluid through the openings form a layer of fluid between the outer wall of the fluid inflated distal support element and a wall of the treated vessel, said layer of fluid forming a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel.

20 There may be a plurality of openings in the outer wall of the fluid inflatable distal support element, said openings being located around the circumference of the outer wall of the fluid inflatable distal support element such that, during rotation of the drive shaft, at least one of said openings faces an inner surface of a treated vessel, so that flows of fluid through the openings form a layer of fluid between the outer wall of the fluid inflated distal
25 support element and a wall of the treated vessel, said layer of fluid forming a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel.

In one embodiment, a fluid inflatable space within the proximal fluid inflatable support
30 element extends uniformly around an entire circumference of the drive shaft to provide a fluid inflated proximal support element with a centre of mass which is coaxial with a longitudinal axis of the drive shaft.

In one embodiment there is a plurality of openings in the outer wall of the fluid inflatable proximal support element, said openings being located around the circumference of the outer wall of the fluid inflatable proximal support element such that, during rotation of the drive shaft, flows of fluid through the openings form a layer of fluid between the outer wall of the fluid inflated proximal support element and a wall of the treated vessel, said layer of fluid forming a fluid bearing between the outer wall of the rotating fluid inflated proximal support element and the wall of the treated vessel. Preferably, there is a plurality of openings in the outer wall of the fluid inflatable proximal support element, said openings being located around the circumference of the outer wall of the fluid inflatable proximal support element such that, during rotation of the drive shaft, at least one of said openings is facing an inner surface of a treated vessel so that flows of fluid through the openings form a layer of fluid between the outer wall of the fluid inflated proximal support element and a wall of the treated vessel, said layer of fluid forming a fluid bearing between the outer wall of the rotating fluid inflated proximal support element and the wall of the treated vessel.

In one embodiment, the fluid impermeable membrane extends distally under and beyond the abrasive element and is folded on itself at a distal end of the drive shaft to form the distal fluid inflatable support element between an inner and outer layers of said folded membrane, the outer layer of the membrane forming an outer wall of the distal fluid inflatable support element and the inner layer of the membrane forming an inner wall of the distal fluid inflatable support element, the inner wall of the inflatable support element having an aperture therein so that a portion of fluid flowing in an antegrade direction through the drive shaft is re-directed through the aperture into the distal fluid inflatable support element to inflate said distal support element.

The inner and outer layers of the folded fluid impermeable membrane may be connected or bonded to each other at least just proximal to the distal fluid inflatable support element. Preferably, the inner and outer layers of the folded fluid impermeable membrane should be connected or bonded to each other around an entire circumference of the drive shaft.

In one embodiment, the outer layer of the folded fluid impermeable membrane, after forming the outer wall of the distal fluid inflatable support element, extends further

proximally to form an outer wall of the proximal fluid inflatable support element. The inner and outer layers of the folded fluid impermeable membrane may be connected or bonded to each other at least just distal and proximal to the proximal fluid inflatable support element. Preferably, the inner and outer layers of the folded fluid impermeable
5 membrane should be connected or bonded to each other around an entire circumference of the drive shaft.

The distal fluid inflatable support element preferably has an inner wall defined by the inner layer of the fluid impermeable membrane, the inner wall having an inflow aperture therein
10 so that a portion of the fluid flowing in an antegrade direction through the drive shaft is redirected through the inflow aperture into the proximal fluid inflatable support element to inflate said proximal support element. Preferably, the aperture through which fluid enters the distal inflatable support element and the opening(s) in the outer wall of the inflated
distal inflatable support element through which fluid exits the distal inflatable support
15 element are configured so that the distal inflatable support element is kept inflated by the pressure of the fluid flowing through the inflatable support element.

The aperture through which fluid enters the distal inflatable support element may be larger than the opening(s) in the outer wall of the inflated distal inflatable support element
20 through which fluid exits the distal inflatable support element so that the distal inflatable support element is kept inflated by the pressure of the fluid flowing through the inflatable support element.

In one embodiment, the abrasive element has a slot and is mounted to the drive shaft by a
25 flexible strap which extends through said slot and is wrapped around the membrane proximal to and spaced away from the distal fluid inflatable support element. The flexible strap is preferably wrapped around the membrane distal to and spaced away from that portion of the drive shaft which is formed from the fluid impermeable membrane and the torque transmitting coils. Preferably, the flexible strap is wrapped around the outer layer of
30 the folded fluid impermeable membrane.

In another embodiment, the abrasive element has a slot and is mounted to the drive shaft such that said slot extends in a longitudinal direction and is attached to the fluid

impermeable membrane by a flexible strap which extends through said slot and is connected to the drive shaft distal and proximal to the abrasive element. The outer layer of the folded fluid impermeable membrane, after forming the outer wall of the distal fluid inflatable support element, may extend further proximally to form an outer wall of the proximal fluid inflatable support element and the flexible strap, which mounts the abrasive element to the drive shaft, extends between the inner and outer layers of the folded fluid impermeable membrane both distal and proximal to the abrasive element.

The outer layer of the folded fluid impermeable membrane conveniently has an opening through which an abrasive surface of the abrasive element at least partially protrudes above a surface of the outer layer of the folded fluid impermeable membrane.

In one embodiment of the invention, the torque transmitting coils are disposed coaxially with respect to each other, one of two coils being an inner torque transmitting coil and the other torque transmitting coil being an outer torque transmitting coil, the inner and the outer torque transmitting coils being wound in opposite directions so that, when the drive shaft is rotated, the outer torque transmitting coil prevents unwinding of the inner torque transmitting coil.

The fluid impermeable membrane may line the inner torque transmitting coil. Alternatively, the fluid impermeable membrane is disposed around the torque transmitting coils. Preferably, the fluid impermeable membrane is sandwiched between the torque transmitting coils.

In one embodiment, the abrasive element extends around the entire circumference of the drive shaft.

In one embodiment, a valve is formed at the distal end of the drive shaft. Preferably, the drive shaft may comprise a radially inwardly extending shoulder located at or just proximal to the distal end of the drive shaft. In this embodiment, the device may also comprise a rounded element configured to be advanced to a distal end of the drive shaft where it is prevented from exiting the drive shaft by the radially inwardly extending shoulder, thereby occluding the distal end of the drive shaft and thereby at least partially preventing flow of

fluid through the very distal end of the drive shaft and assisting in the redirection of the flow of fluid into the fluid inflatable support elements. The radially inwardly extending shoulder can be formed integrally with a distal end of the inner torque transmitting coil.

5 According to yet another embodiment of the invention, there is provided a rotational atherectomy device for removing a stenotic tissue from a vessel of a patient, the device comprising an abrasive element mounted to a rotatable, flexible, hollow, drive shaft, the drive shaft comprised by a fluid impermeable membrane and two coaxially disposed torque transmitting coils, the membrane and one of two coils extending distally beyond the
10 abrasive element which is attached to the membrane distal to a distal end of the other torque transmitting coil and proximal to and spaced away from a distal fluid inflatable support element formed by said fluid impermeable membrane at a distal end of the drive shaft, the distal fluid inflatable support element including at least two openings, an inflow opening communicating a fluid impermeable lumen of the drive shaft with an inflatable
15 space of the distal fluid inflatable support element and an outflow opening located in an outer wall of the distal fluid inflatable support element and communicating the interior space of the distal fluid inflatable support element with a vascular space within the vessel of the patient, said outflow opening having an axis which forms an angle of about ninety (90) degrees with a longitudinal axis of the drive shaft when the distal fluid inflatable support
20 element is inflated.

According to yet another embodiment of the invention, there is provided a rotational atherectomy device for removing a stenotic tissue from a vessel of a patient, the device comprising an abrasive element mounted to a rotatable, flexible, hollow drive shaft, the
25 drive shaft comprised by a fluid impermeable membrane sandwiched between inner and outer torque transmitting coils, the inner torque transmitting coils and the membrane extending distally beyond the abrasive element which is attached to the membrane distal to a distal end of the outer torque transmitting coil and proximal to and spaced away from a distal fluid inflatable support element formed by said fluid impermeable membrane at a
30 distal end of the drive shaft, the distal fluid inflatable support element including at least two openings, an inflow opening communicating a fluid impermeable lumen of the drive shaft with an inflatable space of the distal fluid inflatable support element and an outflow opening located in an outer wall of the distal fluid inflatable support element and

communicating the interior space of the distal fluid inflatable support element with a vascular space within the vessel of a patient, said outflow opening having an axis which forms an angle of about ninety (90) degrees with a longitudinal axis of the drive shaft when the distal fluid inflatable support element is inflated, so that in a rotating fluid inflated distal support element a flow of fluid through the outflow opening forms a thin layer of fluid between the outer wall of the fluid inflated distal support element and an inner surface of a wall of the vessel which is being treated.

10 In one embodiment, the drive shaft is provided with a solid proximal support element located proximal to and spaced away from the abrasive element, the membrane that forms a fluid impermeable lumen for the antegrade flow of fluid through the drive shaft into the distal fluid inflatable support element also forming a lumen for the antegrade flow of fluid through the drive shaft into an outflow channel extending through said solid proximal support element, the solid proximal support element having a rounded outer surface, said outflow channel having an outflow opening in the rounded outer surface of the solid proximal support element such that, during rotation of the drive shaft, said outflow opening on the outer surface of the solid proximal support element is facing an inner surface of a treated vessel so that a flow of fluid out of said outflow opening forms a layer of fluid between the solid proximal support element and a wall of the treated vessel during rotation of the drive shaft, said layer of fluid forming a fluid bearing between the rotating solid proximal support element and the wall of the treated vessel.

It should be appreciated that the present invention covers two most preferred embodiments namely, a first most preferred embodiment in which the fluid inflatable support elements are asymmetrical with respect to the longitudinal axis of the drive shaft and, a second most preferred embodiment in which the fluid inflatable support elements are symmetric with respect to the longitudinal axis of the drive shaft. However, it will be appreciated that, in all the embodiments, the asymmetric and symmetric fluid inflatable elements comprise outflow openings located such that, in the rotating drive shaft, fluid flowing through said openings forms fluid bearings between outer walls of said inflatable elements and the wall of the treated vessel.

It should be noted that throughout this specification, reference is made to “distal” and “proximal” ends and to flow of fluid in an “antegrade” and “retrograde” direction. For the avoidance of doubt, the distal end is considered to refer to the end of the device which is inserted into the vessel in the body of the patient and the proximal end is the end of the device which remains outside the body of the patient and which can be connected to a handle assembly for both rotating and longitudinally moving the drive shaft within the treated vessel. “Antegrade” flow refers to a direction of flow from the proximal towards the distal end of the device. Similarly, “retrograde” flow refers to a direction of flow in the opposite direction, i.e. from the distal towards the proximal end of the device.

Embodiments of the invention will now be described, by way of example only, in conjunction with the following drawings, in which:

FIGURE 1 is a side sectional view of the distal end portion of the rotational atherectomy device illustrating attachment of an abrasive element to a fluid impermeable drive shaft by a longitudinally extending strap and showing fluid inflatable support elements of the drive shaft in their deflated state;

FIGURE 2 is similar to FIGURE 1, except it illustrates flow of fluid into and out of the inflated support elements, the fluid inflated support elements having their centers of mass spaced radially away from the longitudinal axis of the drive shaft;

FIGURE 3 shows an enlarged cross-sectional view of the distal fluid inflatable support element taken along a line A-A in FIGURE 1;

FIGURE 4 is an enlarged cross-sectional view taken along a line B-B in FIGURE 1 and illustrates attachment of the abrasive element to the drive shaft;

FIGURE 5 shows an enlarged cross-sectional view of the proximal inflatable support element taken along a line C-C in FIGURE 1;

FIGURE 6 shows an enlarged cross-sectional view taken along a line D-D in FIGURE 2 and illustrating flow of fluid into and out of the distal fluid inflated support element;

FIGURE 7 is similar to FIGURE 4 except that it is taken along a line E-E in FIGURE 2;

FIGURE 8 shows an enlarged cross-sectional view taken along a line F-F in FIGURE 2 and illustrating flow of fluid into and out of the proximal fluid inflated support element;

FIGURE 9 is a sectional side elevation of a portion of a blood vessel containing a stenotic lesion and shows a guidewire which has been already advanced across the stenotic lesion to be treated;

FIGURE 10 is a side sectional view of the portion of the blood vessel shown in Figure 9
5 and illustrates advancement of the fluid impermeable drive shaft over the guidewire;

FIGURE 11 is similar to FIGURE 10, but illustrates that the drive shaft has been advanced across the stenotic lesion to a position in which the distal fluid inflatable support element is located distal to the stenotic lesion and the proximal fluid inflatable support element is still proximal to the stenotic lesion to be treated;

10 FIGURE 12 is a side sectional view illustrating withdrawal of the guidewire from the drive shaft;

FIGURE 13 is a side sectional view illustrating that the guidewire has been completely withdrawn from the drive shaft;

FIGURE 14 is a side sectional view illustrating antegrade flow of fluid along the fluid
15 impermeable drive shaft, inflation of the fluid inflatable support elements and retrograde flow of fluid around the drive shaft;

FIGURES 15 through 26 illustrate abrading of the stenotic lesion by the rotating abrasive element and formation of fluid bearings between the inner surface of the vessel and the outer walls of the rotating fluid inflated support elements, said fluid bearings being formed
20 by flow of fluid through the openings in the outer walls of the fluid inflated support elements;

FIGURE 27 illustrates that antegrade flow of fluid through the drive shaft and retrograde flow of fluid across the treated stenotic lesion is continued for at least a short period of time after rotation of the drive shaft has been stopped;

25 FIGURE 28 illustrates that the fluid inflatable support elements have been deflated and the drive shaft is ready to be removed from the treated vessel;

FIGURES 29 and 30 illustrate the removal of the drive shaft from the treated vessel and appearance of the treated vessel after removal of the drive shaft;

FIGURES 31 through 34 are similar to FIGURES 15 through 26 except that they illustrate
30 abrading of a very tight stenotic lesion from a large diameter vessel by the rotational atherectomy device with a small diameter drive shaft;

FIGURES 35 through 39 show enlarged views of the abrasive element and the fluid inflatable support elements to illustrate best how the flows of fluid out of the rotating fluid

inflated support elements form fluid bearings between the outer walls of the rotating fluid inflated support elements and the wall of the treated vessel;

FIGURE 40 is similar to FIGURE 1 except that it illustrates the abrasive element being attached to the drive shaft by the longitudinally extending strap which is made integrally with the fluid impermeable membrane of the drive shaft;

FIGURE 41 is similar to FIGURE 1 except that it illustrates the abrasive element being made integrally with the longitudinally extending strap which attaches the abrasive element to the drive shaft;

FIGURES 42 through 49 are similar to FIGURES 1 through 8 except that they illustrate that the abrasive element is attached to the drive shaft by a flexible strap which extends around the drive shaft;

FIGURE 50 is similar to FIGURE 42 except that it illustrates fluid inflatable support elements which extend around the entire circumference of the drive shaft;

FIGURE 51 is similar to FIGURE 43 except that it illustrates flow of fluid into and out of the fluid inflated support elements which extend around the entire circumference of the drive;

FIGURES 52 through 55 illustrate the formation of fluid bearings between the inner surface of the treated vessel and the outer walls of the rotating fluid inflated support elements, each of the support elements having a fluid inflatable space which extends circumferentially around the entire circumference of the drive shaft so that, in a curved vessel said support elements bias the abrasive element towards the inner curvature of the curved vessel and allow preferential removal of stenotic tissue from the inner curvature of the treated curved vessel;

FIGURE 56 illustrates in a transverse cross-section an abrasive element which has its rotationally trailing edge made thicker than its rotationally leading edge;

FIGURE 57 illustrates the drive shaft which has the outer wall of its proximal fluid inflatable support element formed by a membrane which is not continuous with the membrane which forms the outer wall of the distal fluid inflatable support element;

FIGURE 58 illustrates that the fluid impermeable drive shaft has a radially inward extending shoulder located at or just proximal to the distal end of the drive shaft;

FIGURES 59 and 60 show a rounded element being advanced to a distal end of the drive shaft and stopped from exiting from the drive shaft by the radially inward extending

shoulder, thereby preventing flow of fluid through an opening at the distal end of the drive shaft and assisting in the redirecting flow of fluid into the fluid inflatable support elements; FIGURE 61 illustrates that the radially inward extending shoulder at the distal end of the drive shaft has been formed integrally with the distal end of the inner torque transmitting coil;

FIGURE 62 illustrates that a rounded element has been advanced to a distal end of the drive shaft and stopped from exiting from the drive shaft by the radially inward extending shoulder, thereby preventing flow of fluid through an opening at the distal end of the drive shaft and assisting in the redirecting flow of fluid into the fluid inflatable support elements, the radially inward extending shoulder being formed integrally with the inner torque transmitting coil;

FIGURE 63 illustrates the distal end portion of the drive shaft with an asymmetric fluid inflatable distal support element and a solid asymmetric proximal support element, the fluid inflatable element shown in its deflated state, and;

FIGURE 64 illustrates the distal end portion of the drive shaft with an asymmetric fluid inflatable distal support element and a solid asymmetric proximal support element, the fluid inflatable element shown in its inflated state.

In Figures 1 to 64, the atherectomy device is advanced across the stenotic lesion 330 over the guidewire 301. The direction of movement of the device is indicated by arrow marked "DM", the antegrade flow of fluid being indicated by arrows "FF" and the flow of fluid in a retrograde direction is indicated by arrows marked "R". Arrows marked "FP" designate pressure of fluid which distends the support elements. Abraded particles AP abraded from the stenotic lesion 330 are aspirated into a lumen of a drive shaft sheath 5000 so that the retrograde flowing fluid and the abraded particles entrained in said fluid can be removed from the treated vessel and out of the patient's body.

Figures 1 through 8 illustrate in longitudinal and transverse cross-sections a distal portion of the first most preferred embodiment of the rotational atherectomy device of the invention. The rotational atherectomy device is comprised of an abrasive element 1 which is mounted to a rotatable, flexible, hollow, drive shaft 2 proximal to and spaced away from a distal end 6 of the drive shaft. The drive shaft 2 comprises a fluid impermeable membrane 3 and a pair of coaxially disposed torque transmitting coils comprising an inner

torque transmitting coil 44 and, an outer torque transmitting coil 4. Both the inner torque transmitting coil 44 and the fluid impermeable membrane 3 extend distally beyond the abrasive element 1 which is attached to the membrane 3 distal to and spaced away from a distal end 5 of the outer torque transmitting coil 4 and proximal to and spaced away from a distal fluid inflatable support element 10 formed by the fluid impermeable membrane 3 at the distal end 6 of the drive shaft 2. The inner torque transmitting coil 44 has its distal end 55 located at or just proximal to the distal end 6 of the drive shaft 2, thereby substantially alone conveying torque to the abrasive element 1 and to the distal fluid inflatable support element 10 which are located distally and spaced away from the distal end 5 of the outer torque transmitting coil 4. The fluid impermeable membrane 3 is folded on itself at the distal end 6 of the drive shaft 2 and forms the distal fluid inflatable support element 10 between an inner 11 and outer 22 layers of the folded membrane 3. The outer layer 22 of the membrane 3 forms an outer wall 222 of the distal fluid inflatable support element 10 and the inner layer 11 of the membrane 3 forms an inner wall 111 of the distal fluid inflatable support element 10. The inner wall 111 of the distal fluid inflatable support element 10 has an inflow aperture 15 therein. The inflow aperture 15 of the distal fluid inflatable support element 10 communicates a lumen of the fluid impermeable drive shaft 2 with a fluid inflatable space 3000 of the distal fluid inflatable support element 10. Figure 2 illustrates that a portion of flushing fluid FF flowing in an antegrade direction through the drive shaft 2 is redirected through the inflow aperture 15 into the distal fluid inflatable support element 10 to inflate said distal inflatable support element.

It should be noted that the inner 11 and the outer 22 layers of the folded membrane may be formed by either folding the membrane 3 back onto itself or by inverting it.

Figure 2 illustrates best that in order to form the distal fluid inflatable support element 10, the inner 11 and outer 22 layers of the folded fluid impermeable membrane 3 are connected or bonded to each other at least just proximal to the distal fluid inflatable support element 10. In this location, just proximal to the distal fluid inflatable support element 10, the inner 11 and the outer 22 layers of the membrane 3 are preferably connected or bonded to each other around the entire circumference of the drive shaft 2.

In the most preferred embodiment of the invention the outer wall 222 of the distal fluid inflatable support element 10 has at least one outflow opening 20 which enables flow of fluid out of the distended fluid inflatable distal support element 10. The distal fluid inflatable support element 10 becomes distended by flow of fluid through an inflow aperture 15 in its inner wall 111. The inflow aperture 15 communicates a lumen of the fluid impermeable drive shaft 2 with an inflatable space 3000 within the distal fluid inflatable support element 10, said inflatable space 3000 being at least partially defined by a fluid impermeable membrane which forms the outer wall 222 of the distal fluid inflatable support element 10.

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An area of the inflow aperture 15 through which fluid enters the distal inflatable support element 10 is larger than the area of the outflow opening(s) 20 through which fluid exits the distal inflatable support element 10 so that the distal fluid inflatable support element 10 is kept inflated by the pressure of the fluid flowing through the distal inflatable support element 10.

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Figures 1, 2, 3 and 6 show the distal fluid inflatable support element 10 which is asymmetric with respect to a longitudinal axis of the drive shaft. After being inflated by fluid, such asymmetric distal support element has its centre of mass CM spaced away from the longitudinal axis W-W of the drive shaft 2. Figures 1, 2 and 4 show an abrasive element 1 which is mounted to the drive shaft 2 proximal to and spaced away from the asymmetric distal fluid inflatable support element 10. The abrasive element 1 extends only around a portion of the circumference of the drive shaft 2 and has its centre of mass spaced radially away from the longitudinal axis of the drive shaft. Preferably, the centre of mass CM of the asymmetric fluid inflated distal support element 10 is spaced radially away from the longitudinal axis W-W of the drive shaft in one direction and the centre of mass of the abrasive element 1 is spaced radially away from the longitudinal axis W-W of the drive shaft in another diametrically opposite direction, so that in a rotating drive shaft such asymmetric fluid inflated distal support element 10 acts as a distal fluid inflatable counterweight with respect to the abrasive element 1.

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Figure 2 illustrates that the outer wall 222 of the fluid inflated distal support element 10 is rounded and is bowing radially outwards at least along its longitudinally middle section

which extends in a longitudinal cross-section between an outflow opening 20 which is located longitudinally most distally within the outer wall 222 and another outflow opening 20 which is located longitudinally most proximally within the outer wall 222.

- 5 Each outflow opening 20 in the outer wall 222 of the distal fluid inflatable support element has its own axis K-K. Figure 2 illustrates that the asymmetric distal fluid inflatable support element 10 when inflated has at least one outflow opening 20 in its rounded outer wall 222 located such that the axis K-K of the outflow opening 20 forms an acute angle α of at least sixty (60) degrees with respect to the longitudinal axis of the drive shaft. In the most
10 preferred embodiment of the invention, the asymmetric distal fluid inflatable support element 10 when inflated has at least one outflow opening 20 in its outer wall 222 located such that the axis K-K of the outflow opening 20 forms an angle β of about ninety (90) degrees with respect to the longitudinal axis of the drive shaft. Figures 15 through 26 illustrate that in the rotating asymmetric fluid inflated distal support element 10 at least one
15 of the above described outflow openings 20 is located such that its axis K-K forms about a ninety (90) degrees angle with respect to the inner surface of the wall 300 of the treated vessel. Centrifugal force attempts to press a rotating asymmetric fluid inflated distal support element 10 against the wall 300 of the treated vessel, but fluid exiting from the outflow opening 20 along its axis K-K at an angle of about ninety (90) degrees with respect
20 to the wall 300 of the vessel forms a thin layer of fluid between the outer wall 222 of the fluid inflated distal support element 10 and an inner surface of the wall 300 of the vessel. The formation of a thin layer of fluid between the outer wall 222 of the rotating fluid inflated distal support element 10 and an inner surface of the wall 300 of the vessel is best illustrated in figure 38. Figure 38 shows a portion of the vascular wall 300 and a magnified
25 view of the rotating fluid inflated distal support element 10 which has its outer wall 222 separated from the inner surface of the wall 300 by a thin layer of fluid exiting from the rotating extended distal support element 10 through outflow opening(s) 20 in its outer wall 222. Preferably, the fluid inflated distal support element 10 with the centre of mass radially spaced away from the longitudinal (rotational) axis of the drive shaft should have at least
30 one outflow opening 20 in the outer wall 222 of the distal inflatable support element 10 located such that at any time during rotation of the drive shaft 2 said outflow opening 20 is facing an inner surface of the treated vessel so that a flow of fluid through the opening 20 forms a layer of fluid between the outer wall 222 of the rotating fluid inflated distal support

element 10 and the wall 300 of a treated vessel. Said layer of fluid forms a fluid bearing between the outer wall 222 of the rotating fluid inflated distal support element 10 and the wall 300 of the treated vessel.

5 Figures 1 and 4 show one embodiment of the invention in which the abrasive element 1 has a longitudinally extending slot 40. The abrasive element 1 is mounted to the drive shaft 2 by a flexible strap 41 which extends through said slot 40 and is bonded to the fluid impermeable membrane both distal and proximal to the abrasive element 1. Preferably, the outer layer 22 of the folded fluid impermeable membrane 3 extends proximally beyond the
10 abrasive element 1 and the flexible strap 41 which mounts the abrasive element 1 to the drive shaft 2 extends between the inner 11 and outer 22 layers of the folded fluid impermeable membrane 3 both distal and proximal to the abrasive element 1. The outer layer 22 of the folded fluid impermeable membrane 3 has an opening through which an abrasive surface of the abrasive element 1 protrudes above a surface of the outer layer 22
15 of the folded fluid impermeable membrane. Figure 40 shows one variation of the invention in which longitudinally extending strap 41' is formed integrally with the outer layer 22 of the folded fluid impermeable membrane 3. Figure 40 illustrates that in such embodiment the longitudinally extending strap 41' is continuous with the outer layer 22 of the folded fluid impermeable membrane 3 distally to the abrasive element 1 and is bonded to the fluid
20 impermeable membrane 3 proximally to the abrasive element 1.

Figure 41 shows another variation of the invention in which the abrasive element 1' is formed integrally with the longitudinally extending strap 41". Both the body of the abrasive element and the longitudinally extending strap in such embodiment may be made from
25 sufficiently flexible material such as gold, the longitudinally extending strap being made substantially thinner than the body of the abrasive element in order to make the strap sufficiently flexible. It should be noted that the rotational atherectomy devices with abrasive elements which do not extend around the entire circumference of the drive shaft may have advantages for crossing and abrading tight stenotic lesions. Therefore, any
30 abrasive element which is attached to the drive shaft by a longitudinally extending strap should extend around less than a half of the circumference of the drive shaft and preferably even around less than a third of the circumference of the drive shaft..

In yet another variation of the first most preferred embodiment of the invention shown in figures 42 through 49 the abrasive element 101 has a transverse extending slot 140 and is mounted to the drive shaft 2 by a flexible strap 141 which extends through said slot and is wrapped around the drive shaft 2. Preferably, in this embodiment the flexible strap 141 is wrapped around the fluid impermeable membrane 3 distal to the distal end 5 of the outer torque transmitting coil 4. In the most preferred embodiment the flexible strap 141 is wrapped around the outer layer 22 of the folded fluid impermeable membrane. Figure 45 illustrates that the flexible strap 141 has leading and trailing edge portions relative to the direction (arrow V) of rotation of the drive shaft 2, the trailing edge portion 142 of the flexible strap 141 extends around the drive shaft and at least partially overlaps the leading edge portion 143 of said strap 141. The overlapping trailing 142 and leading 143 edge portions of the flexible strap 141 are preferably bonded to each other. The abrasive element 101 also has a rotationally leading edge 801 and a rotationally trailing edge 802 relative to the direction of rotation of the drive shaft 2.

Figure 56 shows that the rotationally leading edge 801 of the abrasive element 101 is made thinner than its trailing edge 802 so that during rotation of the drive shaft an abrasive surface 10001 of the abrasive element 101 may engage and abrade stenotic tissue only by a thicker portion of the abrasive element 101, said thicker portion 10002 of the abrasive element being spaced away from the leading edge 801 of the abrasive element 101. The abrasive element with thinner leading edge 801 and thicker trailing edge 802 allows to gradually increase the degree of engagement of the abrasive surface 10001 of the abrasive element 101 with the stenotic tissue to be abraded. It should be noted that variation of the abrasive element shown in Figure 56 may be used with any embodiment of the rotational atherectomy device of the invention.

It should be noted that the rotational atherectomy devices with abrasive elements which do not extend around the entire circumference of the drive shaft may have advantages for crossing and abrading tight stenotic lesions. Preferably, abrasive elements which are attached to the drive shaft by straps should extend around less than a half of the circumference of the drive shaft. The abrasive elements which extend around less than a third of the circumference of the drive shaft may allow the crossing and abrading of very tight stenotic lesions even when they are attached to the drive shaft by the straps which

extend around the entire circumference of the drive shaft. However, the abrasive elements which extend around the entire circumference of the drive shaft and their fixations to the drive shaft known from WO 2006/126076 and other sources, may be used with any embodiments of this invention.

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It should be noted that in the most preferred embodiments of the invention, the fluid impermeable drive shaft is provided with two fluid inflatable support elements, one located at the distal end of the drive shaft and the other proximal to and spaced away from the abrasive element. Figures 1 through 8 illustrate one such embodiment in which the drive shaft 2 is provided with both a distal fluid inflatable support element 10 and a proximal fluid inflatable support element 10p. The proximal fluid inflatable support element 10p has an inner wall 111p and an outer wall 222p. In the most preferred embodiment of the invention, the outer wall 222p of the proximal fluid inflatable support element 10p is formed by the outer layer 22 of the folded fluid impermeable membrane 3. The inner wall 111p of the proximal fluid inflatable support element 10p is formed by the inner layer 11 of the folded fluid impermeable membrane 3. The inner wall 111p of the proximal fluid inflatable support element 10p has an inflow aperture 15p therein. Figure 2 illustrates that a portion of flushing fluid FF flowing in an antegrade direction along the drive shaft 2 is redirected through the inflow aperture 15p into the proximal inflatable support element 10p to inflate said proximal inflatable support element. Figure 2 illustrates best that in order to form the proximal fluid inflatable support element 10p, the inner 11 and outer 22 layers of the folded fluid impermeable membrane 3 are connected or bonded to each other at least just distal and proximal to the proximal fluid inflatable support element 10p. In this location, just distal and proximal to the proximal fluid inflatable support element 10p, the inner 11 and the outer 22 layers of the membrane 3 are preferably connected or bonded to each other around the entire circumference of the drive shaft 2.

It should be noted that the outer wall of the proximal fluid inflatable support element may be formed not only by a proximal portion of the outer layer 22 of the folded fluid impermeable membrane 3, but by a separate fluid impermeable membrane 333 shown in figure 57. The separate fluid impermeable membrane 333 should be bonded

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circumferentially to the fluid impermeable membrane 3 at least just distal and proximal to the proximal fluid inflatable support element.

The following discussion is focused on the design and function of the proximal fluid inflatable support element 10p which has its outer wall 222p formed by the outer layer 22 of the folded fluid impermeable membrane 3, but it should be understood that the same discussion would be applicable to a proximal fluid inflatable support element which has its outer wall formed by the separate fluid impermeable membrane 333 shown in figure 57. The following discussion is particularly applicable with respect to the location and function of openings in the outer wall of the proximal fluid inflatable support element.

In the most preferred embodiments of the invention the outer wall 222p of the proximal fluid inflatable support element 10p has at least one outflow opening 20p which enables flow of fluid out of the distended fluid inflatable proximal support element 10p. The proximal fluid inflatable support element 10p becomes distended by flow of fluid through its inflow aperture 15p which communicates the lumen of the fluid impermeable drive shaft 2 with the inflatable space 3000p within the proximal fluid inflatable support element 10p. The fluid inflatable space 3000p is at least partially defined by a fluid impermeable membrane which forms an outer wall 222p of the proximal fluid inflatable support element 10p.

An area of the inflow aperture 15p through which fluid enters the proximal inflatable support element 10p is larger than the area of the outflow opening(s) 20p through which fluid exits the proximal inflatable support element 10p so that the proximal fluid inflatable support element 10p is kept inflated by the pressure of the fluid flowing through the proximal inflatable support element 10p.

Figures 1, 2, 5 and 8 show the proximal fluid inflatable support element 10p which is asymmetric with respect to a longitudinal axis of the drive shaft 2. Figures 1, 2, 5 and 8 show that, after being inflated by fluid, such asymmetric proximal support element 10p has its centre of mass CMp spaced away from the longitudinal axis W-W of the drive shaft 2. Figures 1, 2, 4 and 7 show best an abrasive element 1 which is mounted to the drive shaft 2 distal to and spaced away from the asymmetric proximal fluid inflatable support element

10p. As previously mentioned, the abrasive element 1 extends only around a portion of the circumference of the drive shaft 2 and therefore has its centre of mass spaced radially away from the longitudinal axis W-W of the drive shaft 2. Preferably, the centre of mass CMp of the asymmetric fluid inflated proximal support element 10p is spaced radially away from
5 the longitudinal axis W-W of the drive shaft in one direction and the centre of mass of the abrasive element 1 is spaced radially away from the longitudinal axis W-W of the drive shaft 2 in another diametrically opposite direction, so that in a rotating drive shaft such asymmetric fluid inflated proximal support element 10p forms (acts as) a proximal fluid inflatable counterweight with respect to the abrasive element 1

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Figure 2 illustrates that the outer wall 222p of the fluid inflated proximal support element 10p is bowing longitudinally outwards at least along its longitudinally middle section which extends in a longitudinal cross-section between an outflow opening 20p which is located longitudinally most distally within the outer wall 222p and another outflow opening 20p
15 which is located longitudinally most proximally within the outer wall 222p.

Each outflow opening 20p in the outer wall 222p of the proximal fluid inflatable support element has its own axis L-L. Figure 2 illustrates that the asymmetric proximal fluid inflatable support element 10p when inflated has at least one outflow opening 20p in its
20 outer wall 222p located such that the axis L-L of the outflow opening 20p forms an acute angle α of at least sixty (60) degrees with respect to the longitudinal axis W-W of the drive shaft 2. In the most preferred embodiment of the invention, the asymmetric proximal fluid inflatable support element 10p when inflated has at least one outflow opening 20p in its outer wall 222p located such that the axis L-L of the outflow opening 20p forms about a
25 ninety (90) degrees angle β with respect to the longitudinal axis of the drive shaft 2.

Figures 15 through 26 illustrate that in the rotating asymmetric fluid inflated proximal support element 10p at least one of the above described outflow openings 20p is located such that its axis L-L forms about a ninety (90) degrees angle with respect to the inner
30 surface of the wall 300 of the treated vessel. Centrifugal force attempts to press a rotating asymmetric fluid inflated proximal support element 10p against the wall 300 of the treated vessel, but fluid exiting from the outflow opening 20p along its axis L-L at an angle of about ninety (90) degrees with respect to the wall 300 of the vessel forms a thin layer of

fluid between the rounded outer wall 222p of the fluid inflated proximal support element 10p and an inner surface of the wall 300 of the vessel. The asymmetric fluid inflated proximal support element 10p has its centre of mass spaced radially away from the longitudinal (rotational) axis of the drive shaft. Centrifugal force attempts to press the rotating fluid inflated proximal support element 10p against the wall 300 of the vessel, but at least one outflow opening 20p in the longitudinally rounded outer wall 222p of said rotating fluid inflated proximal support element 10p is located such that a flow of fluid through said opening 222p forms a layer of fluid between the outer wall 222p of the rotating fluid inflated proximal support element 10p and the wall 300 of the treated vessel. Preferably, the fluid inflated proximal support element 10p with the centre of mass radially spaced away from the longitudinal (rotational) axis of the drive shaft 2 should have at least one outflow opening 20p in the longitudinally rounded outer wall 222p of the proximal inflatable support element 10p located such that at any time during rotation of the drive shaft 2 said outflow opening 20p is facing an inner surface of the treated vessel so that a flow of fluid through the outflow opening 20p forms a layer of fluid between the longitudinally rounded outer wall 222p of the rotating fluid inflated proximal support element 10p and the wall 300 of a treated vessel. Said layer of fluid forms a fluid bearing between the outer wall 222p of the rotating fluid inflated proximal support element 10p and the wall 300 of the treated vessel.

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Figures 50 and 51 illustrate the second most preferred embodiment of the distal end portion of the rotational atherectomy device of the invention. In this second most preferred embodiment, the distal fluid inflatable support element 10s is symmetric with respect to a longitudinal axis W-W of the drive shaft. This symmetric distal fluid inflatable support element 10s has a fluid inflatable space 3000s which extends uniformly around the drive shaft 2, so that after being inflated by fluid the distal support element 10s has its centre of mass coaxial with the longitudinal axis W-W of the drive shaft 2. An inflow opening (aperture) 15s communicates the fluid inflatable space 3000s within the inflatable support element 10s with the lumen of the fluid impermeable drive shaft 2. The fluid inflatable space 3000s is defined by a fluid impermeable membrane which forms at least a portion of the wall 222s of the symmetric distal fluid inflatable support element 10s.

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Figure 51 illustrates in a longitudinal cross-section that the symmetric distal fluid inflatable support element has a maximum diameter circumference when inflated and that the outer wall 222s of the fluid inflated symmetric distal support element 10s is bowing longitudinally outward at least along the maximum diameter circumference of the inflated symmetric
5 distal support element.

The outer wall 222s of the symmetric distal fluid inflatable support element 10s has at least one outflow opening 20s. Preferably, the symmetric distal fluid inflatable support element 10s has a plurality of outflow openings 20s in its outer wall 222s. Each outflow opening 20s
10 in the outer wall 222s of the symmetric distal fluid inflatable support element 10s has its own axis M-M. Figure 51 illustrates that the symmetric distal fluid inflatable support element 10s when inflated has at least one outflow opening 20s in its outer wall 222s located such that the axis M-M of the outflow opening 20s forms an acute angle α of at least sixty (60) degrees with respect to the longitudinal axis W-W of the drive shaft 2. In the
15 second most preferred embodiment of the invention, the symmetric distal fluid inflatable support element 10s when inflated has at least one outflow opening 20s in its outer wall 222s located such that the axis M-M of the outflow opening 20s forms about a ninety (90) degrees angle β with respect to the longitudinal axis W-W of the drive shaft. Figures 52 through 55 illustrate that in the rotating symmetric fluid inflated distal support element 10s
20 at least one of the above described outflow openings 20s is located such that its axis M-M forms about a ninety (90) degrees angle with respect to the inner surface of the wall 300 of the treated vessel. Figures 52 through 55 also illustrate that in a curved vessel the drive shaft 2 attempts to maintain its straight configuration and therefore attempts to press a rotating symmetric distal fluid inflated support element 10s against the outer curvature of
25 the vessel but fluid exiting from the outflow opening 20s along its axis M-M at an angle of about ninety (90) degrees with respect to the wall 300 of the vessel forms a thin layer of fluid between the outer wall 222s of the fluid inflated distal support element 10s and the inner surface of the outer curvature of the wall 300 of the treated vessel.

30 Preferably, the fluid inflated symmetric distal support element 10s should have a plurality of outflow openings 20s located around the circumference of the outer wall 222s, the outflow openings 20s located in a longitudinally bowing outward segment of the outer wall 222s such that at any time during rotation of the drive shaft 2 at least one of these outflow

openings 20s is facing an inner surface of the treated vessel so that a flow of fluid through the outflow opening 20s forms a layer of fluid between the outer wall 222s of the rotating fluid inflated symmetric distal support element 10s and the wall 300 of the treated vessel. Said layer of fluid forms a fluid bearing between the outer wall 222s of the rotating fluid
5 inflated distal support element 10s and the wall 300 of the treated vessel.

It should be noted that in the second most preferred embodiments of the invention, the fluid impermeable drive shaft is provided with two symmetric fluid inflatable support elements, one located at the distal end of the drive shaft and the other proximal to and
10 spaced away from the abrasive element. Figures 50 and 51 illustrate the second most preferred embodiment of the invention in which the drive shaft 2 is provided with both a symmetric distal fluid inflatable support element 10s and a symmetric proximal fluid inflatable support element 10sp. The symmetric proximal fluid inflatable support element 10sp has an inner wall 111sp and an outer wall 222sp. In the preferred embodiment of the
15 invention, the outer wall 222sp of the symmetric proximal fluid inflatable support element 10sp is formed by the outer layer 22 of the folded fluid impermeable membrane 3. The inner wall 111sp of the symmetric proximal fluid inflatable support element 10sp is formed by the inner layer 11 of the folded fluid impermeable membrane 3. The inner wall 111sp of the symmetric proximal fluid inflatable support element 10sp has an inflow opening
20 (aperture) 15sp therein. This inflow opening (aperture) 15sp communicates the lumen of the fluid impermeable drive shaft 2 with an inflatable space 3000sp within the symmetric proximal fluid inflatable support element 10sp. The inflatable space 3000sp is at least partially defined by a fluid impermeable membrane which forms the outer wall 222sp of the symmetric proximal fluid inflatable support element 10sp. Figure 51 illustrates that a
25 portion of flushing fluid FF flowing in an antegrade direction along the drive shaft 2 is redirected through the inflow opening (aperture) 15sp into the symmetric proximal fluid inflatable support element 10sp to inflate said support element 10sp. Figure 51 illustrates best that in order to form the symmetric proximal fluid inflatable support element 10sp, the inner 11 and outer 22 layers of the folded fluid impermeable membrane 3 are
30 connected or bonded to each other at least just distal and proximal to the symmetric proximal fluid inflatable support element 10sp. In this location, just distal and proximal to the symmetric proximal fluid inflatable support element 10sp, the inner 11 and the outer 22

layers of the membrane 3 are preferably connected or bonded to each other around the entire circumference of the drive shaft 2.

5 The outer wall 222sp of the symmetric proximal fluid inflatable support element 10sp has at least one outflow opening 20sp. The symmetric proximal fluid inflatable support element 10sp preferably has a plurality of outflow openings 20sp in its outer wall 222sp. Each outflow opening 20sp in the outer wall 222sp of the symmetric proximal fluid inflatable support element 10sp has its own axis N-N. Figure 52 illustrates that the symmetric proximal fluid inflatable support element 10sp when inflated has at least one outflow opening 20sp in its outer wall 222sp located such that the axis N-N of the outflow opening 20sp forms an acute angle α of at least sixty (60) degrees with respect to the longitudinal axis W-W of the drive shaft. In the second most preferred embodiment of the invention, the symmetric proximal fluid inflatable support element 10sp when inflated has at least one outflow opening 20sp in its outer wall 222sp located such that the axis N-N of the outflow opening 20sp forms about a ninety (90) degrees angle β with respect to the longitudinal axis W-W of the drive shaft 2.

Figures 52 through 55 illustrate that in the rotating symmetric fluid inflated proximal support element 10sp at least one of the above described outflow openings 20sp is located such that its axis N-N forms about a ninety (90) degrees angle with respect to the inner surface of the wall 300 of the treated vessel. Figures 52 through 55 also illustrate that in a curved vessel the drive shaft 2 attempts to maintain its straight configuration and therefore attempts to press the rotating symmetric proximal fluid inflated support element 10sp against the outer curvature of the vessel but fluid exiting from the outflow opening 20sp along its axis N-N at an angle of about ninety (90) degrees with respect to the wall 300 of the vessel forms a thin layer of fluid between the outer wall 222sp of the fluid inflated proximal support element 10sp and an inner surface of the wall 300 of the vessel.

30 Preferably, the fluid inflated symmetric proximal support element 10sp should have a plurality of outflow openings 20sp spaced about equally around the circumference of the outer wall 222sp, the openings located such that at any time during rotation of the drive shaft 2 at least one of these outflow openings 20sp is facing an inner surface of the treated vessel so that a flow of fluid through the outflow opening 20sp forms a layer of fluid

between the outer wall 222sp of the rotating fluid inflated symmetric proximal support element 10sp and the wall 300 of the treated vessel. Said layer of fluid forms a fluid bearing between the outer wall 222sp of the rotating fluid inflated proximal support element 10sp and the wall 300 of the treated vessel.

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FIGURES 52 through 55 illustrate the formation of fluid bearings between the inner surface of the treated vessel and the outer walls of the rotating fluid inflated support elements, each of the support elements having fluid inflatable space which extends circumferentially around the entire circumference of the drive shaft so that, in a curved vessel said support elements are biasing the abrasive element towards the inner curvature of the curved vessel and allow preferential removal of stenotic tissue from the inner curvature of the treated curved vessel.

It should be noted that the rotational atherectomy device comprising symmetrical fluid inflatable support elements may also be used successfully in a straight vessel where said elements, when supported by fluid bearings, allow safe rotation of the drive shaft within the treated vessel even after the guidewire has been removed from the rotational atherectomy device. The rotational atherectomy device with symmetric fluid inflatable support elements preferably comprises either an eccentric abrasive element with a centre of mass spaced away from the longitudinal axis of the drive shaft or, an abrasive element which is capable of being magnetically biased in any direction with respect to the circumference of the treated vessel.

Figure 58 to 60 shows how the drive shaft 2 may comprise a radially inwardly extending shoulder 79 located at or just proximal to the distal end 6 of the drive shaft 2. In this embodiment, the device comprises a rounded element 80 configured to be advanced to a distal end 6 of the drive shaft 2 where it is prevented from exiting the drive shaft 2 by the radially inwardly extending shoulder 79, thereby occluding the distal end 6 of the drive shaft 2 to at least partially prevent flow of fluid through the distal end 6 of the drive shaft 2. The rounded element 80 together with the inwardly extending shoulder 79 act as a ball-valve which assists in the redirection of the flow of fluid into the fluid inflatable support elements. In one embodiment, shown in Figures 61 and 62, the radially inwardly extending shoulder is formed integrally with the distal end 55 of the inner torque transmitting coil 44.

Figure 63 illustrates the distal end portion of the drive shaft with an asymmetric fluid inflatable distal support element 10 and a solid asymmetric proximal support element 10p, the fluid inflatable element shown in its deflated state and, Figure 64 illustrates the distal end portion of the drive shaft with an asymmetric fluid inflatable distal support element 10 and a solid asymmetric proximal support element 10p, the fluid inflatable element shown in its inflated state.

It should be noted that the outer wall 222sp of the symmetric proximal fluid inflatable support element 10sp may be formed not only by a proximal portion of the outer layer 22 of the folded fluid impermeable membrane 3, but by another fluid impermeable membrane.

It should be noted that the distal end portion of the device which includes fluid inflatable support elements may be manufactured separately from the rest of the device using manufacturing methods such as injection moulding or insertion moulding.

It should be noted that a non-stretchable membrane should extend around the drive shaft between the fluid inflatable elements when such elements are formed from a fluid stretchable membrane.

It should be noted that any of the above discussions with respect to the configuration of the abrasive element and its attachment to the drive shaft with asymmetric fluid inflatable support element(s) are also relevant with respect to the drive shaft with symmetric fluid inflatable support element(s). The abrasive elements and their fixations to the drive shaft known from WO 2006/126076 and other sources, may be used with any of the above described embodiments of this invention.

Many modifications and variations falling within the terms of the following claims will be apparent to those skilled in the art and the foregoing description should be regarded as a description of the preferred embodiments only.

Claims

1. A rotational atherectomy device for removing a stenotic tissue from a vessel of a patient, the device comprising a rotatable, flexible, hollow drive shaft having a fluid
5 impermeable wall defining a fluid impermeable lumen of the drive shaft and, an abrasive element mounted to a distal end portion of the drive shaft proximal to and spaced away from a distal support element formed at a distal end of the drive shaft, the distal support element being inflatable by pressurized fluid which flows in an antegrade direction through said lumen of the drive shaft and is at least partially re-directed into the distal fluid
10 inflatable support element, wherein the distal fluid inflatable support element has an outer wall comprising an outflow opening located such that said outflow opening faces an inner surface of a treated vessel during rotation of the drive shaft so that a flow of fluid through said outflow opening forms a layer of fluid between the outer wall of the rotating fluid
15 inflated distal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel, the drive shaft being comprised of at least one fluid impermeable membrane and at least two torque transmitting coils, one of said coils extending distally beyond the distal end of the other coil and conveying torque to the abrasive element mounted to the drive shaft distal to and spaced away from a portion of the drive shaft
20 formed from the fluid impermeable membrane and said torque transmitting coils.
2. A rotational atherectomy device according to claim 1, wherein the outer wall of the distal fluid inflatable support element has a plurality of outflow openings located such that at least one of said outflow openings, during rotation of the drive shaft, faces an inner
25 surface of a treated vessel so that fluid flowing through the outflow openings forms a layer of fluid between the outer wall of the rotating fluid inflated distal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel.
- 30 3. A rotational atherectomy device according to claim 1, wherein the abrasive element has a slot and is mounted to the drive shaft such that said slot extends in a longitudinal direction and is attached to the drive shaft by a flexible strap which extends through said slot and is connected to the drive shaft distal and proximal to the abrasive element.

4. A rotational atherectomy device according to claim 1, wherein the abrasive element has a slot and is mounted to the drive shaft by a flexible strap which extends through said slot and is wrapped circumferentially around the drive shaft.

5

5. A rotational atherectomy device according to claim 1, wherein the abrasive element has a slot and is mounted to the drive shaft by a flexible strap which extends through said slot and is wrapped circumferentially around the drive shaft distal to and spaced away from the distal end of one of the torque transmitting coils.

10

6. A rotational atherectomy device according to claim 4 or claim 5, wherein the flexible strap has leading and trailing edge portions relative to the direction of rotation of the drive shaft, wherein the trailing edge portion of the flexible strap at least partially overlaps the leading edge portion when wrapped around the drive shaft.

15

7. A rotational atherectomy device according to claim 6, wherein the leading and trailing edge portions of the flexible strap are bonded to each other in their overlapping region.

20

8. A rotational atherectomy device according to claims 3, 4 or 5, wherein the abrasive element has a leading edge and a trailing edge relative to the direction of rotation of the drive shaft, the leading edge of the abrasive element being thinner than the trailing edge so that, during rotation of the drive shaft, an abrasive surface of the abrasive element engages and abrades stenotic tissue only by a thicker portion of the abrasive element, said thicker portion of the abrasive element being spaced away from the leading edge of the abrasive element.

25

9. A rotational atherectomy device according to claims 3, 4 or 5, wherein the abrasive element has a rotationally leading edge and a rotationally trailing edge relative to the direction of rotation of the drive shaft, the rotationally leading edge of the abrasive element being thinner than the trailing edge so that the degree of engagement of the abrasive element with the stenotic tissue gradually increases during a revolution of the drive shaft.

30

10. A rotational atherectomy device according to claims 1, 3, 4 or 5, wherein the abrasive element extends around less than a half of the circumference of the drive shaft.
11. A rotational atherectomy device according to claims 1, 3, 4 or 5, wherein the
5 abrasive element extends around less than a third of a circumference of the drive shaft.
12. A rotational atherectomy device according to claim 1, wherein the fluid impermeable drive shaft has a longitudinal axis and the distal fluid inflatable support element has a centre of mass offset from the longitudinal axis of the drive shaft when the
10 distal inflatable support element is fluid inflated.
13. A rotational atherectomy device according to claim 1, wherein the outer wall of the distal fluid inflatable support element defines a fluid inflatable space that extends only partially around a circumference of the drive shaft so that, when the distal inflatable
15 support element is fluid inflated, its centre of mass is offset from a longitudinal axis of the drive shaft in one direction, the distal fluid inflated support element acting, during rotation of the drive shaft, as a counterweight to the abrasive element which has its centre of mass offset from the longitudinal axis of the drive shaft in the opposite direction.
- 20 14. A rotational atherectomy device according to claim 1, wherein the fluid impermeable drive shaft is provided with a proximal fluid inflatable support element located proximal to and spaced away from the abrasive element, the proximal fluid inflatable support element having an outer wall.
- 25 15. A rotational atherectomy device according to claim 14, wherein the proximal fluid inflatable support element comprises an inner wall having an aperture therein so that a portion of fluid flowing in an antegrade direction through the drive shaft is re-directed through the aperture into the inflatable support element to inflate said proximal fluid inflatable support element.
- 30 16. A rotational atherectomy device according to claim 14 or claim 15, wherein the fluid impermeable drive shaft has a longitudinal axis and the proximal fluid inflatable

support element has a centre of mass offset from the longitudinal axis of the drive shaft when the proximal inflatable support element is fluid inflated.

17. A rotational atherectomy device according to any of claims 14 to 16, wherein the
5 outer wall of the proximal inflatable support element comprises an outflow opening located such that said outflow opening faces an inner surface of a treated vessel during rotation of the drive shaft so that a flow of fluid through said outflow opening forms a layer of fluid between the outer wall of the rotating fluid inflated proximal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the
10 rotating fluid inflated proximal support element and the wall of the treated vessel.

18. A rotational atherectomy device according to any of claims 14 to 17, wherein the outer wall of the proximal fluid inflatable support element has a plurality of outflow openings located such that at least one of said outflow openings, during rotation of the
15 drive shaft, faces an inner surface of a treated vessel so that fluid flowing through the outflow openings forms a layer of fluid between the outer wall of the rotating fluid inflated proximal support element and a wall of the treated vessel to form a fluid bearing between the outer wall of the rotating fluid inflated proximal support element and the wall of the treated vessel.

20 19. A rotational atherectomy device according to claim 14, wherein the outer wall of the proximal fluid inflatable support element defines a fluid inflatable space that extends only partially around a circumference of the drive shaft so that, when the proximal inflatable support element is fluid inflated, its centre of mass is offset from a longitudinal axis of the drive shaft in one direction, the proximal fluid inflated support element acting,
25 during rotation of the drive shaft, as a counterweight to the abrasive element which has its centre of mass offset from the longitudinal axis of the drive shaft in the opposite direction.

20. A rotational atherectomy device according to claim 14, wherein the fluid inflatable
30 space within both the distal and proximal fluid inflatable support elements extends circumferentially only partially around circumferential segments of the drive shaft which are spaced away in one direction with respect to the longitudinal axis of the drive shaft so that, when both the distal and proximal fluid inflatable support elements are inflated by fluid,

their centers of mass become offset from a longitudinal axis of the drive shaft in said one direction and the distal and proximal fluid inflatable support elements act as counterweights to the abrasive element which is located on the drive shaft between the support elements and has its centre of mass offset from the longitudinal axis of the drive shaft in the opposite direction.

21. A rotational atherectomy device according to claim 1, wherein a fluid inflatable space within the distal fluid inflatable support element extends uniformly around an entire circumference of the drive shaft to provide the distal support element with a centre of mass which is coaxial with a longitudinal axis of the drive shaft when said distal support element is fluid inflated.

22. A rotational atherectomy device according to claim 21, wherein there is a plurality of openings in the outer wall of the fluid inflatable distal support element, said openings being located around the circumference of the outer wall of the fluid inflatable distal support element such that, during rotation of the drive shaft, flows of fluid through the openings form a layer of fluid between the outer wall of the fluid inflated distal support element and a wall of the treated vessel, said layer of fluid forming a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel.

23. A rotational atherectomy device according to claim 21, wherein there is a plurality of openings in the outer wall of the fluid inflatable distal support element, said openings being located around the circumference of the outer wall of the fluid inflatable distal support element such that, during rotation of the drive shaft, at least one of said openings faces an inner surface of a treated vessel, so that flows of fluid through the openings form a layer of fluid between the outer wall of the fluid inflated distal support element and a wall of the treated vessel, said layer of fluid forming a fluid bearing between the outer wall of the rotating fluid inflated distal support element and the wall of the treated vessel.

24. A rotational atherectomy device according to claim 14, wherein a fluid inflatable space within the proximal fluid inflatable support element extends uniformly around an

entire circumference of the drive shaft to provide a fluid inflated proximal support element with a centre of mass which is coaxial with a longitudinal axis of the drive shaft.

25. A rotational atherectomy device according to claim 24, wherein there is a plurality
5 of openings in the outer wall of the fluid inflatable proximal support element, said
openings being located around the circumference of the outer wall of the fluid inflatable
proximal support element such that, during rotation of the drive shaft, flows of fluid
through the openings form a layer of fluid between the outer wall of the fluid inflated
proximal support element and a wall of the treated vessel, said layer of fluid forming a fluid
10 bearing between the outer wall of the rotating fluid inflated proximal support element and
the wall of the treated vessel.

26. A rotational atherectomy device according to claim 24, wherein there is a plurality
of openings in the outer wall of the fluid inflatable proximal support element, said
15 openings being located around the circumference of the outer wall of the fluid inflatable
proximal support element such that, during rotation of the drive shaft, at least one of said
openings is facing an inner surface of a treated vessel so that flows of fluid through the
openings form a layer of fluid between the outer wall of the fluid inflated proximal support
element and a wall of the treated vessel, said layer of fluid forming a fluid bearing between
20 the outer wall of the rotating fluid inflated proximal support element and the wall of the
treated vessel.

27. A rotational atherectomy device according to claim 1, wherein the fluid
impermeable membrane extends distally under and beyond the abrasive element and is
25 folded on itself at a distal end of the drive shaft to form the distal fluid inflatable support
element between an inner and outer layers of said folded membrane, the outer layer of the
membrane forming an outer wall of the distal fluid inflatable support element and the inner
layer of the membrane forming an inner wall of the distal fluid inflatable support element,
the inner wall of the inflatable support element having an aperture therein so that a portion
30 of fluid flowing in an antegrade direction through the drive shaft is re-directed through the
aperture into the distal fluid inflatable support element to inflate said distal support
element.

28. A rotational atherectomy device according to claim 27, wherein the inner and outer layers of the folded fluid impermeable membrane are connected or bonded to each other at least just proximal to the distal fluid inflatable support element.

5 29. A rotational atherectomy device according to claim 28, wherein the inner and outer layers of the folded fluid impermeable membrane are connected or bonded to each other around an entire circumference of the drive shaft.

30. A rotational atherectomy device according to claim 29, wherein the outer layer of
10 the folded fluid impermeable membrane, after forming the outer wall of the distal fluid inflatable support element, extends further proximally to form an outer wall of the proximal fluid inflatable support element.

31. A rotational atherectomy device according to claim 30, wherein the inner and outer
15 layers of the folded fluid impermeable membrane are connected or bonded to each other at least just distal and proximal to the proximal fluid inflatable support element.

32. A rotational atherectomy device according to claim 31, wherein the inner and outer
20 layers of the folded fluid impermeable membrane are connected or bonded to each other around an entire circumference of the drive shaft.

33. A rotational atherectomy device according to claim 31, wherein the proximal fluid inflatable support element has an inner wall defined by the inner layer of the fluid impermeable membrane, the inner wall having an aperture therein so that a portion of the
25 fluid flowing in an antegrade direction through the drive shaft is redirected through the aperture into the proximal fluid inflatable support element to inflate said proximal support element.

34. A rotational atherectomy device according to claim 1 or claim 29, wherein the
30 aperture through which fluid enters the distal inflatable support element and the opening(s) in the outer wall of the inflated distal inflatable support element through which fluid exits the distal inflatable support element are configured so that the distal inflatable support

element is kept inflated by the pressure of the fluid flowing through the inflatable support element

35. A rotational atherectomy device according to claim 34, wherein the aperture
5 through which fluid enters the distal inflatable support element is larger than the opening(s) in the outer wall of the inflated distal inflatable support element through which fluid exits the distal inflatable support element so that the distal inflatable support element is kept inflated by the pressure of the fluid flowing through the inflatable support element.

10 36. A rotational atherectomy device according to claim 29, wherein the abrasive element has a slot and is mounted to the drive shaft by a flexible strap which extends through said slot and is wrapped around the membrane proximal to and spaced away from the distal fluid inflatable support element.

15 37. A rotational atherectomy device according to claim 36, wherein the flexible strap is wrapped around the membrane distal to and spaced away from a portion of the drive shaft which is formed by the fluid impermeable membrane and the torque transmitting coils.

38. A rotational atherectomy device according to claim 36 or claim 37, wherein the
20 flexible strap is wrapped around the outer layer of the folded fluid impermeable membrane.

39. A rotational atherectomy device according to claim 29, wherein the abrasive element has a slot and is mounted to the drive shaft such that said slot extends in a longitudinal direction and is attached to the fluid impermeable membrane by a flexible
25 strap which extends through said slot and is connected to the drive shaft distal and proximal to the abrasive element.

40. A rotational atherectomy device according to claim 39, wherein the outer layer of the folded fluid impermeable membrane, after forming the outer wall of the distal fluid
30 inflatable support element, extends further proximally to form an outer wall of the proximal fluid inflatable support element, wherein the flexible strap, which mounts the abrasive element to the drive shaft, extends between the inner and outer layers of the folded fluid impermeable membrane both distal and proximal to the abrasive element.

41. A rotational atherectomy device according to claim 40, wherein the outer layer of the folded fluid impermeable membrane has an opening through which an abrasive surface of the abrasive element at least partially protrudes above a surface of the outer layer of the folded fluid impermeable membrane.

42. A rotational atherectomy device according to claim 1, wherein the torque transmitting coils are disposed coaxially with respect to each other, one of two coils being an inner torque transmitting coil and the other torque transmitting coil being an outer torque transmitting coil, the inner and the outer torque transmitting coils being wound in opposite directions so that, when the drive shaft is rotated, the outer torque transmitting coil prevents unwinding of the inner torque transmitting coil.

43. A rotational atherectomy device according to claim 42, wherein the fluid impermeable membrane lines the inner torque transmitting coil.

44. A rotational atherectomy device according to claim 1 or claim 42, wherein the fluid impermeable membrane is disposed around the torque transmitting coils.

45. A rotational atherectomy device according to claim 1 or 42, wherein the fluid impermeable membrane is sandwiched between the torque transmitting coils.

46. A rotational atherectomy device according to claims 1 or 29, wherein the abrasive element extends around the entire circumference of the drive shaft.

47. A rotational atherectomy device according to any preceding claim, wherein the drive shaft comprises a radially inwardly extending shoulder located at or just proximal to the distal end of the drive shaft.

48. A rotational atherectomy device according to claim 47, comprising a rounded element configured to be advanced to a distal end of the drive shaft where it is prevented from exiting the drive shaft by the radially inwardly extending shoulder, thereby occluding

the distal end of the drive shaft and thereby at least partially preventing flow of fluid through the very distal end of the drive shaft and assisting in the redirection of the flow of fluid into the fluid inflatable support elements.

5 49. A rotational atherectomy device according to claim 47 or 48, wherein the radially inwardly extending shoulder is formed integrally with a distal end of the inner torque transmitting coil.

50. A rotational atherectomy device for removing a stenotic tissue from a vessel of a
10 patient, the device comprising an abrasive element mounted to a rotatable, flexible, hollow, drive shaft, the drive shaft comprised by a fluid impermeable membrane and two coaxially disposed torque transmitting coils, the membrane and one of two coils extending distally beyond the abrasive element which is attached to the membrane distal to a distal end of the other torque transmitting coil and proximal to and spaced away from a distal fluid inflatable
15 support element formed by said fluid impermeable membrane at a distal end of the drive shaft, the distal fluid inflatable support element including at least two openings, an inflow opening communicating a fluid impermeable lumen of the drive shaft with an inflatable space of the distal fluid inflatable support element and an outflow opening located in an outer wall of the distal fluid inflatable support element and communicating the interior
20 space of the distal fluid inflatable support element with a vascular space within the vessel of the patient, said outflow opening having an axis which forms an angle of about ninety (90) degrees with a longitudinal axis of the drive shaft when the distal fluid inflatable support element is inflated.

25 51. A rotational atherectomy device for removing a stenotic tissue from a vessel of a patient, the device comprising an abrasive element mounted to a rotatable, flexible, hollow drive shaft, the drive shaft comprised by a fluid impermeable membrane sandwiched between inner and outer torque transmitting coils, the inner torque transmitting coils and the membrane extending distally beyond the abrasive element which is attached to the
30 membrane distal to a distal end of the outer torque transmitting coil and proximal to and spaced away from a distal fluid inflatable support element formed by said fluid impermeable membrane at a distal end of the drive shaft, the distal fluid inflatable support element including at least two openings, an inflow opening communicating a fluid

impermeable lumen of the drive shaft with an inflatable space of the distal fluid inflatable support element and an outflow opening located in an outer wall of the distal fluid inflatable support element and communicating the interior space of the distal fluid inflatable support element with a vascular space within the vessel of a patient, said outflow
5 opening having an axis which forms an angle of about ninety (90) degrees with a longitudinal axis of the drive shaft when the distal fluid inflatable support element is inflated, so that in a rotating fluid inflated distal support element a flow of fluid through the outflow opening forms a thin layer of fluid between the outer wall of the fluid inflated distal support element and an inner surface of a wall of the vessel which is being treated.

10

52. A rotational atherectomy device according to claim 1, wherein the drive shaft is provided with a solid proximal support element located proximal to and spaced away from the abrasive element, the membrane that forms a fluid impermeable lumen for the
15 antegrade flow of fluid through the drive shaft into the distal fluid inflatable support element also forming a lumen for the antegrade flow of fluid through the drive shaft into an outflow channel extending through said solid proximal support element, the solid proximal support element having a rounded outer surface, said outflow channel having an outflow opening in the rounded outer surface of the solid proximal support element such
20 that, during rotation of the drive shaft, said outflow opening on the outer surface of the solid proximal support element is facing an inner surface of a treated vessel so that a flow of fluid out of said outflow opening forms a layer of fluid between the solid proximal support element and a wall of the treated vessel during rotation of the drive shaft, said layer of fluid forming a fluid bearing between the rotating solid proximal support element and
25 the wall of the treated vessel.

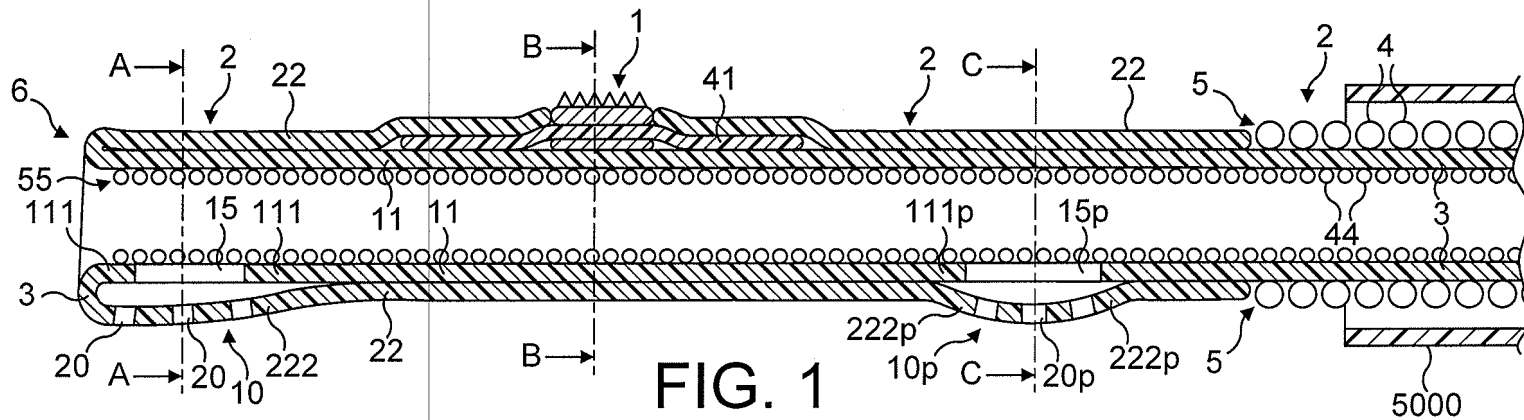


FIG. 1

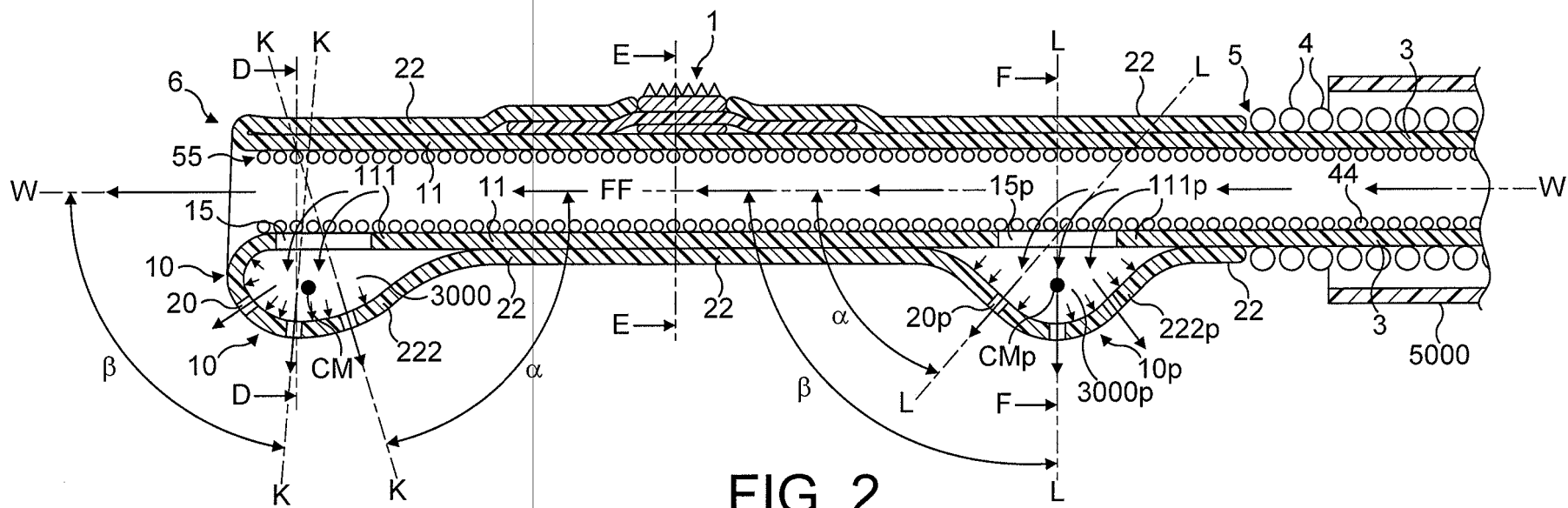


FIG. 2

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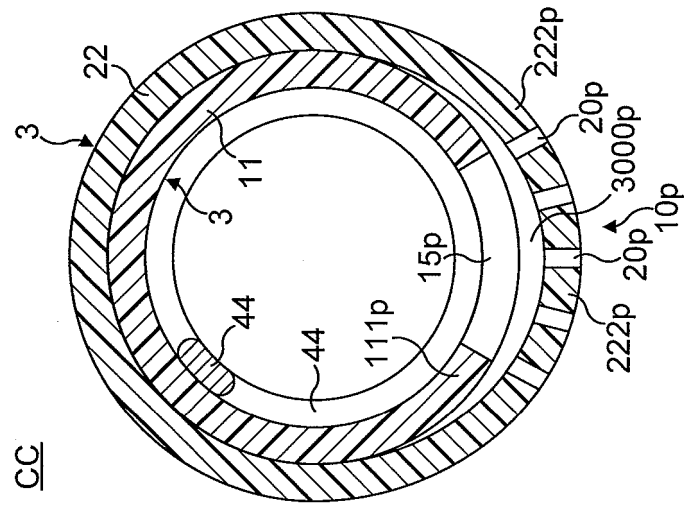


FIG. 5

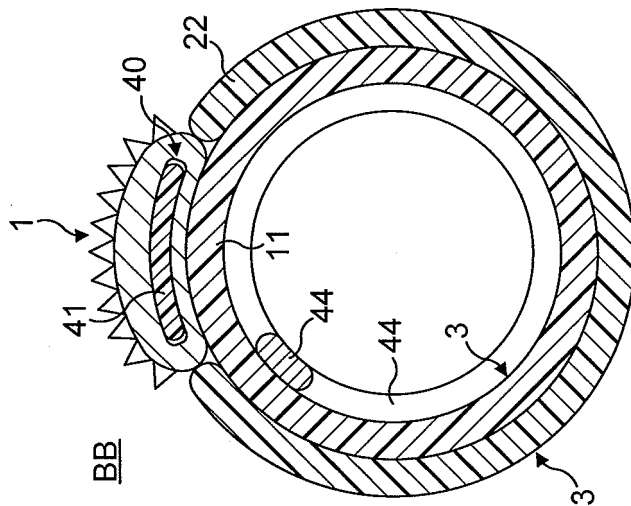


FIG. 4

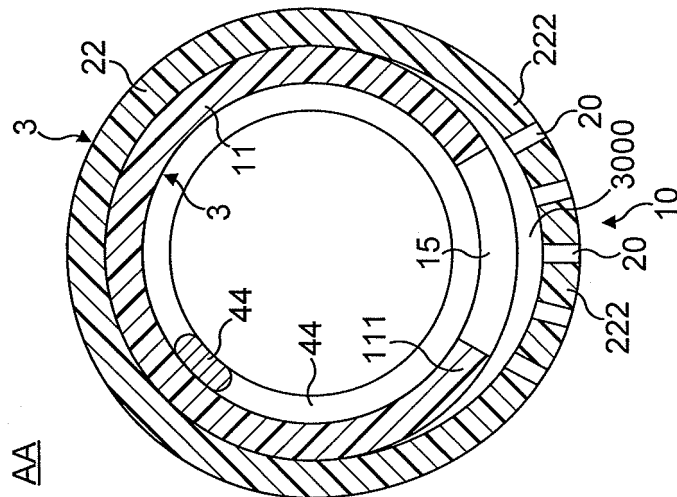


FIG. 3

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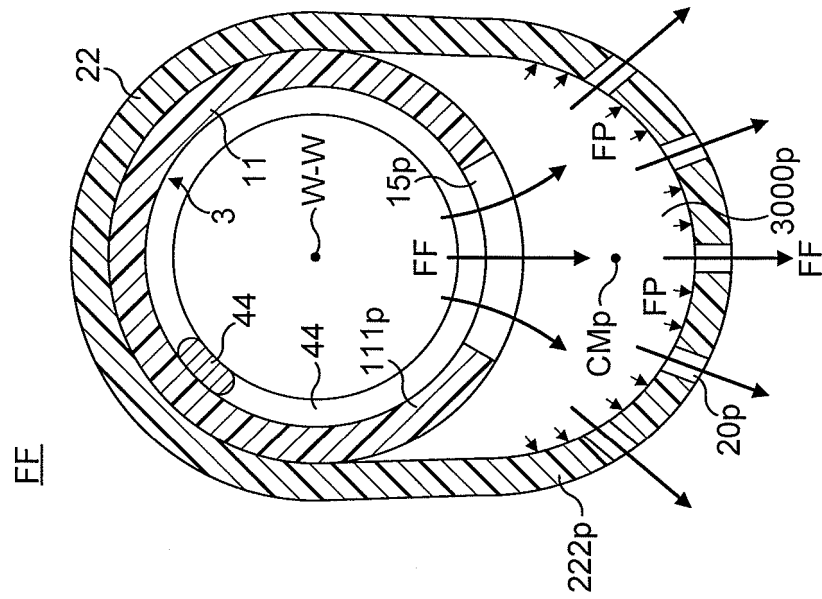


FIG. 8

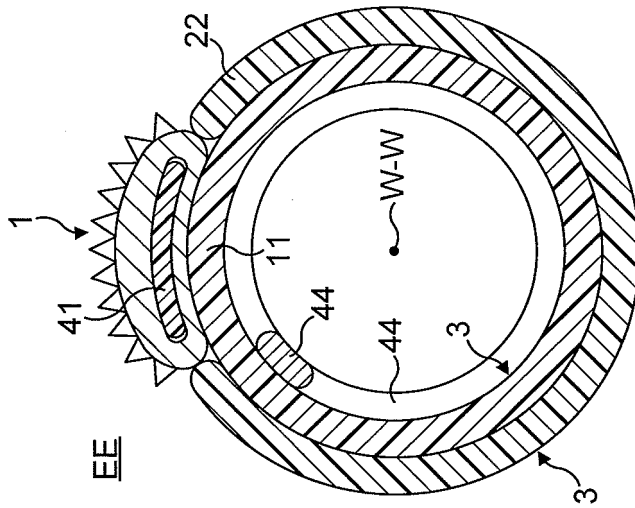


FIG. 7

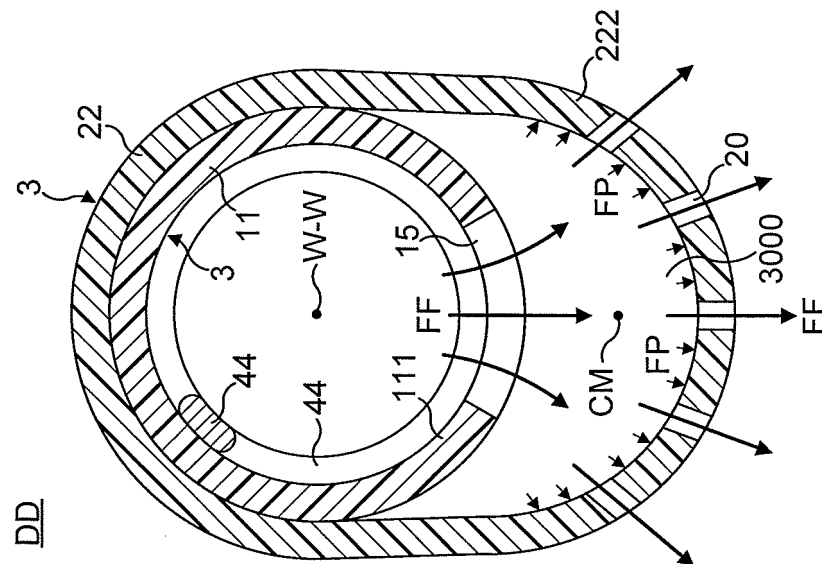


FIG. 6

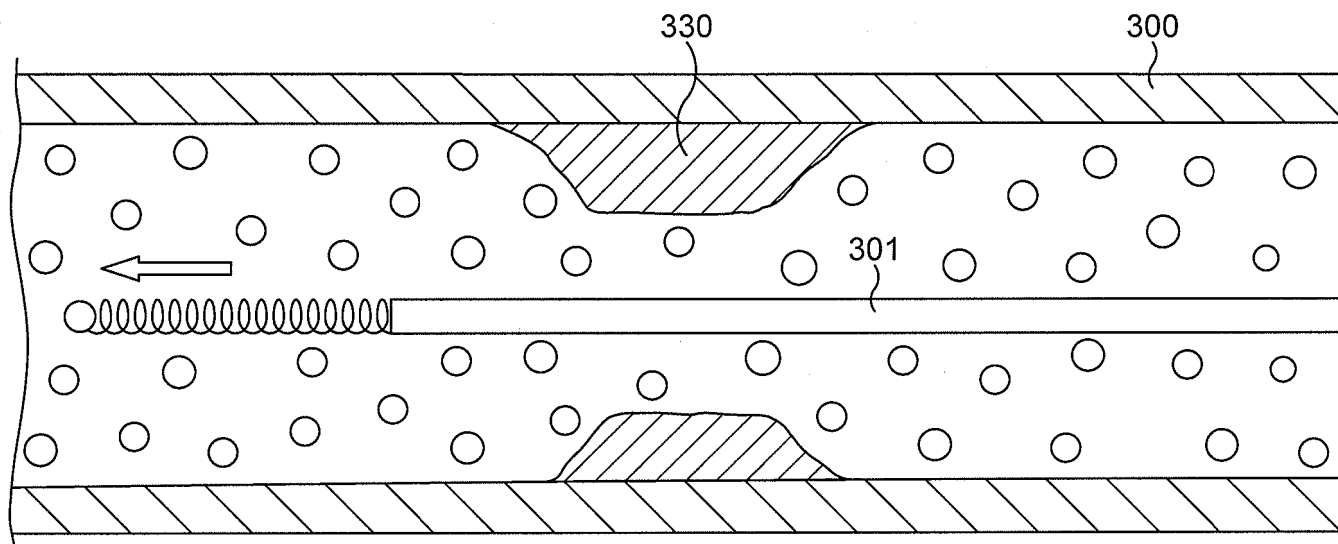


FIG. 9

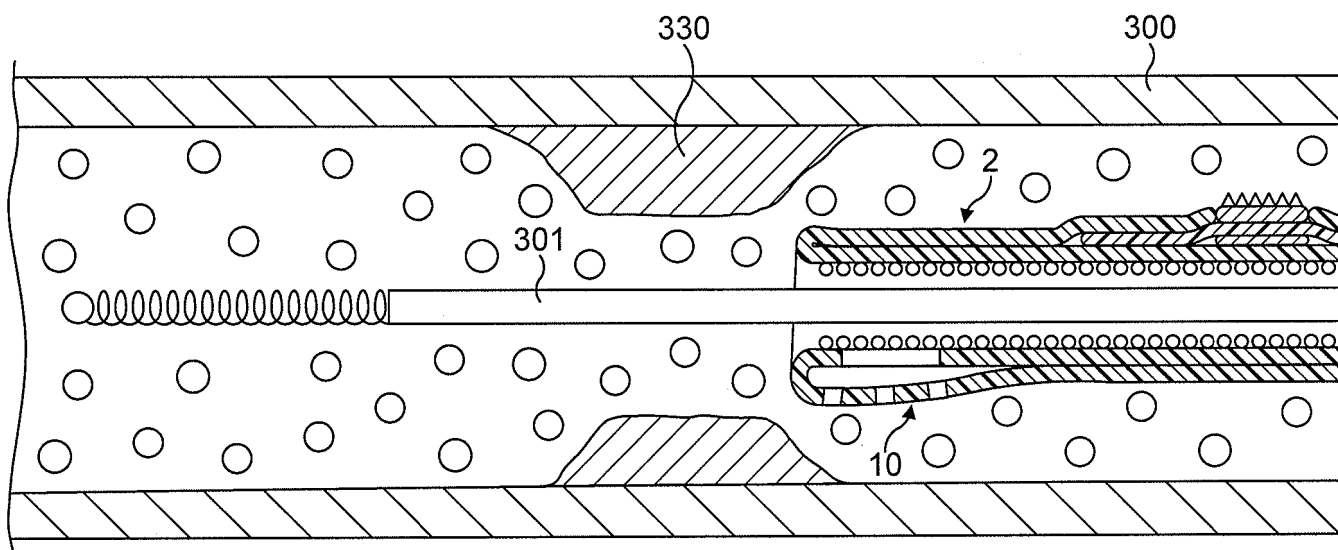


FIG. 10

← DM

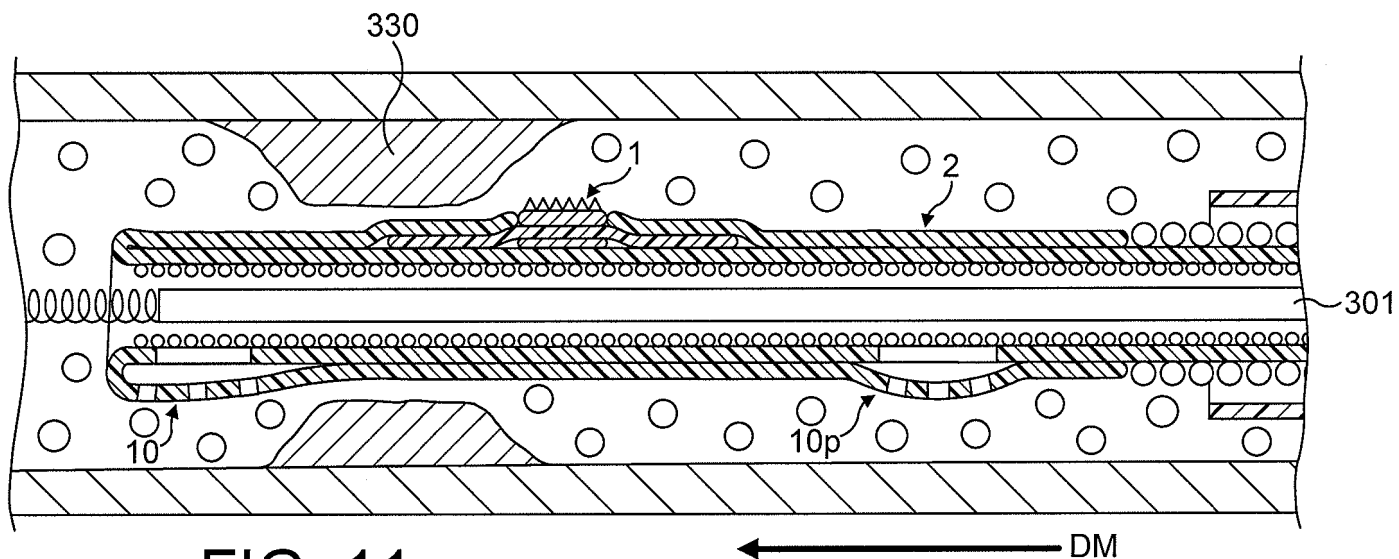


FIG. 11

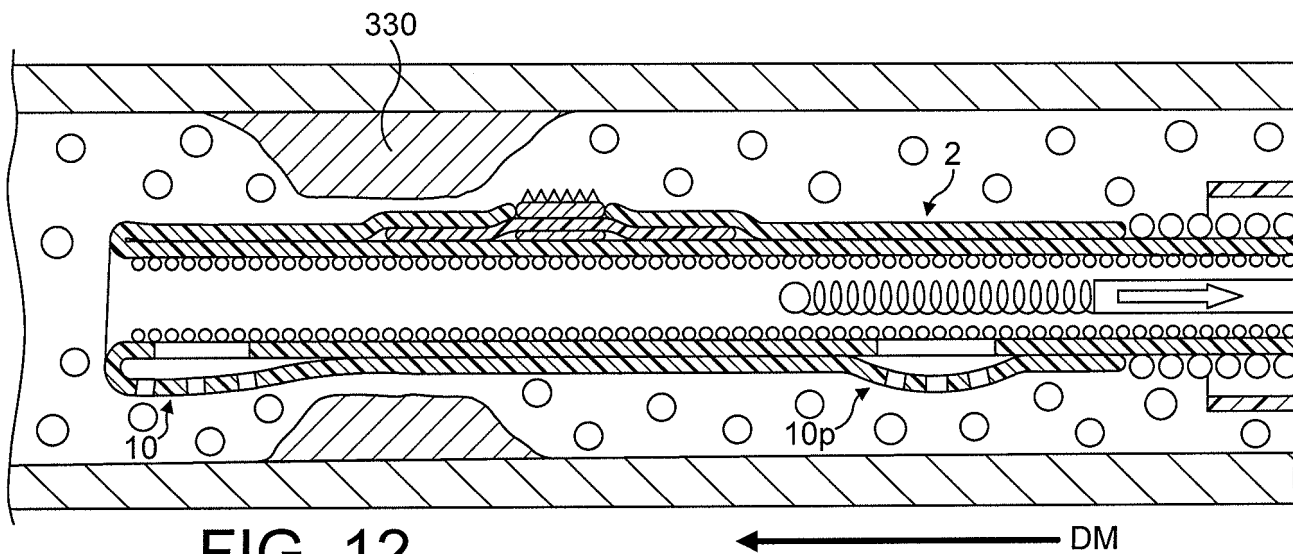


FIG. 12

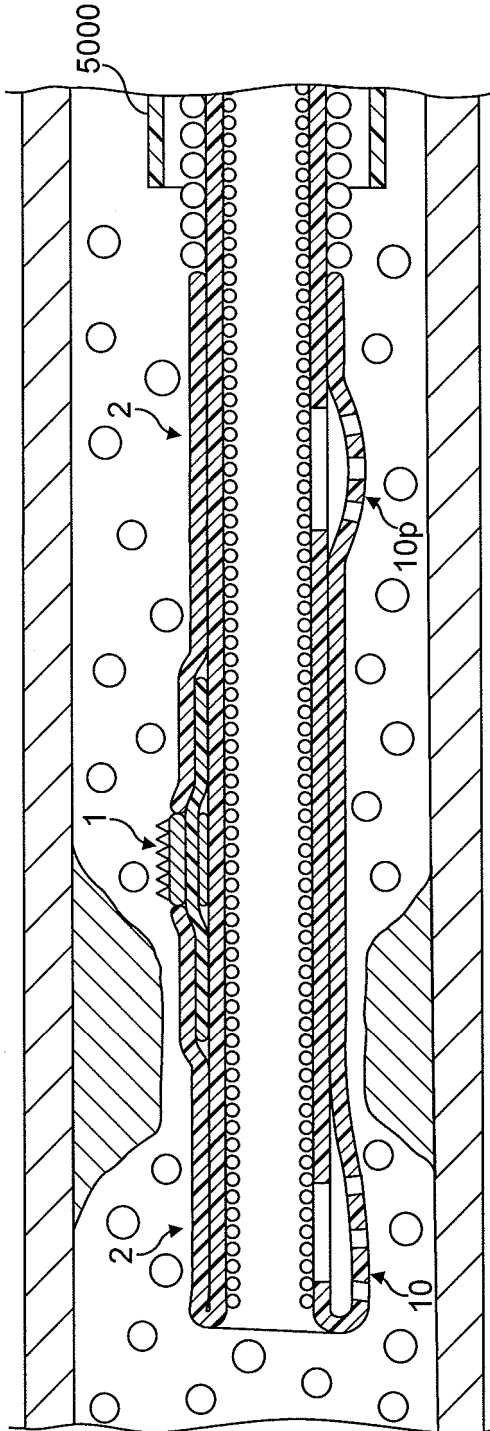


FIG. 13

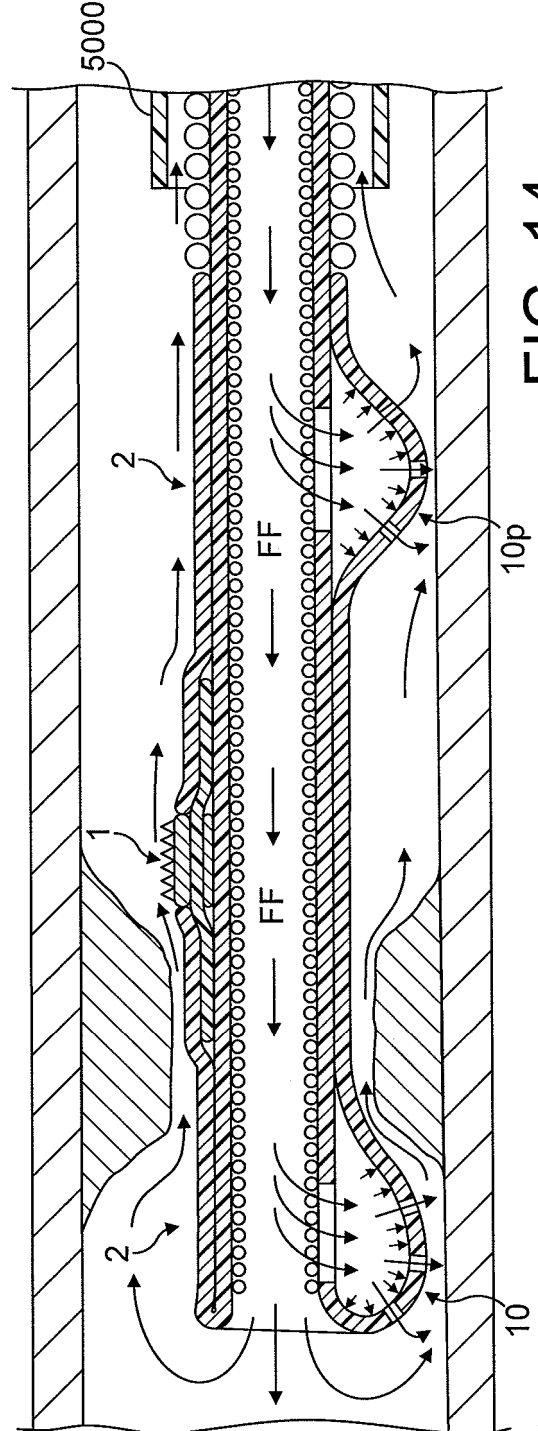
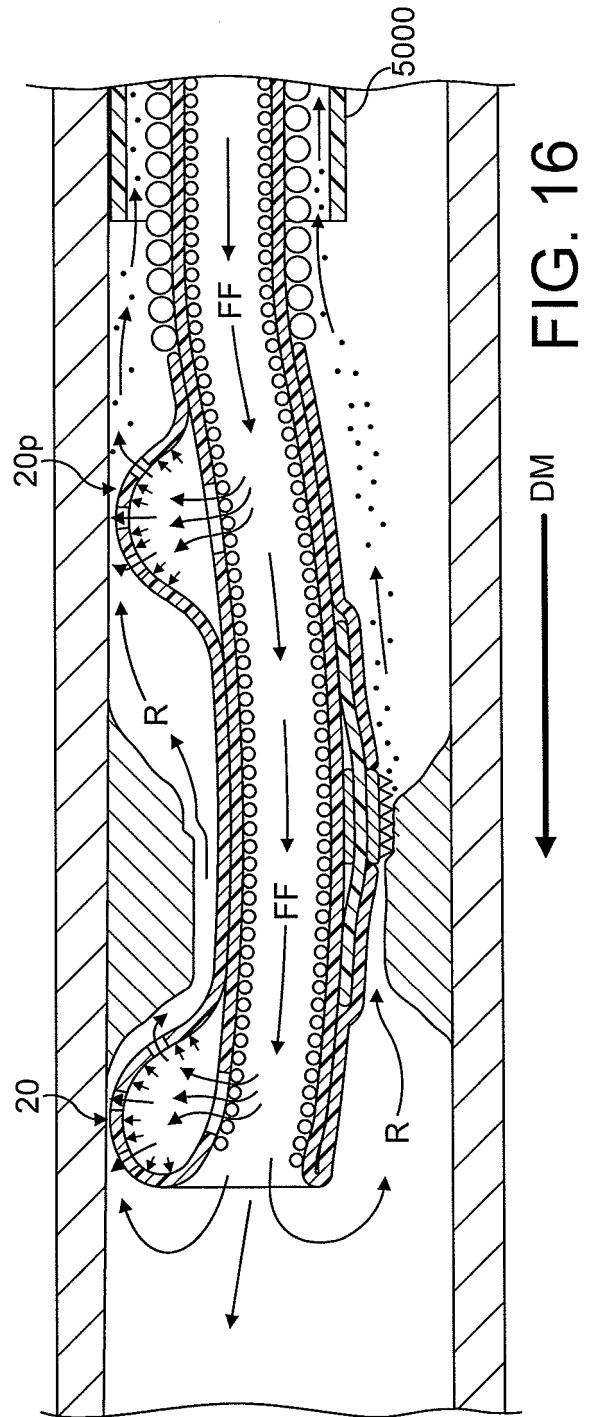
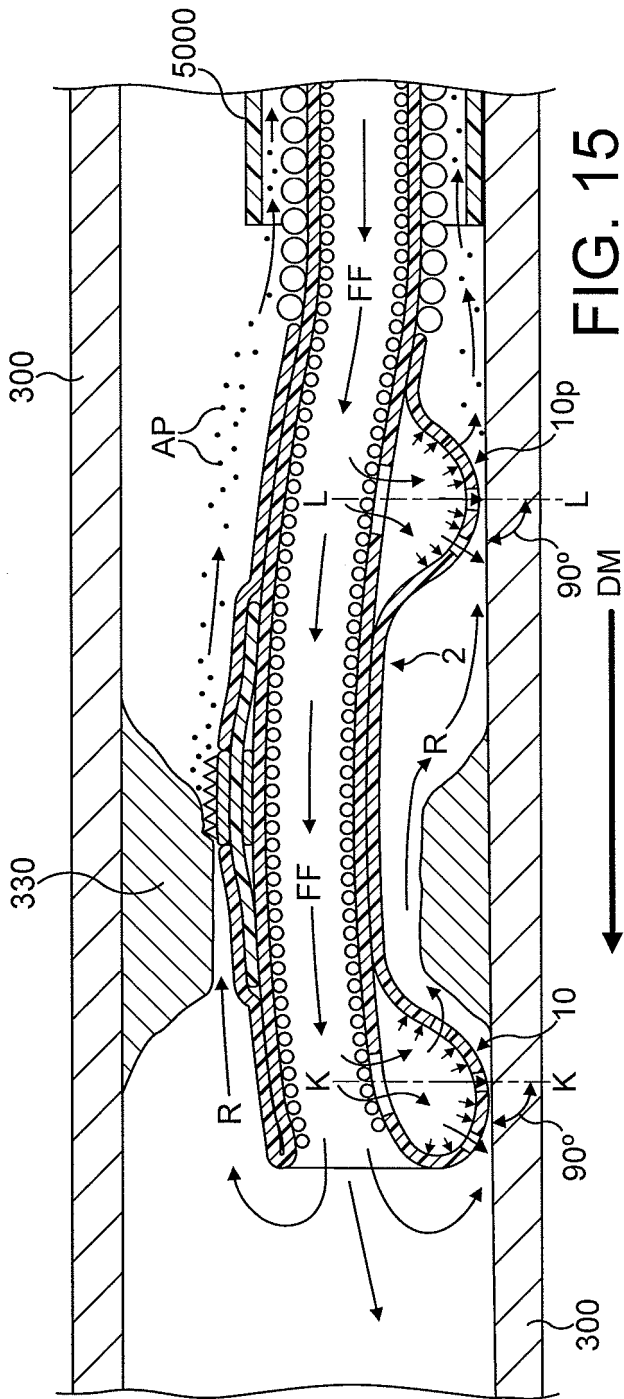
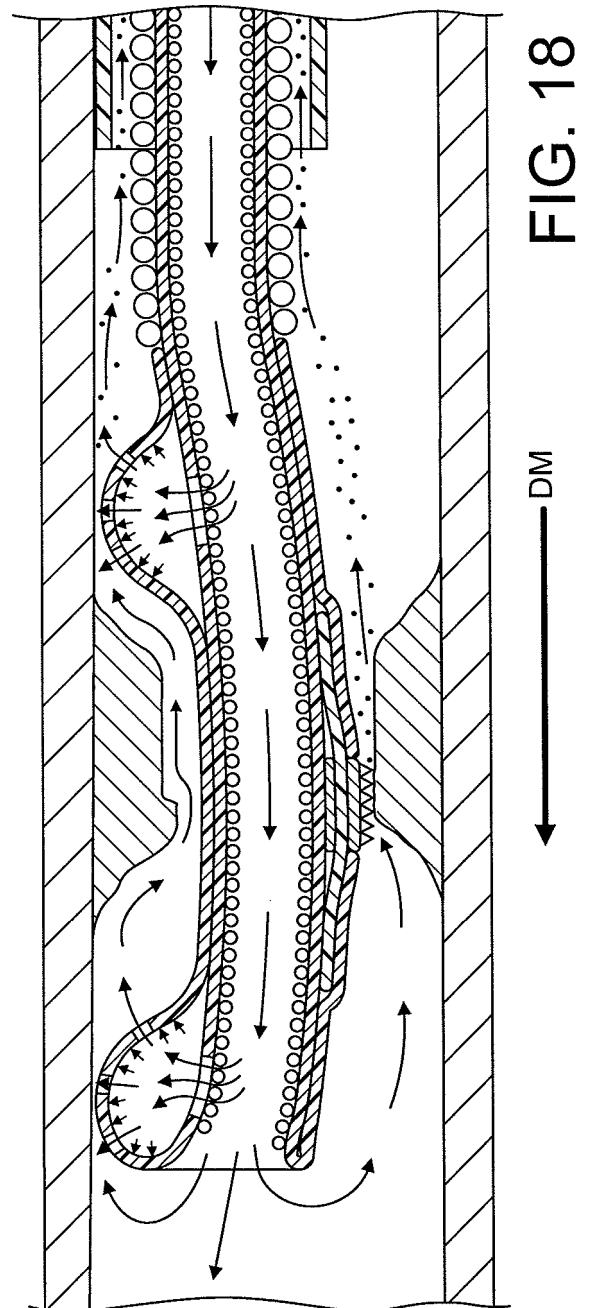
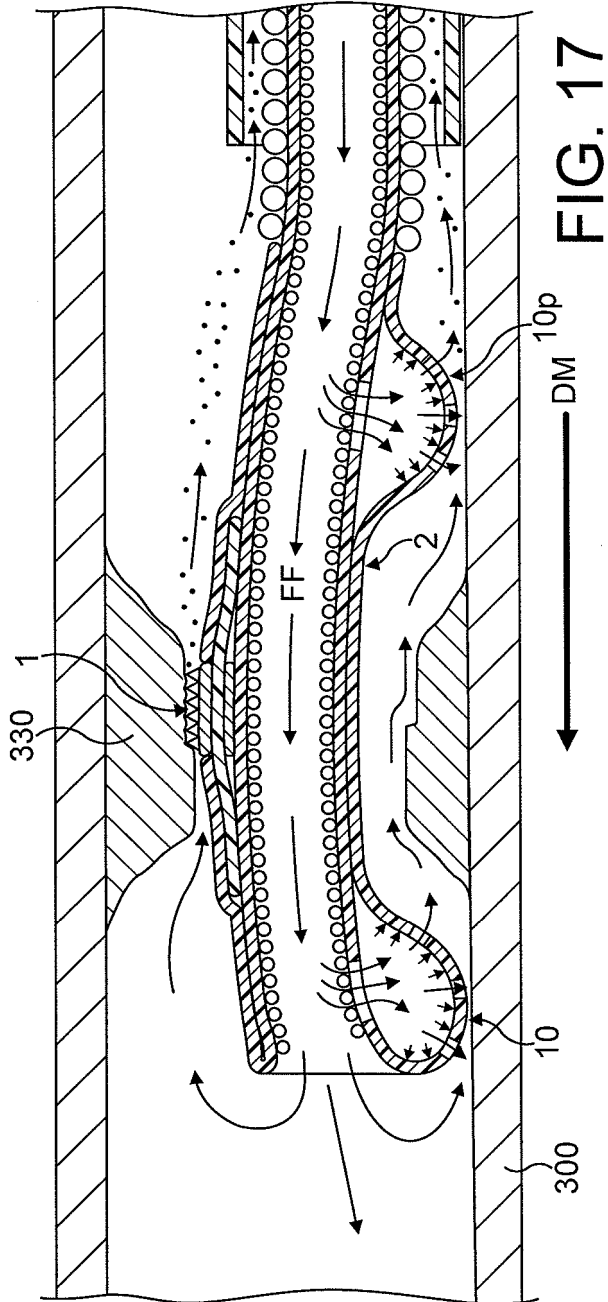
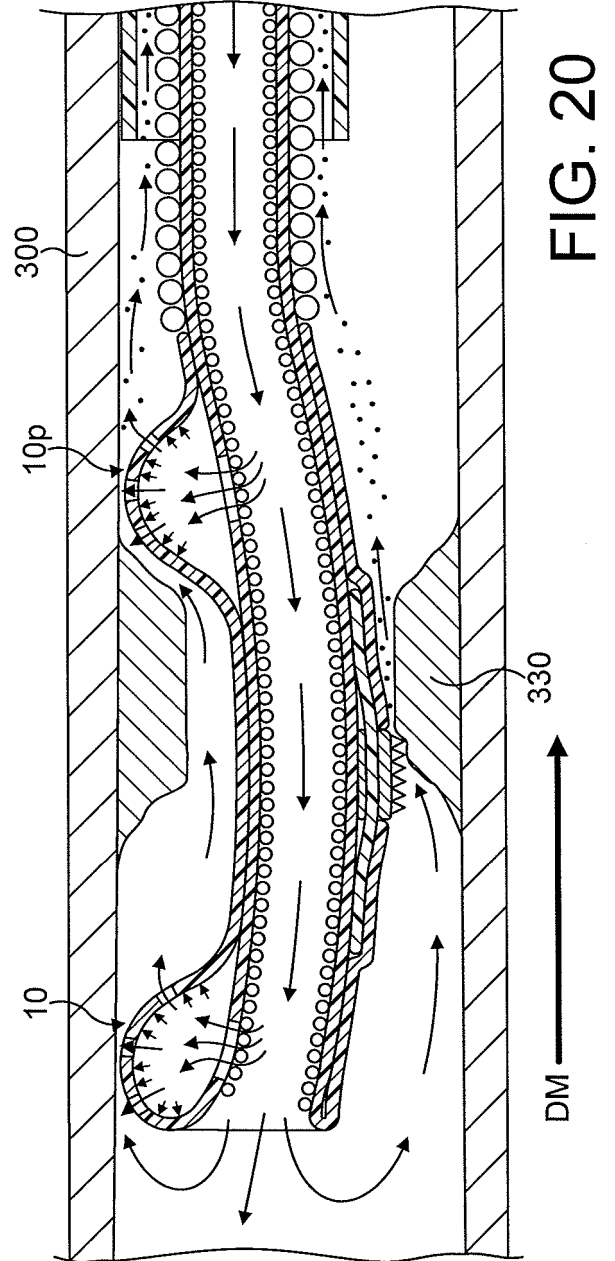
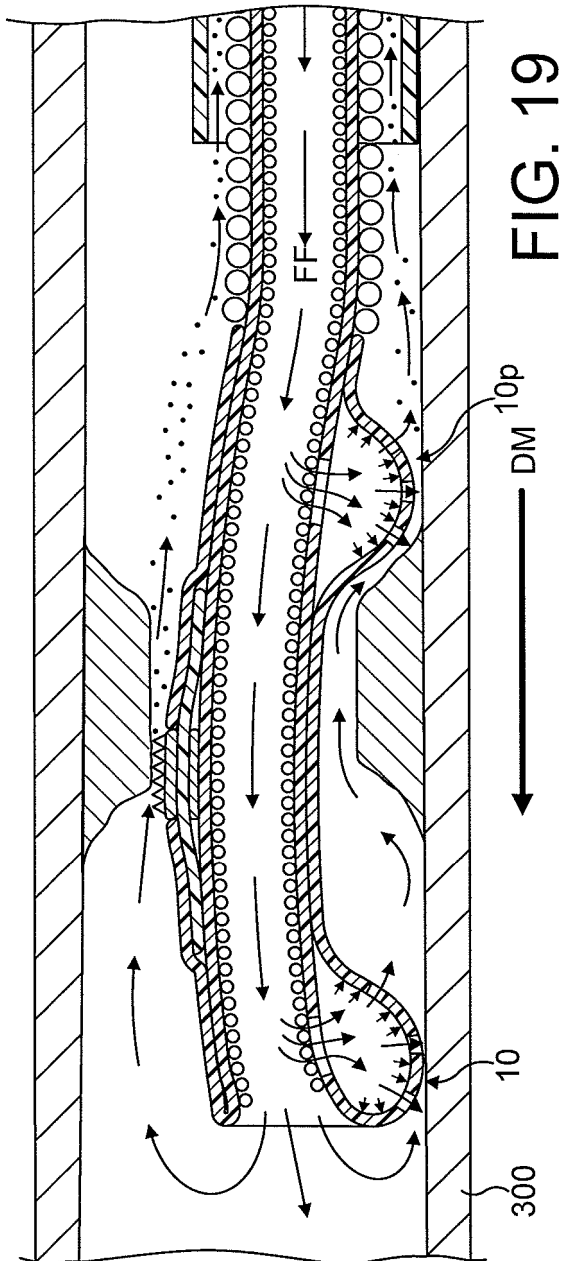
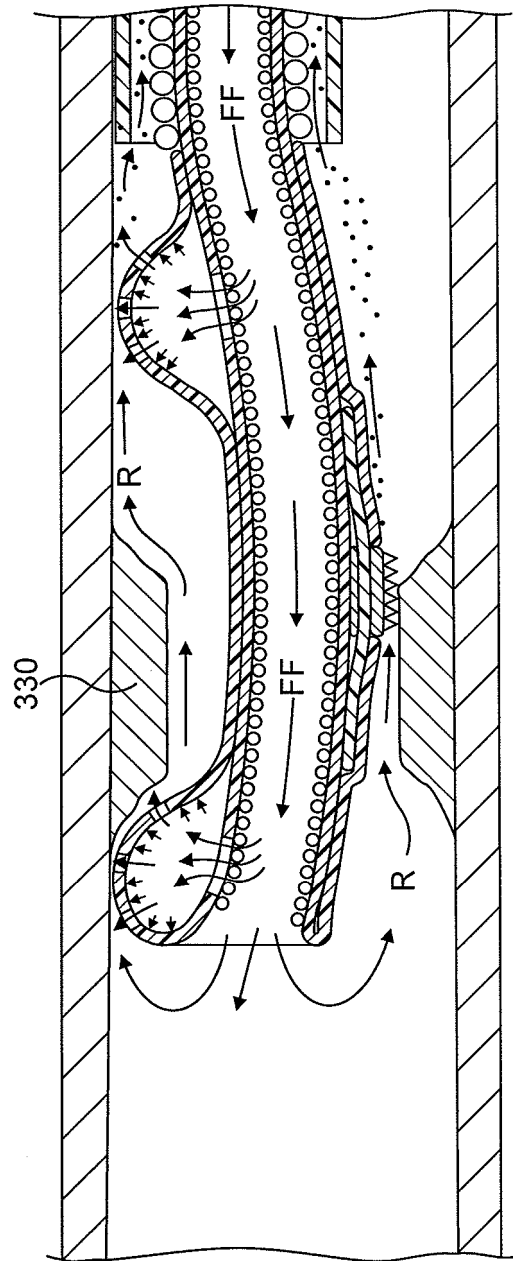
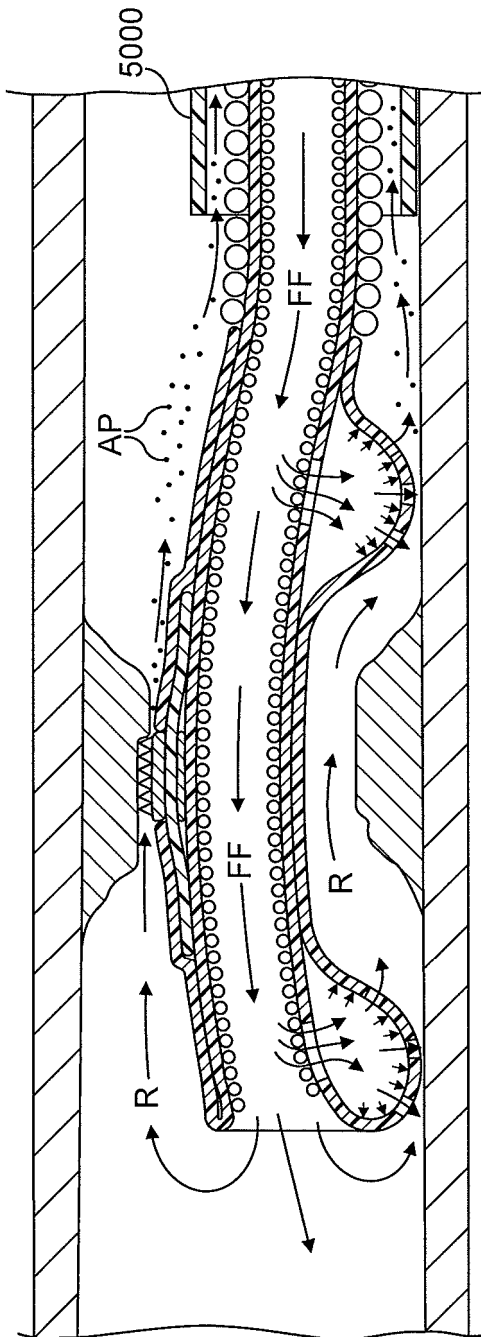


FIG. 14









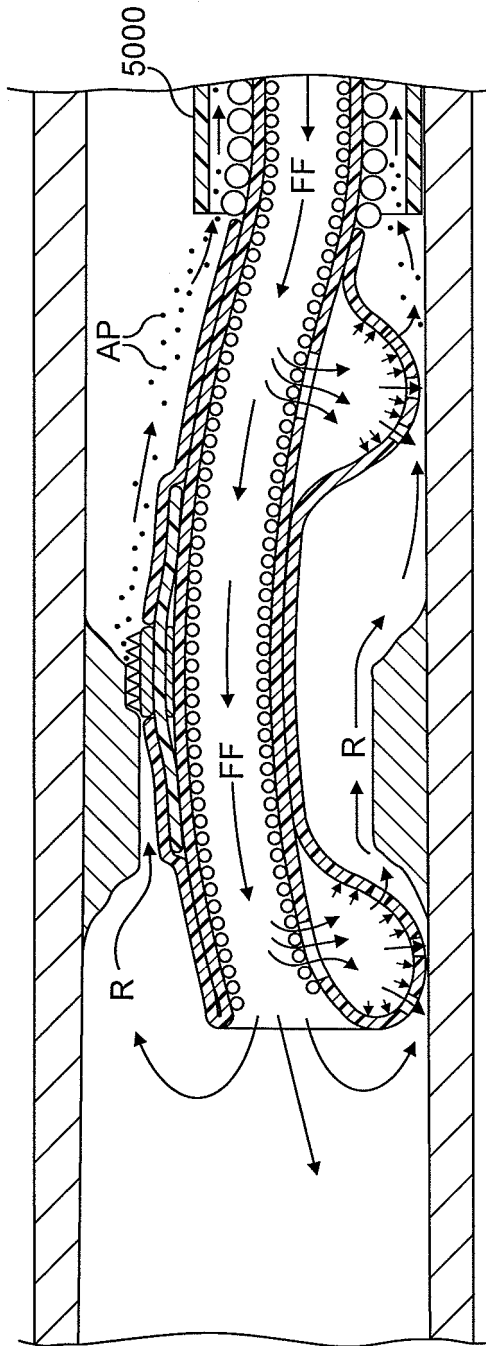


FIG. 23

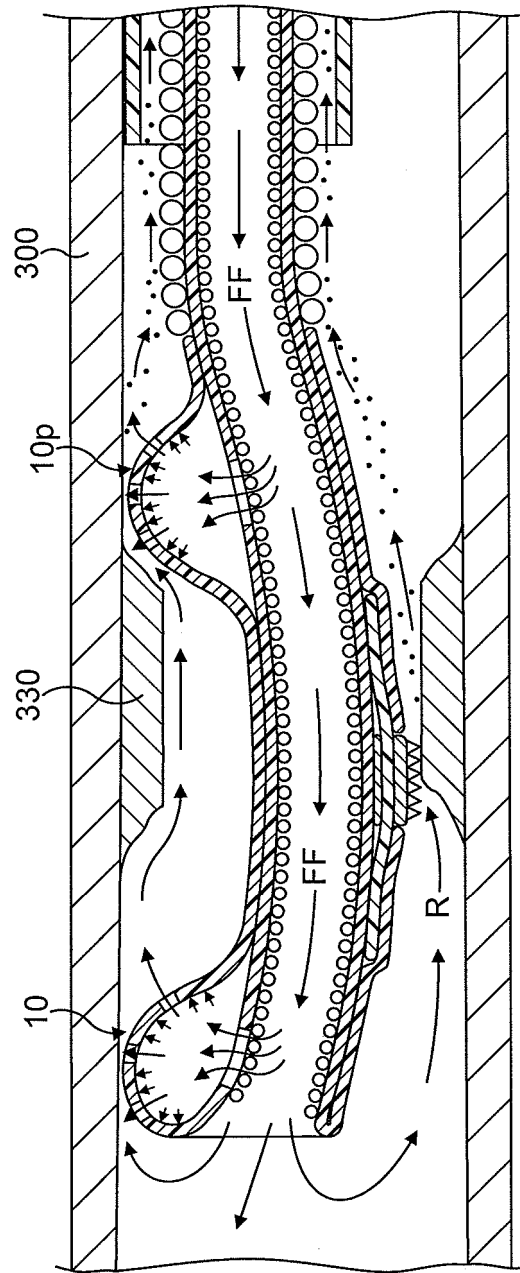


FIG. 24

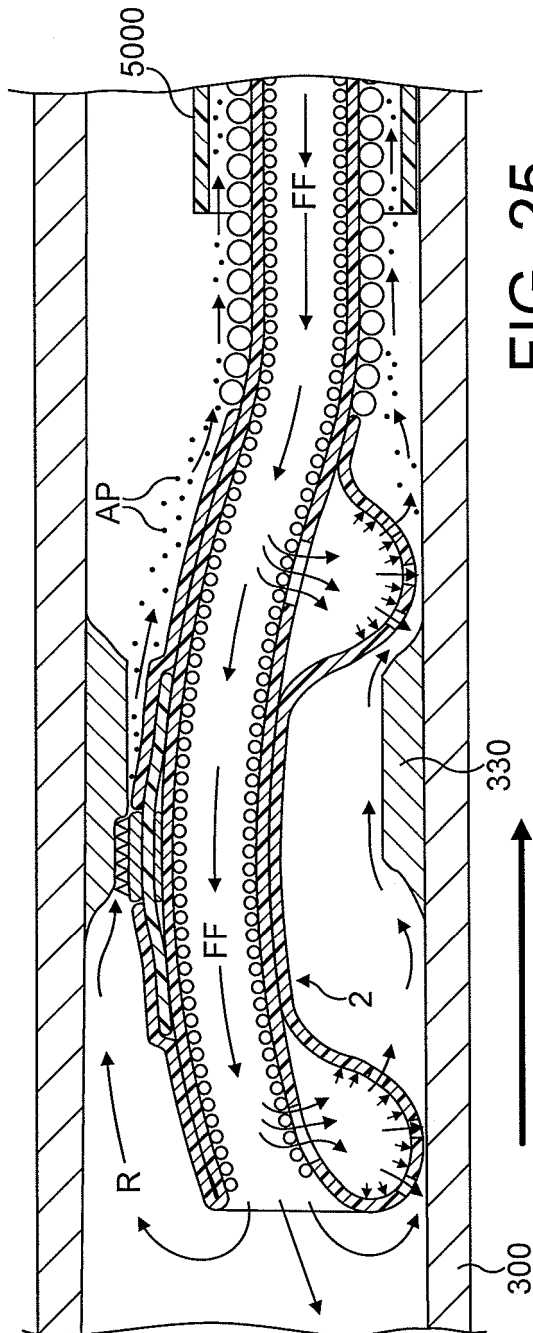


FIG. 25

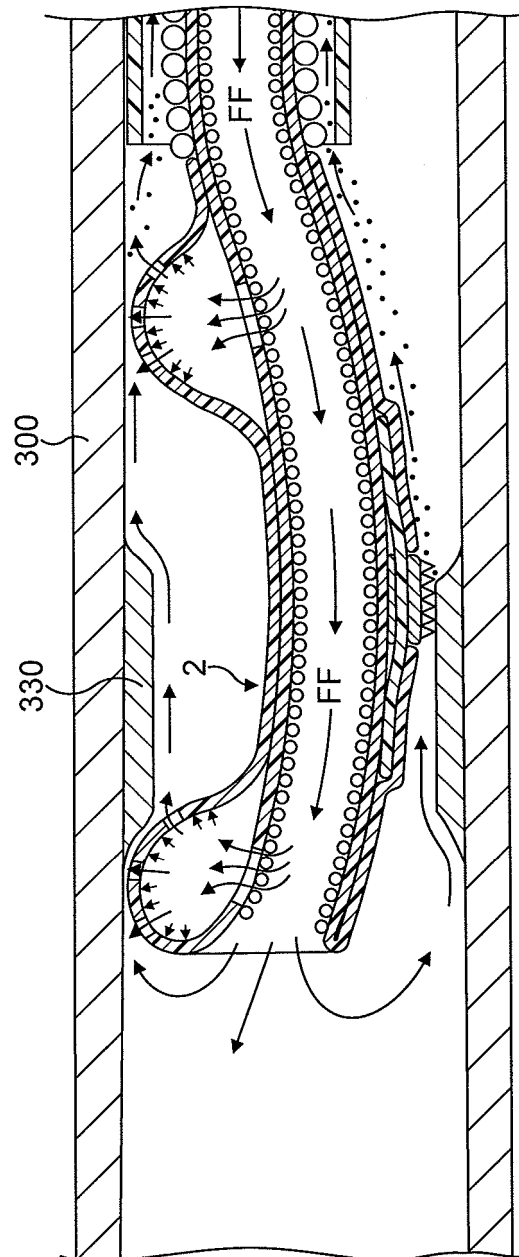


FIG. 26

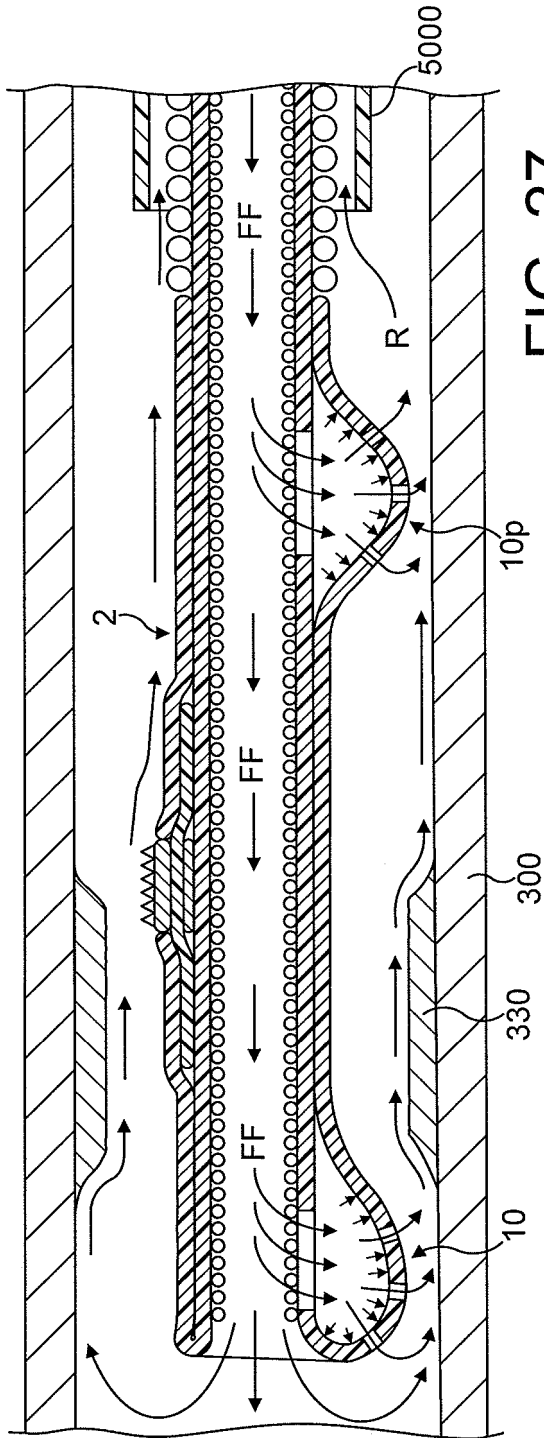


FIG. 27

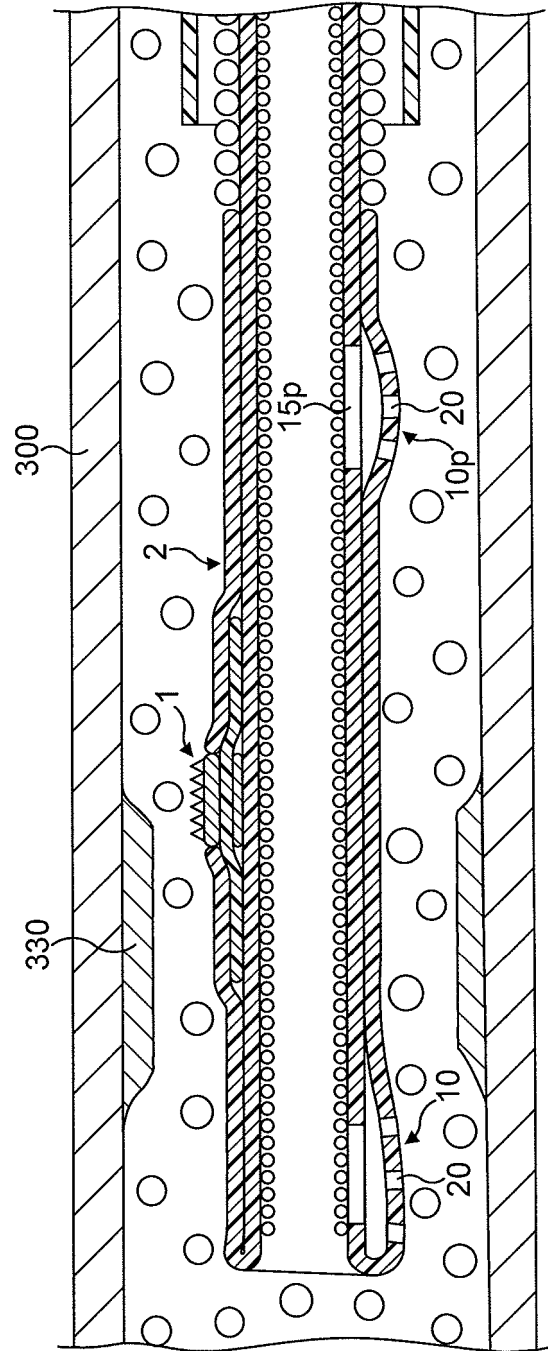


FIG. 28

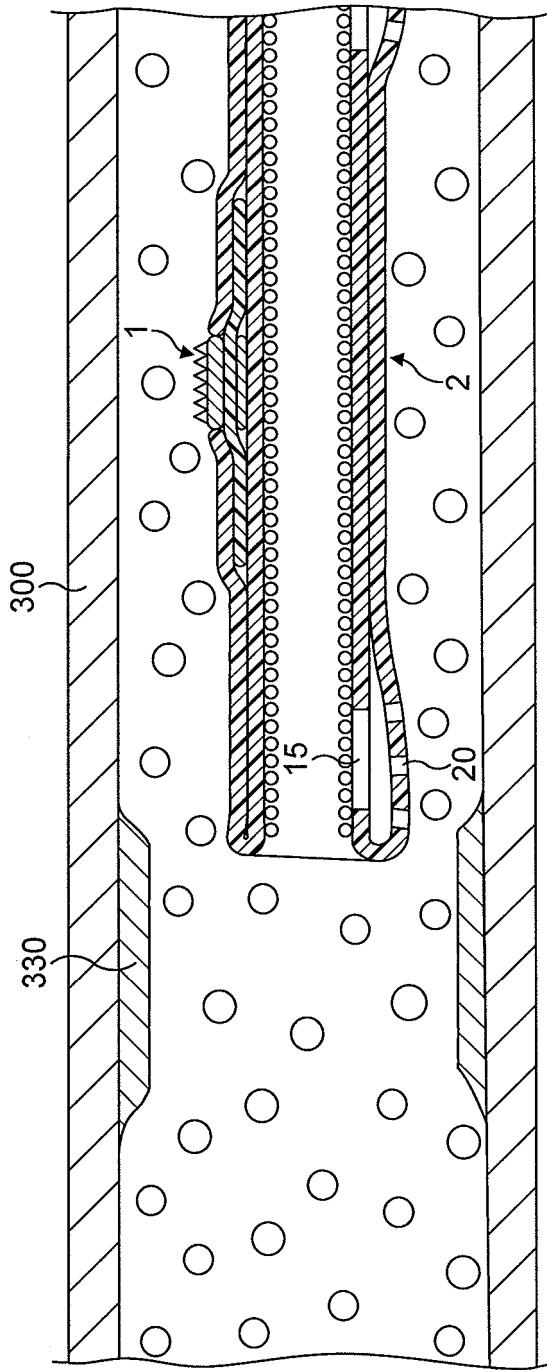


FIG. 29

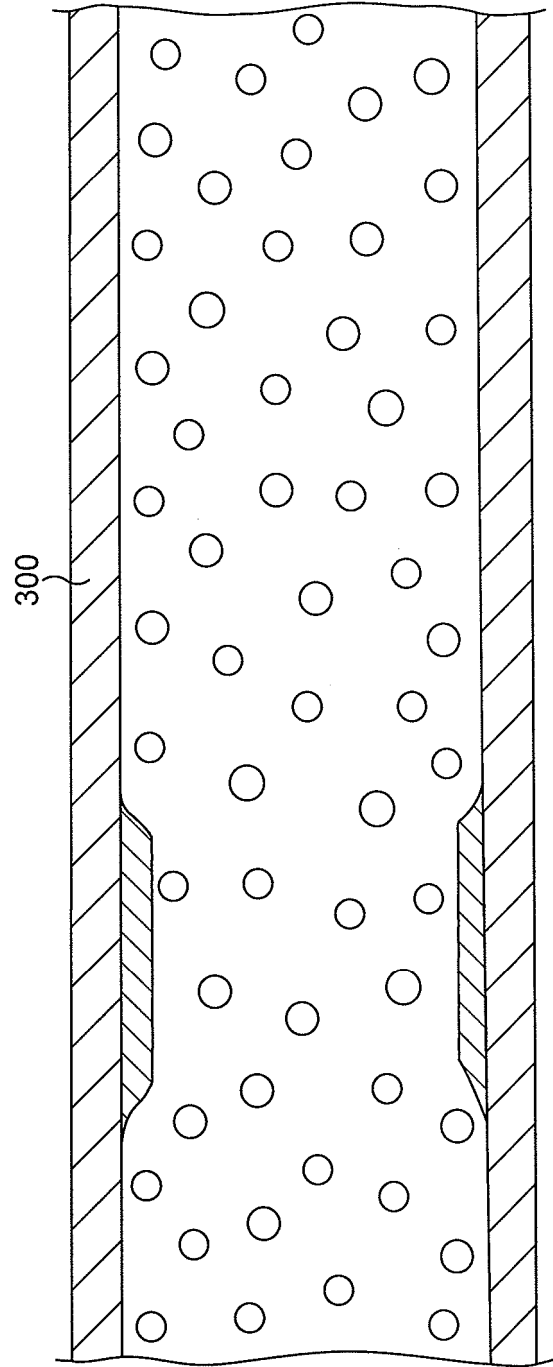


FIG. 30

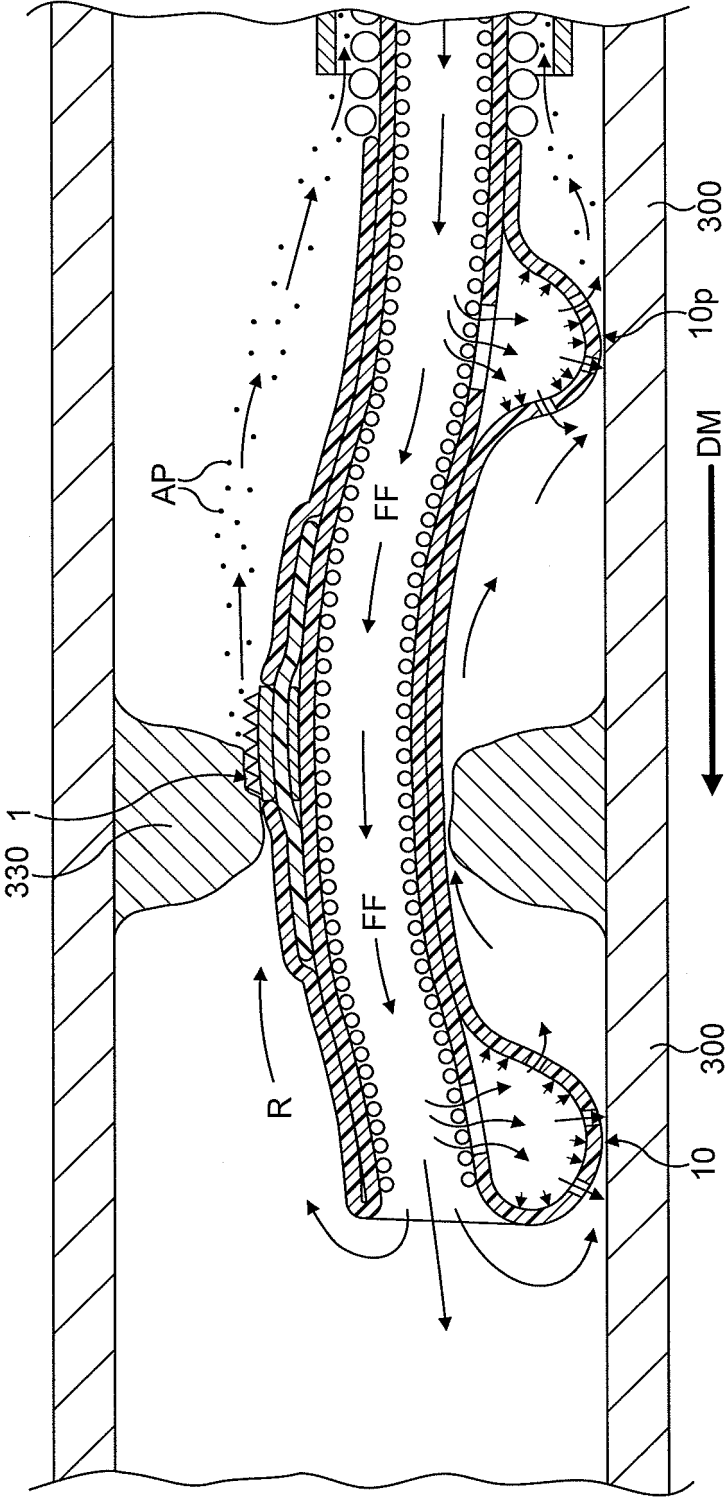


FIG. 31

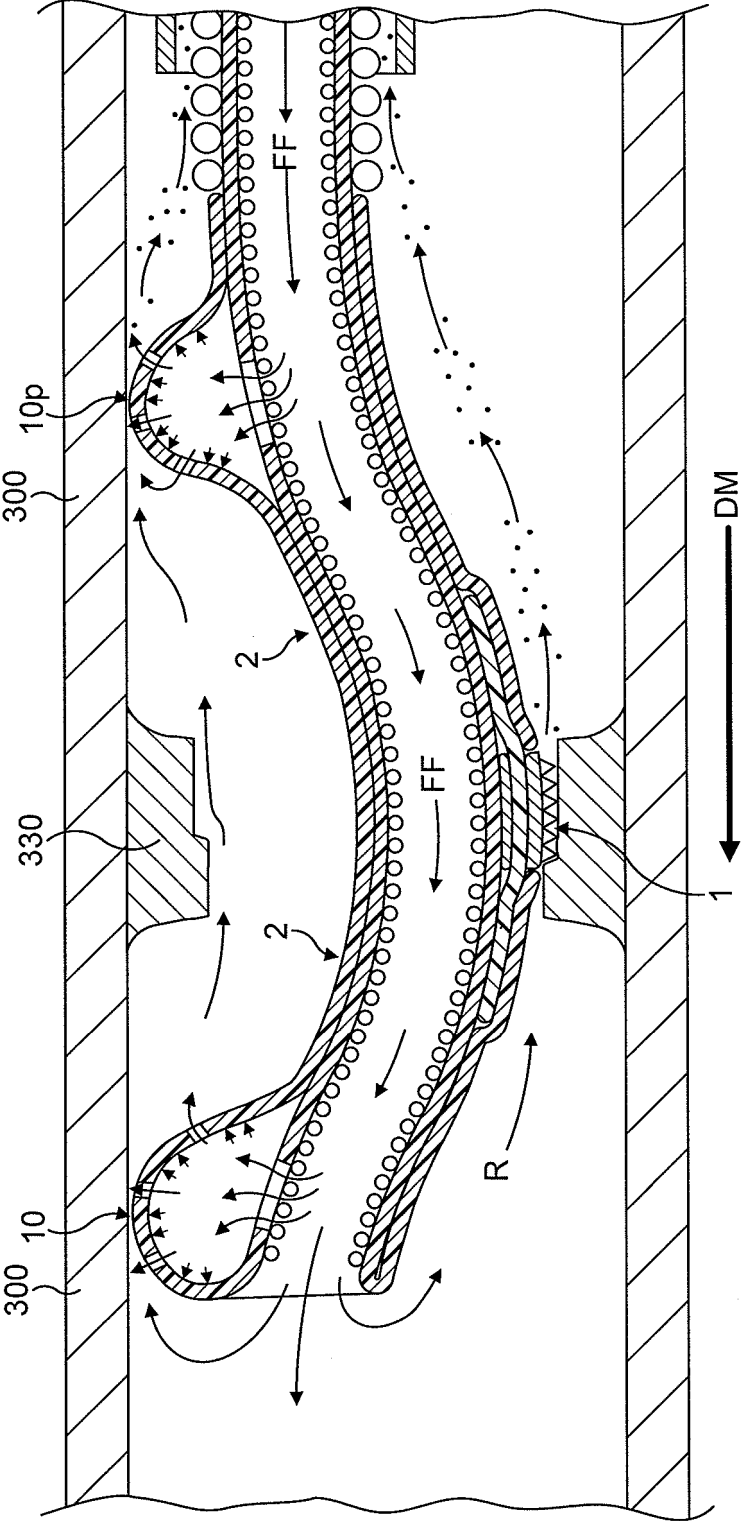


FIG. 32

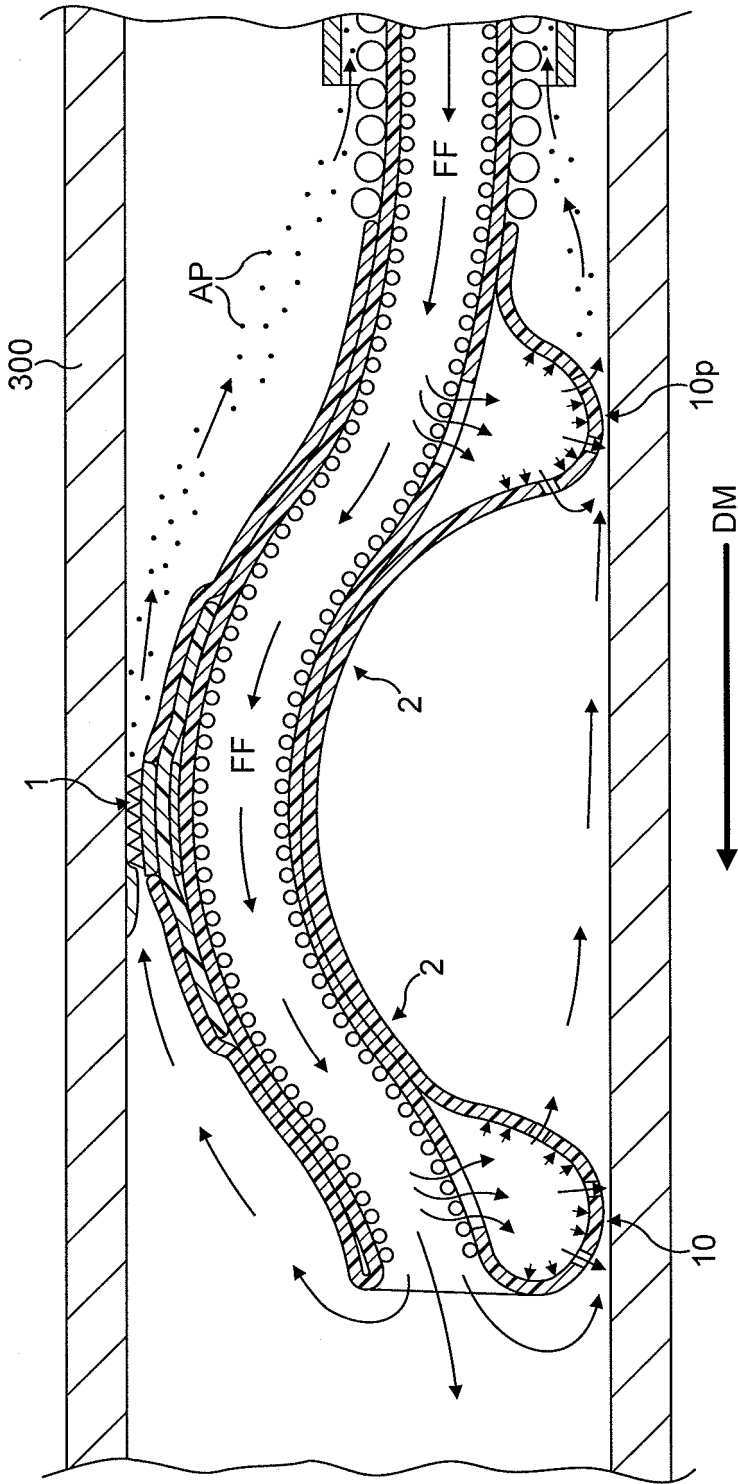


FIG. 33

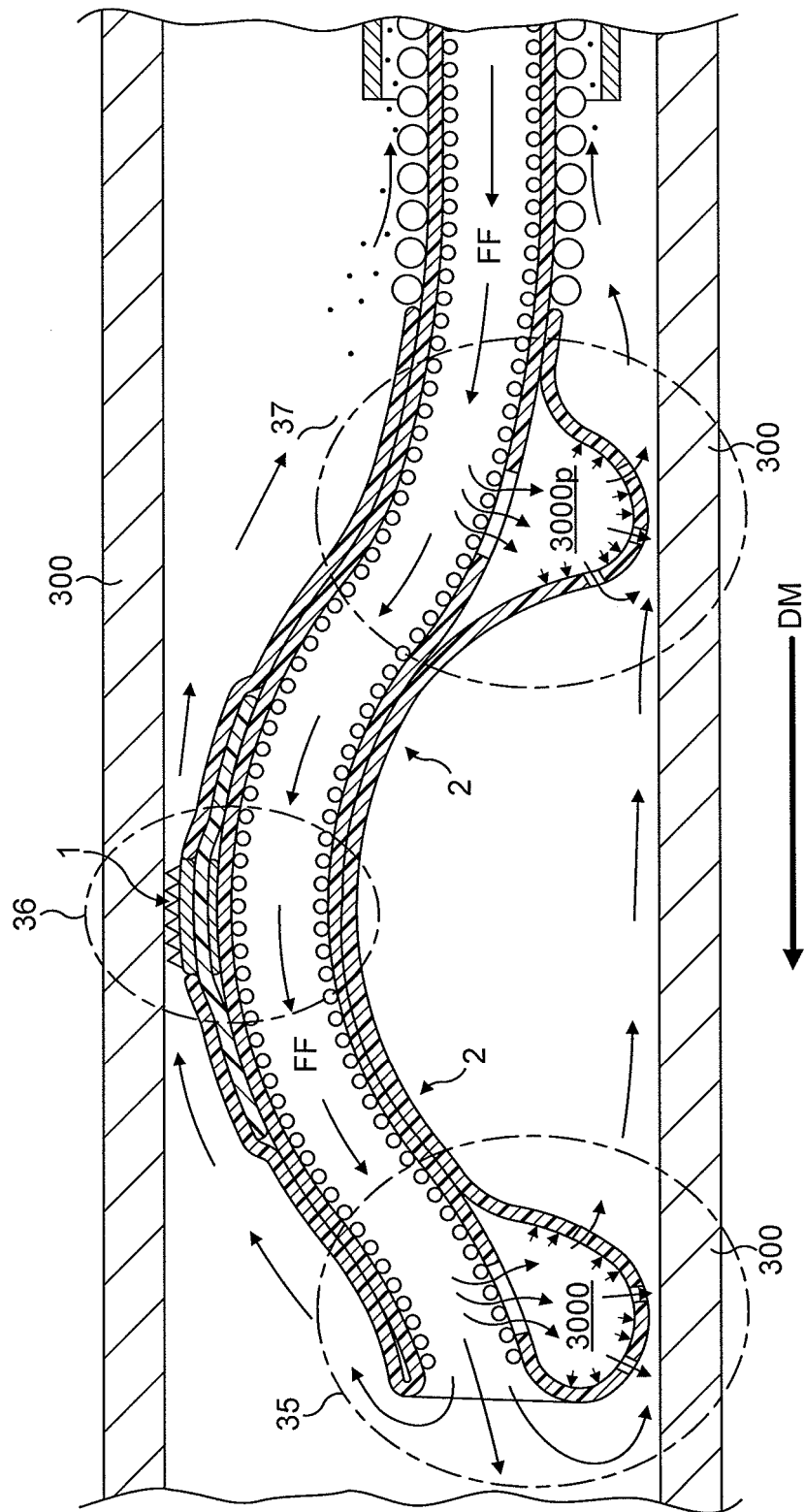


FIG. 34

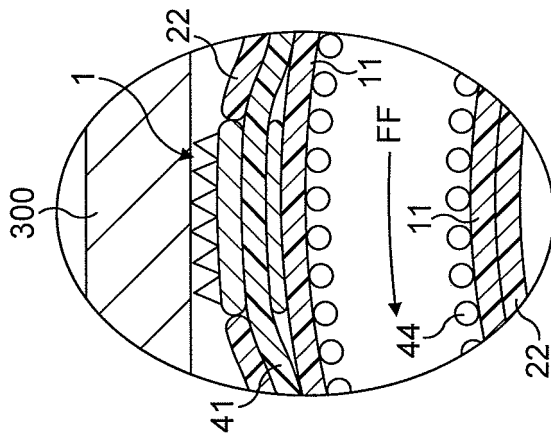


FIG. 36

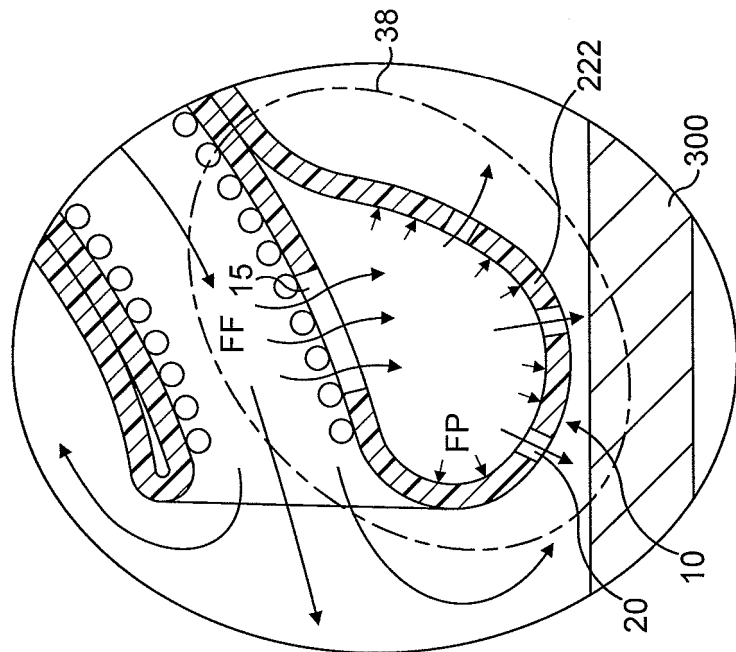


FIG. 35

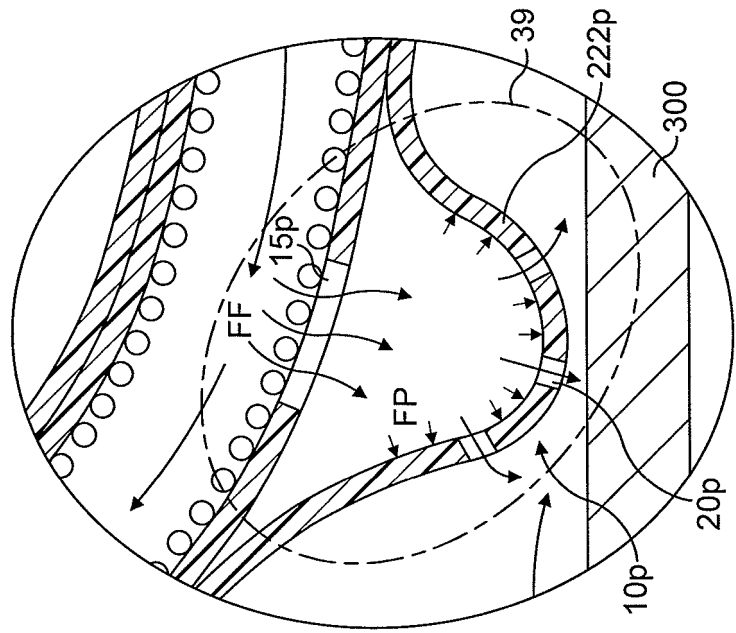


FIG. 37

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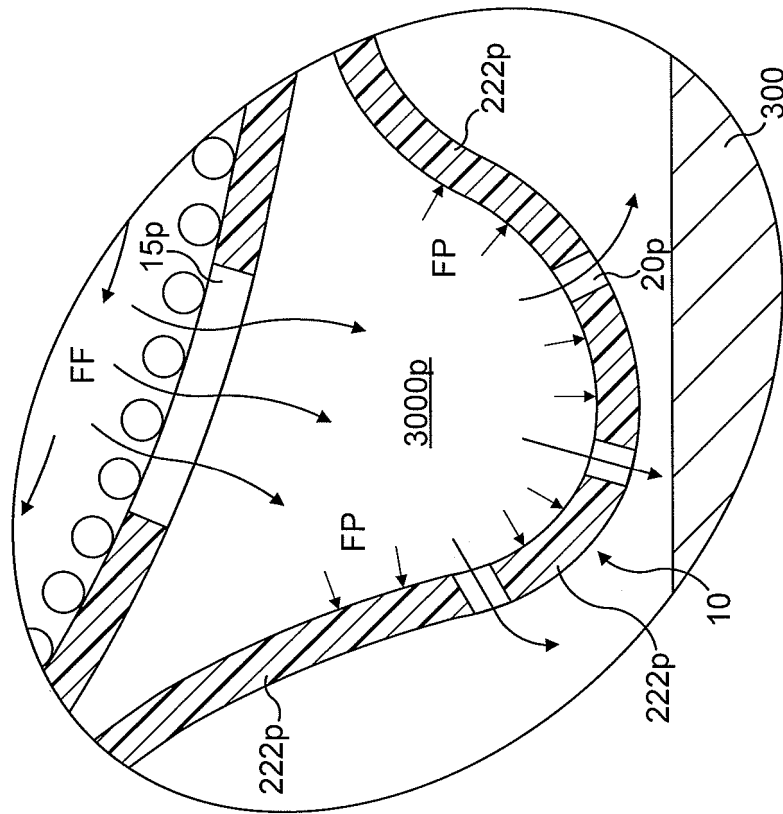


FIG. 39

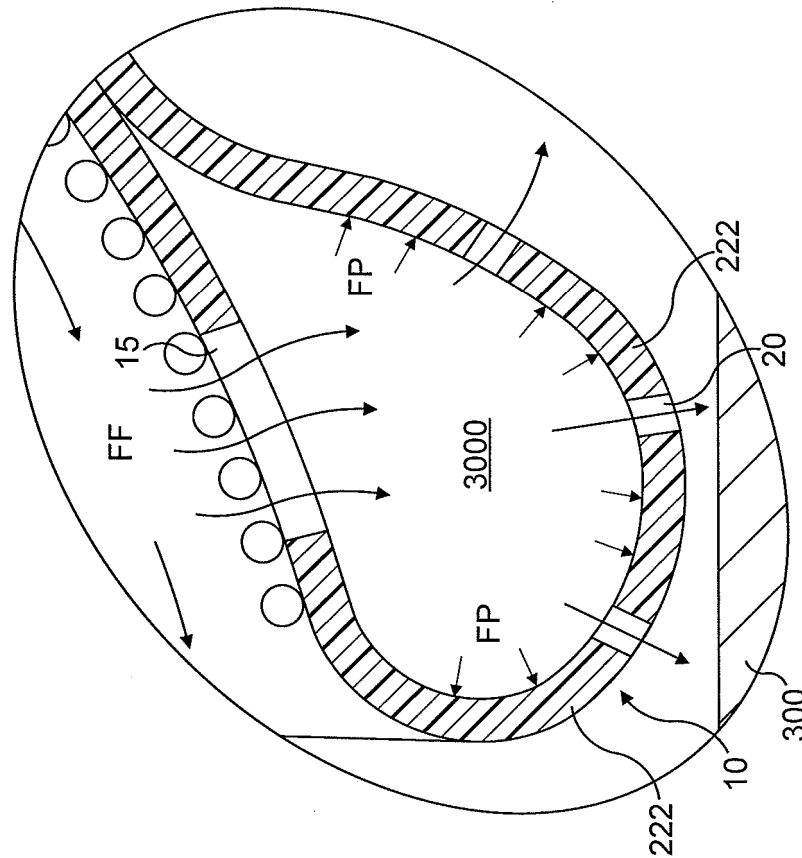
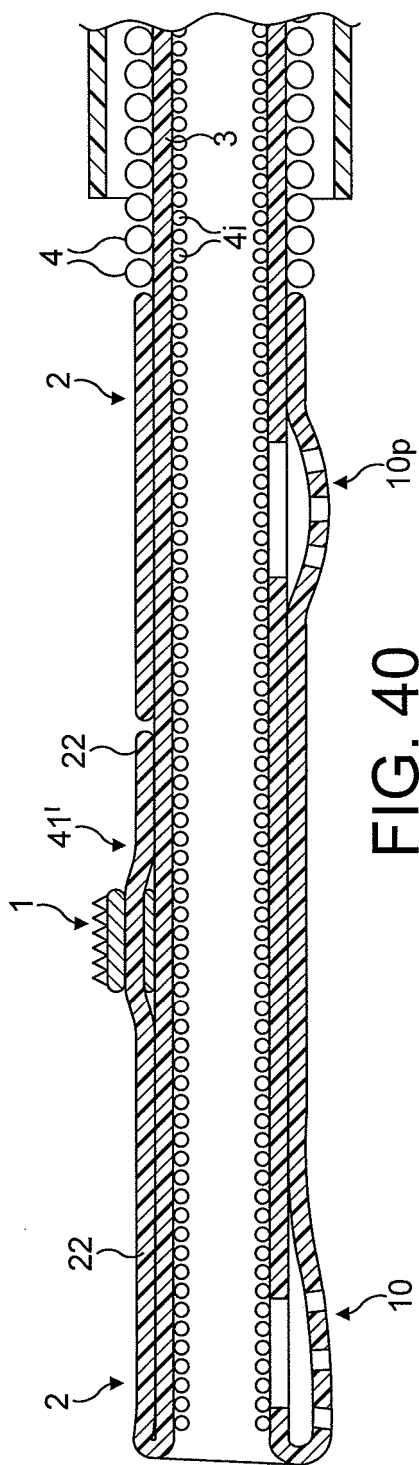


FIG. 38



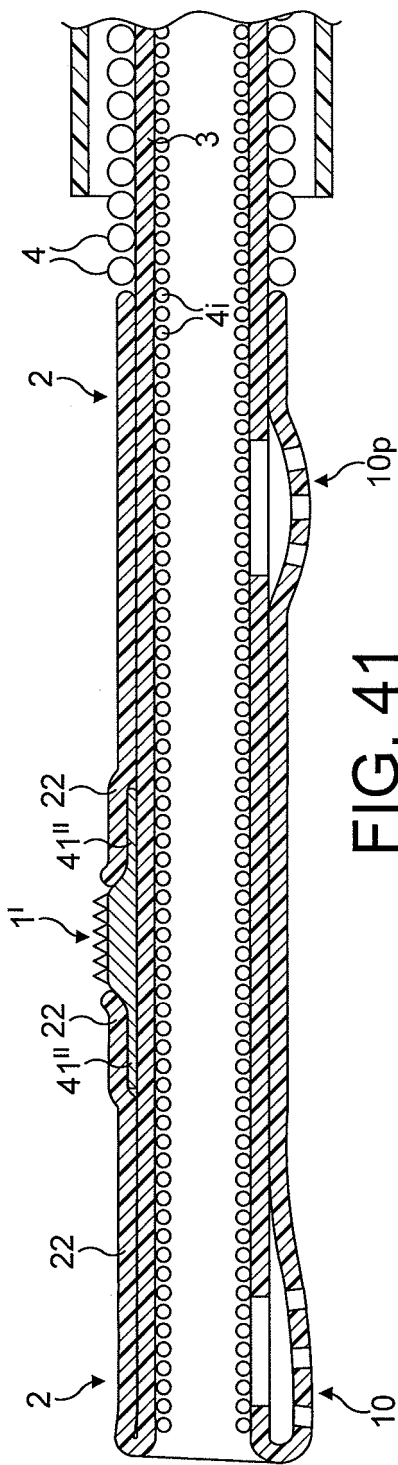


FIG. 41

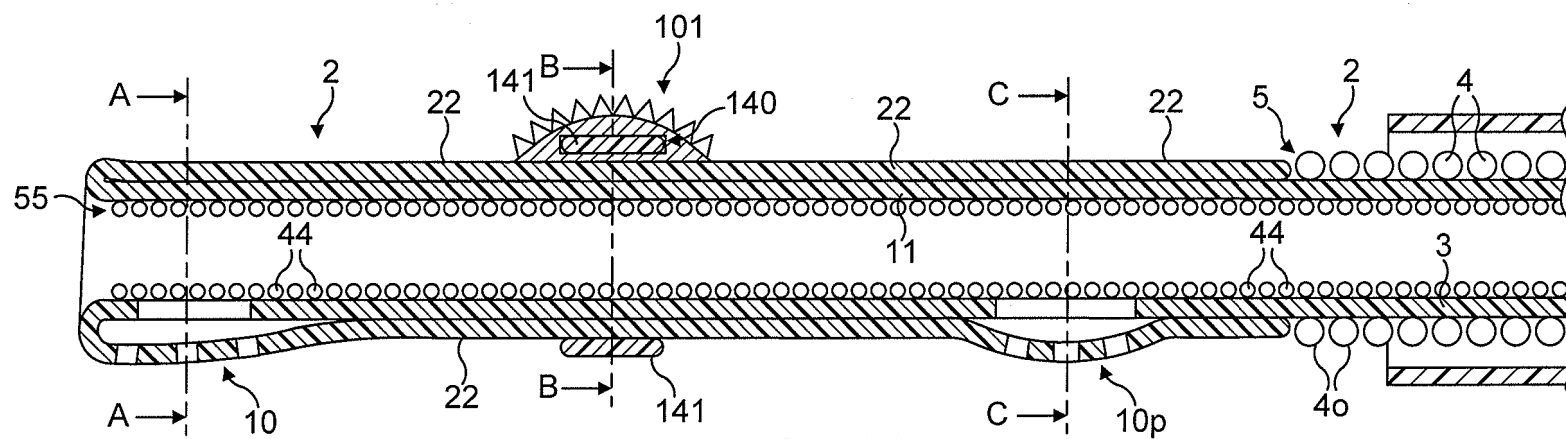


FIG. 42

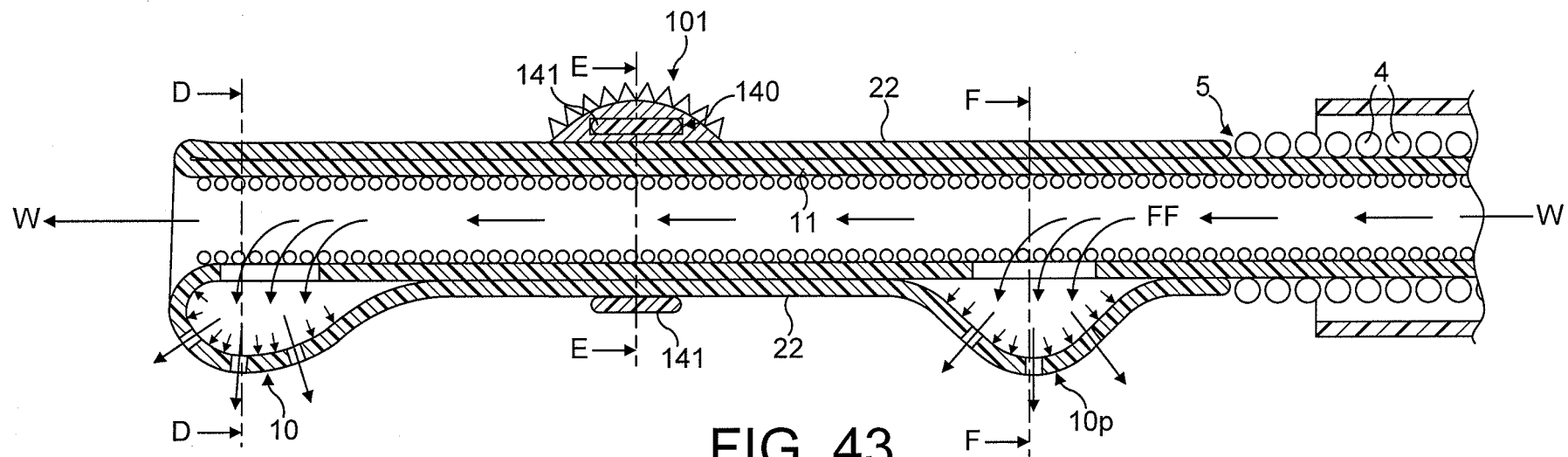


FIG. 43

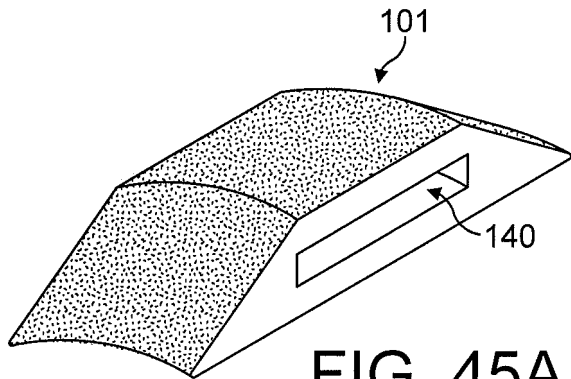


FIG. 45A

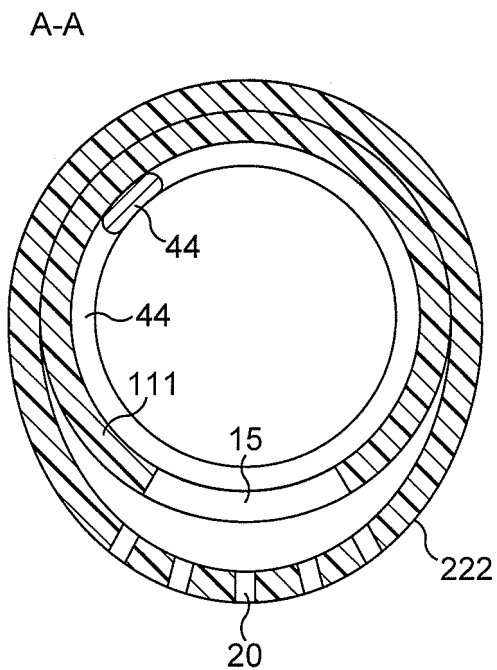


FIG. 44

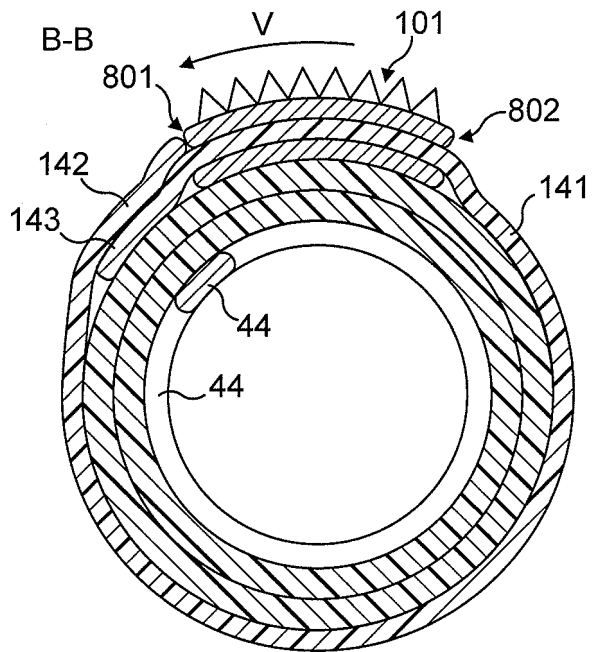


FIG. 45

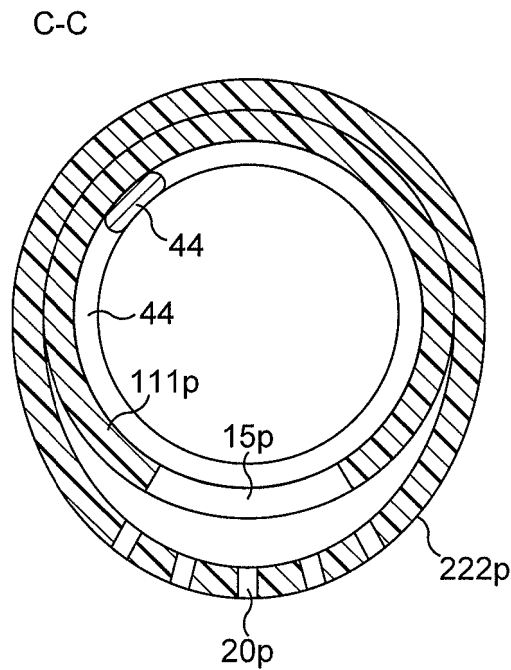


FIG. 46

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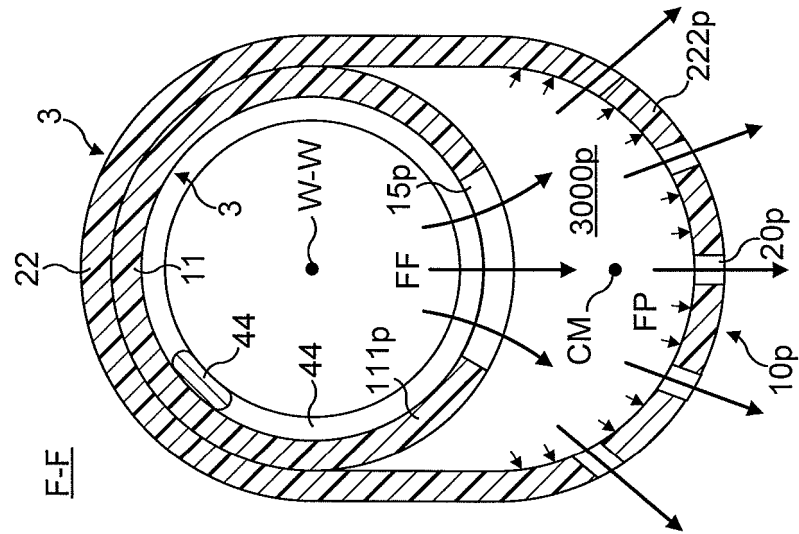


FIG. 49

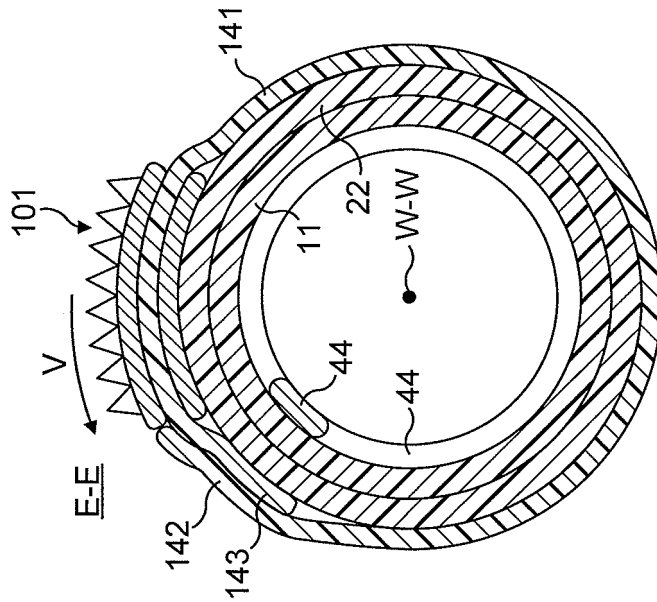


FIG. 48

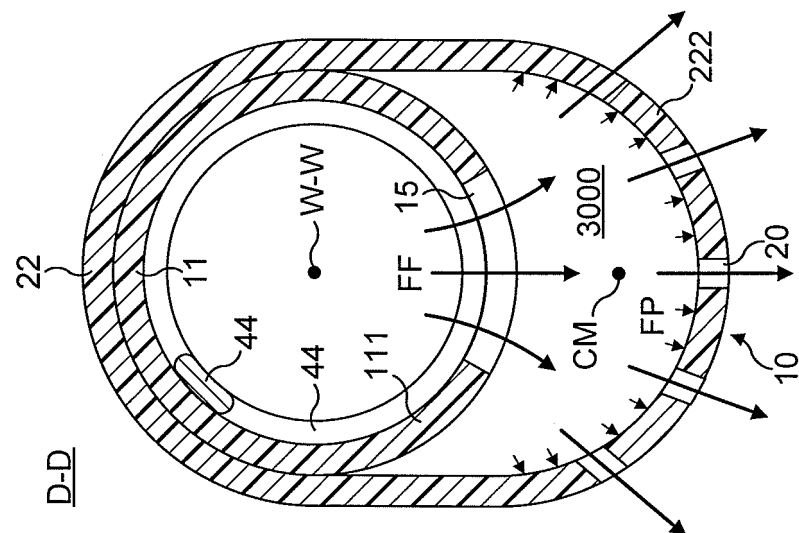


FIG. 47

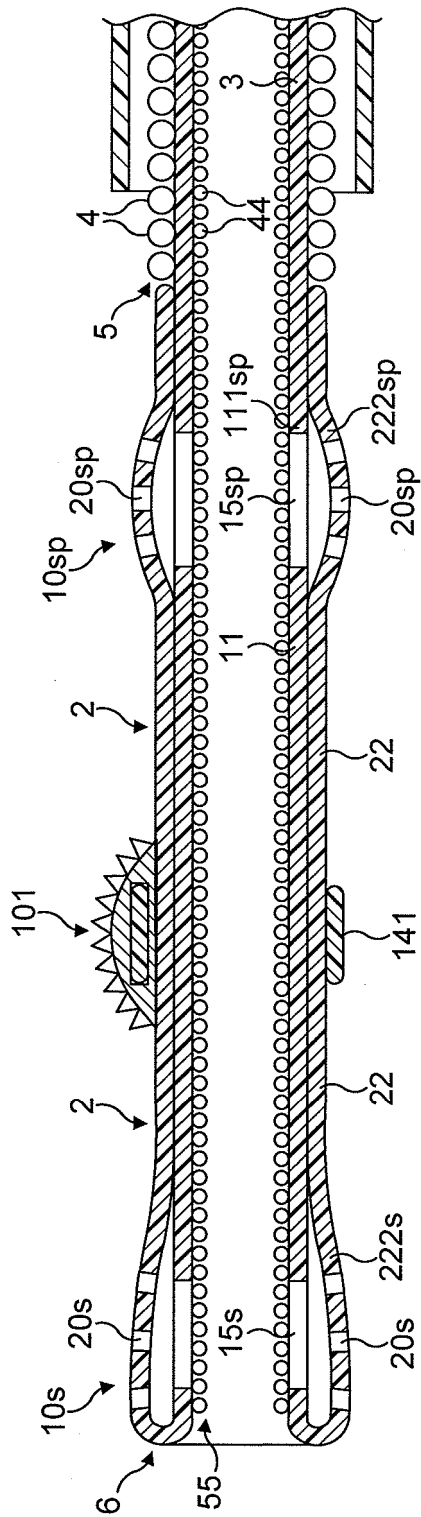


FIG. 50

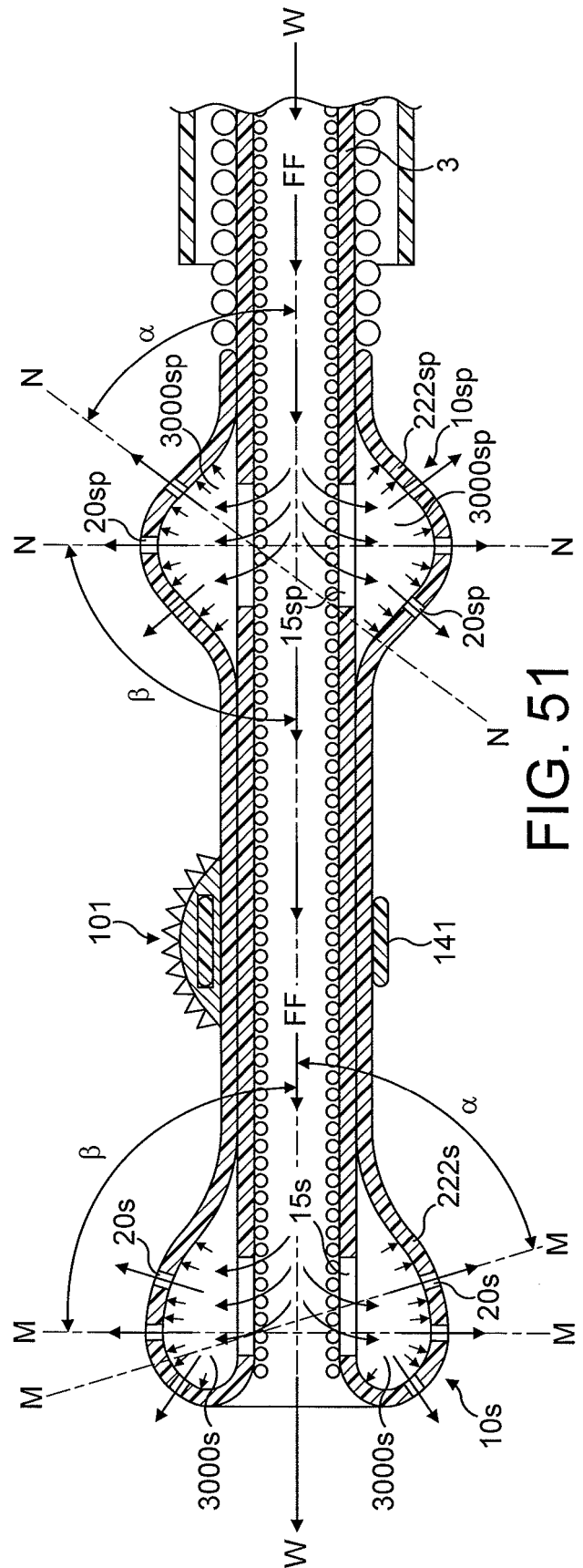


FIG. 51

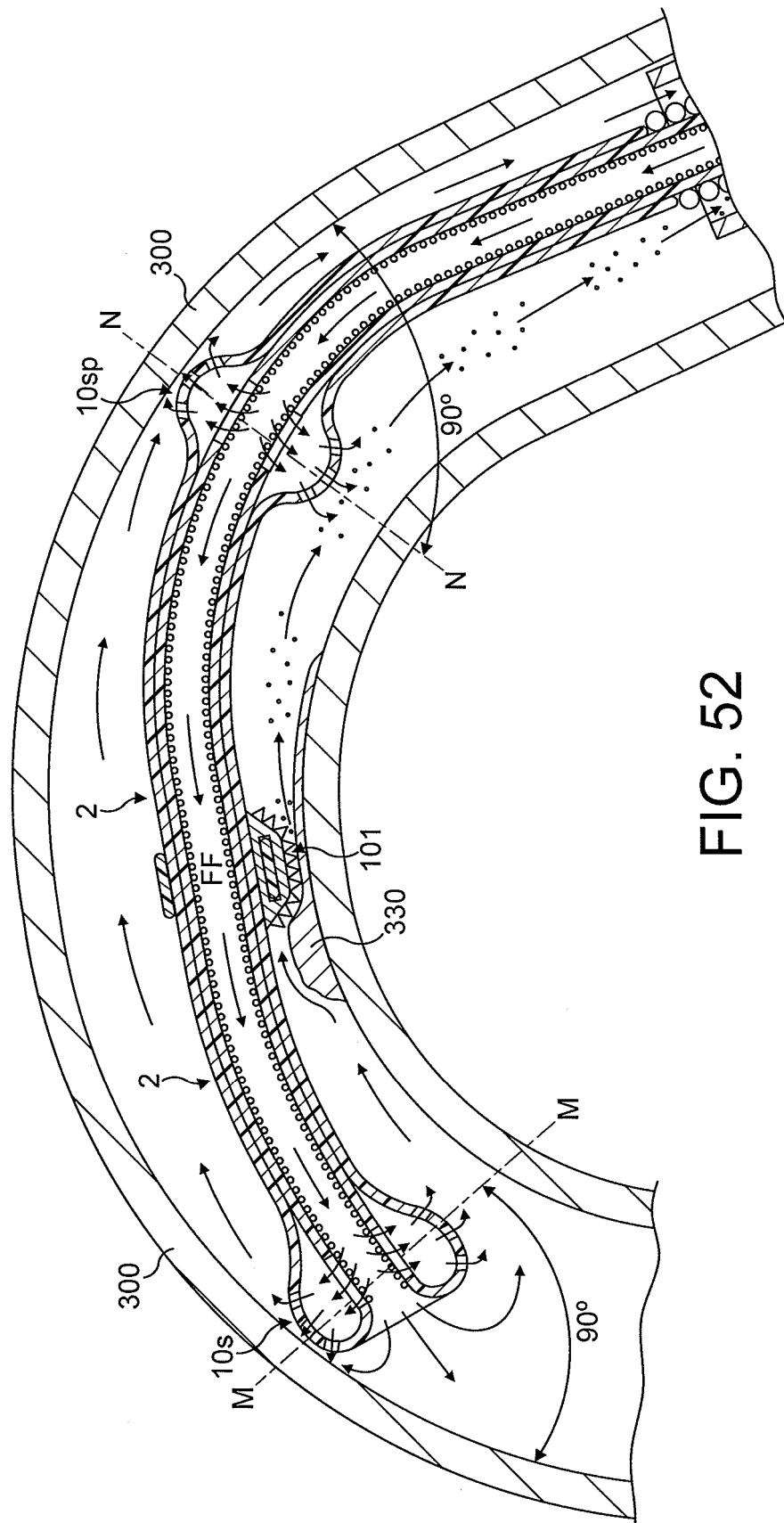


FIG. 52

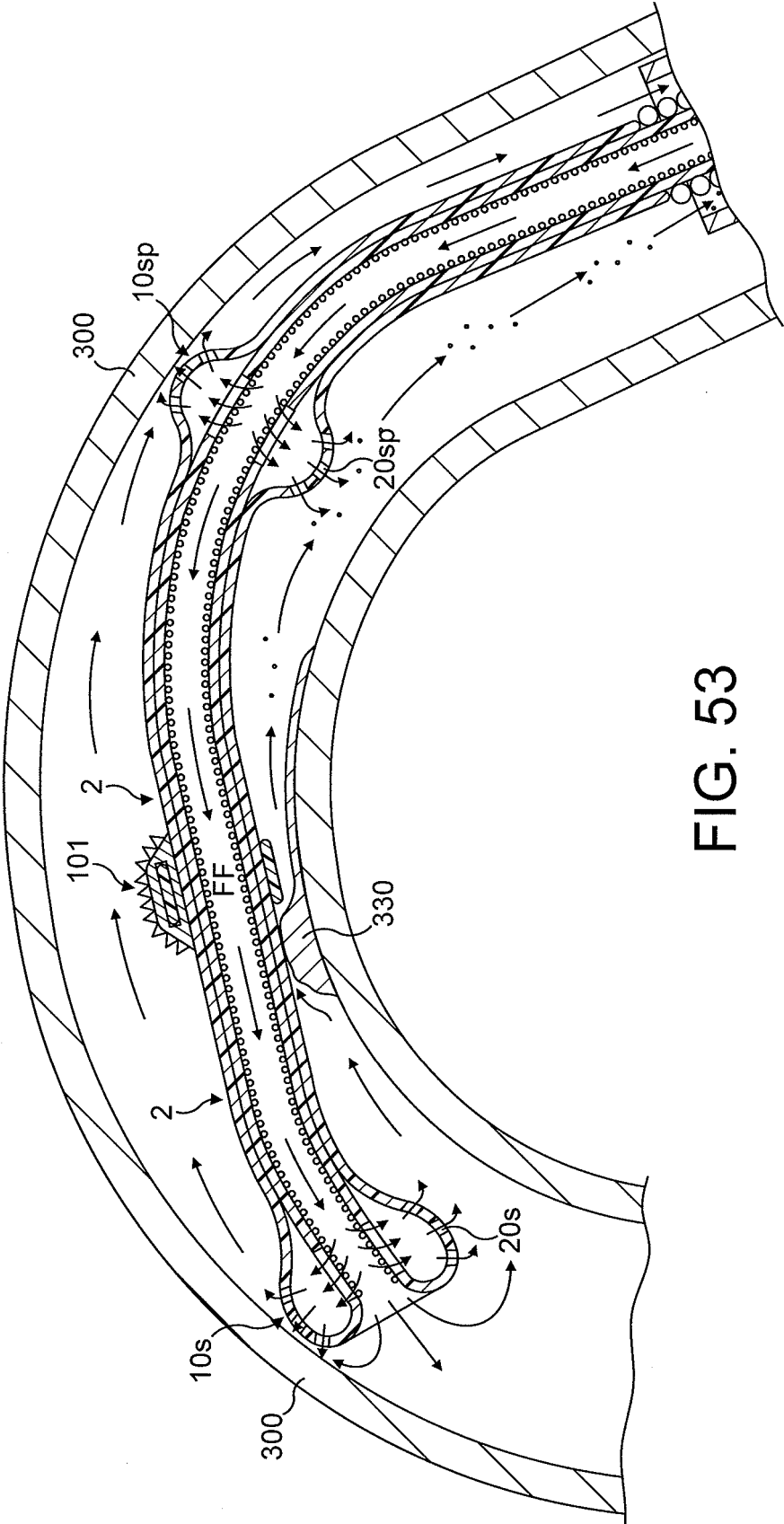
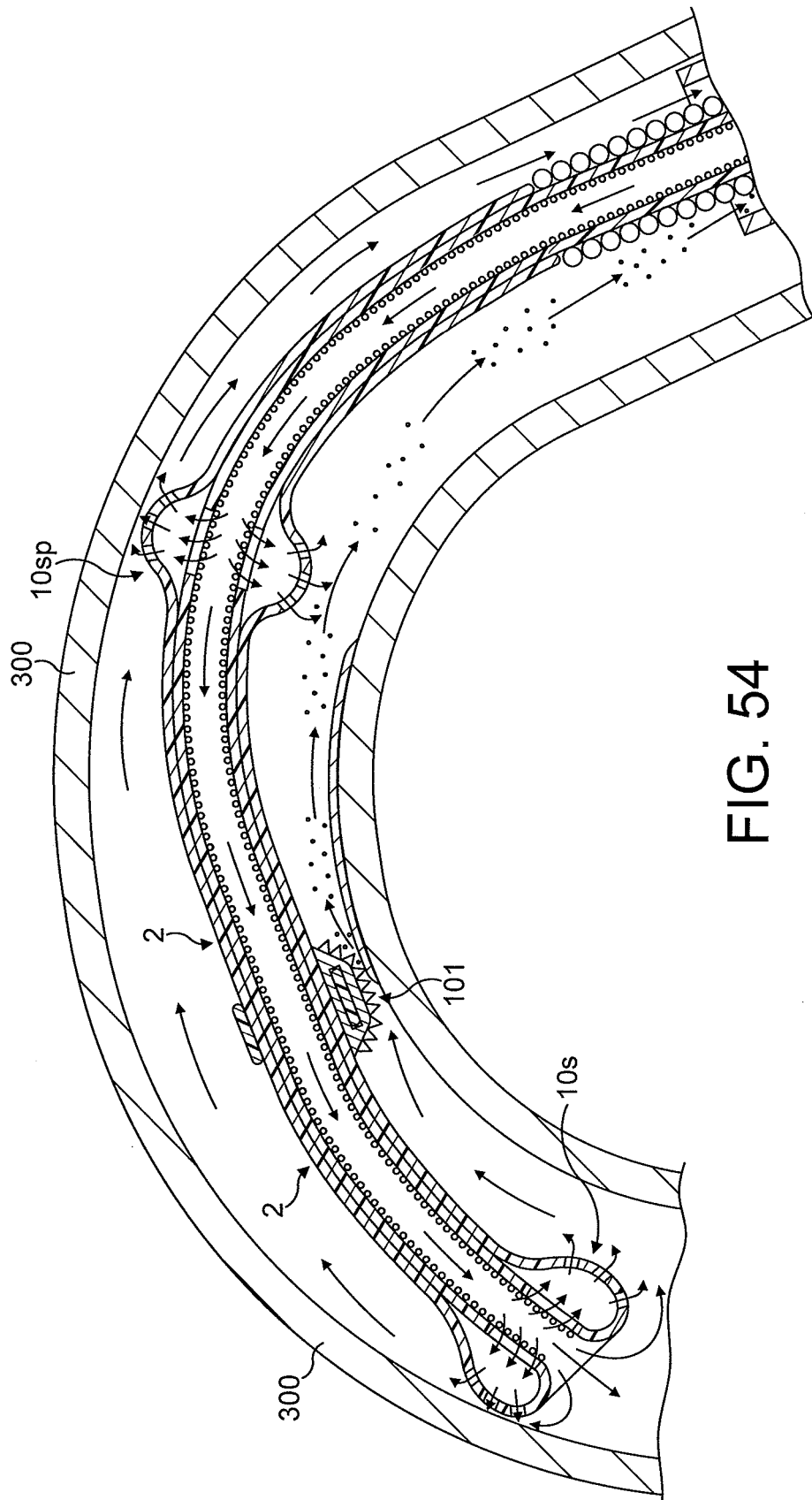


FIG. 53



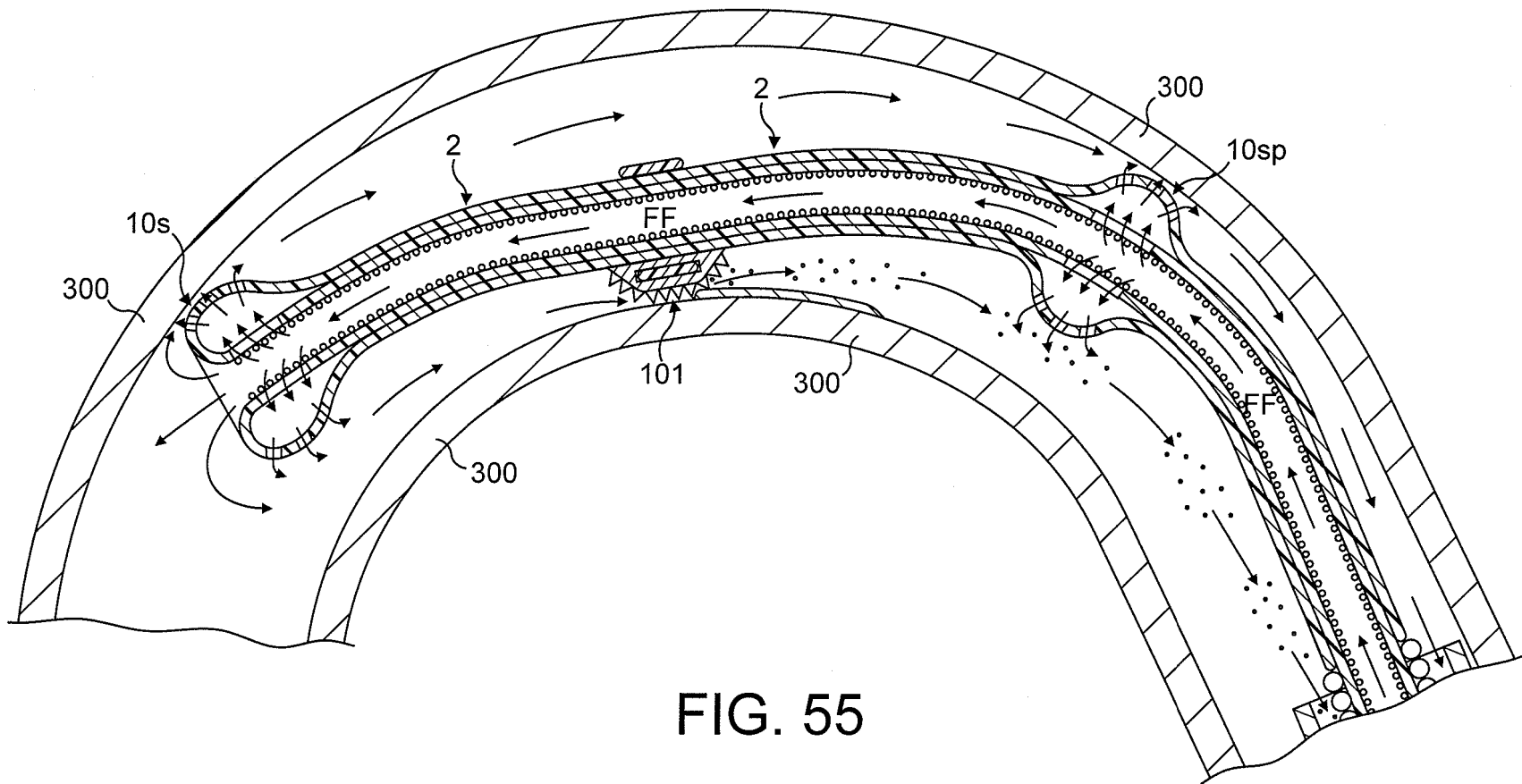


FIG. 55

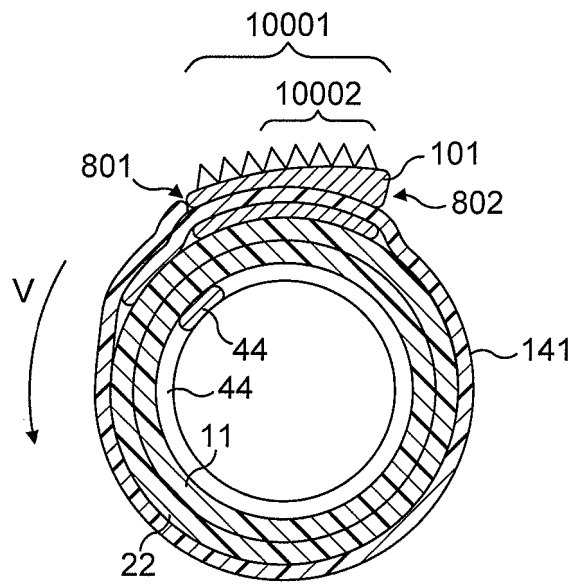


FIG. 56

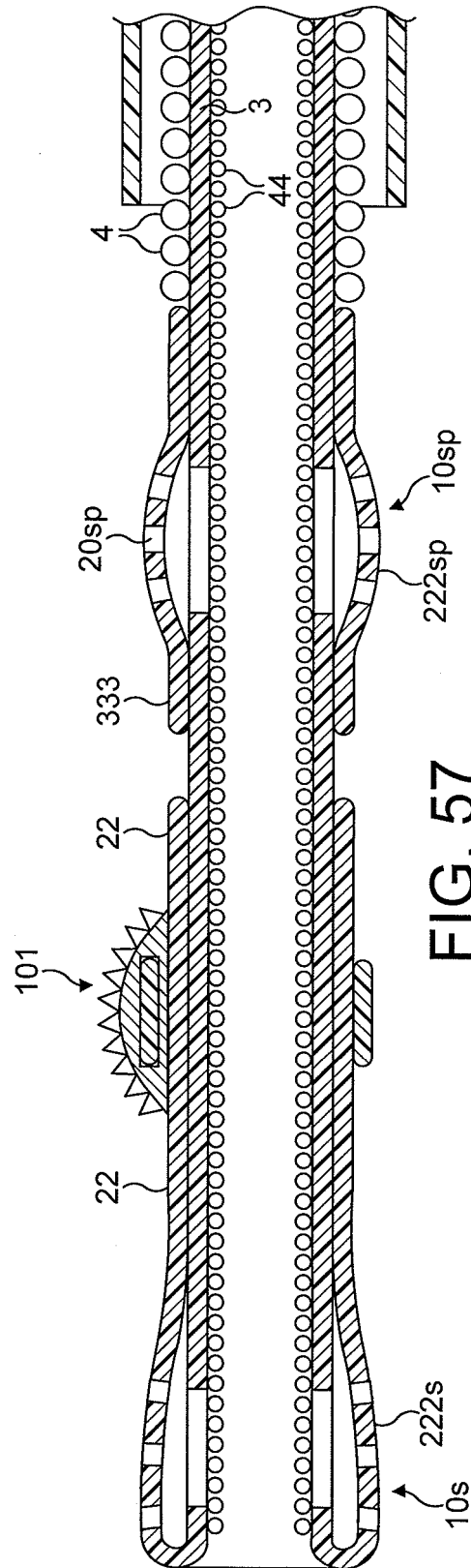


FIG. 57

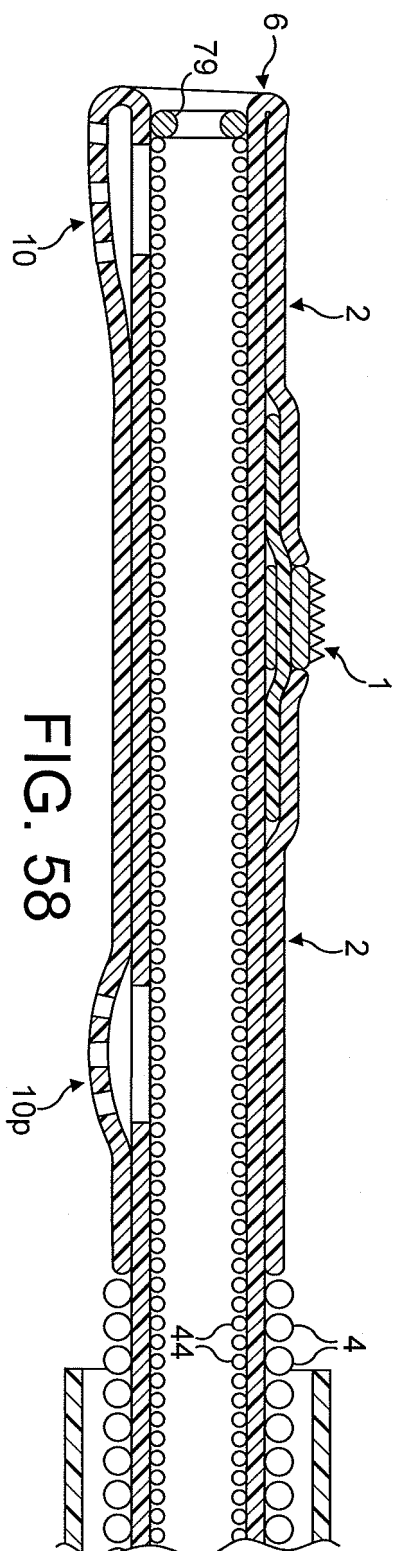


FIG. 58

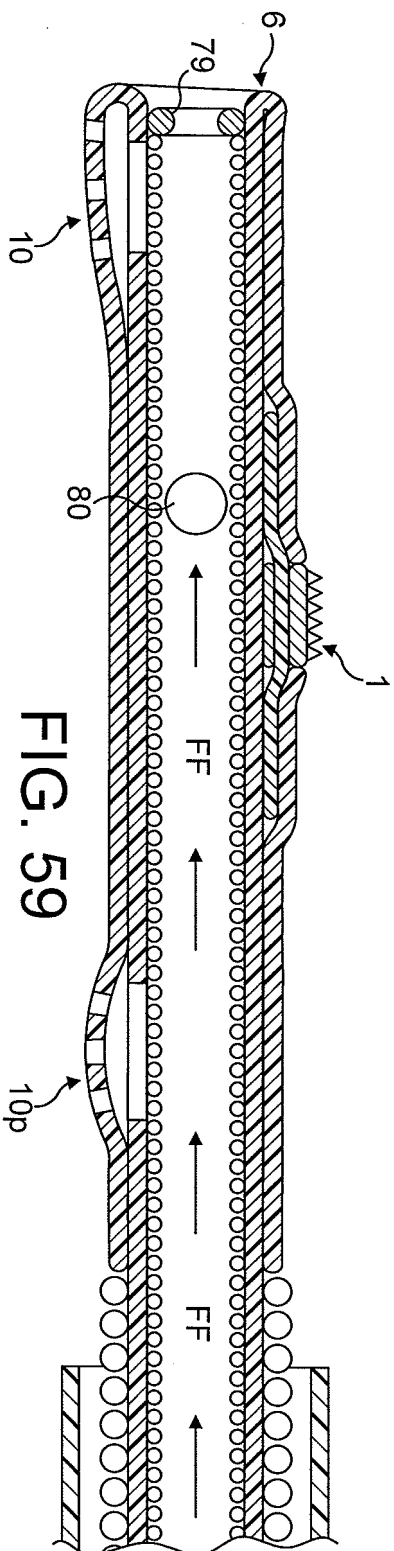


FIG. 59

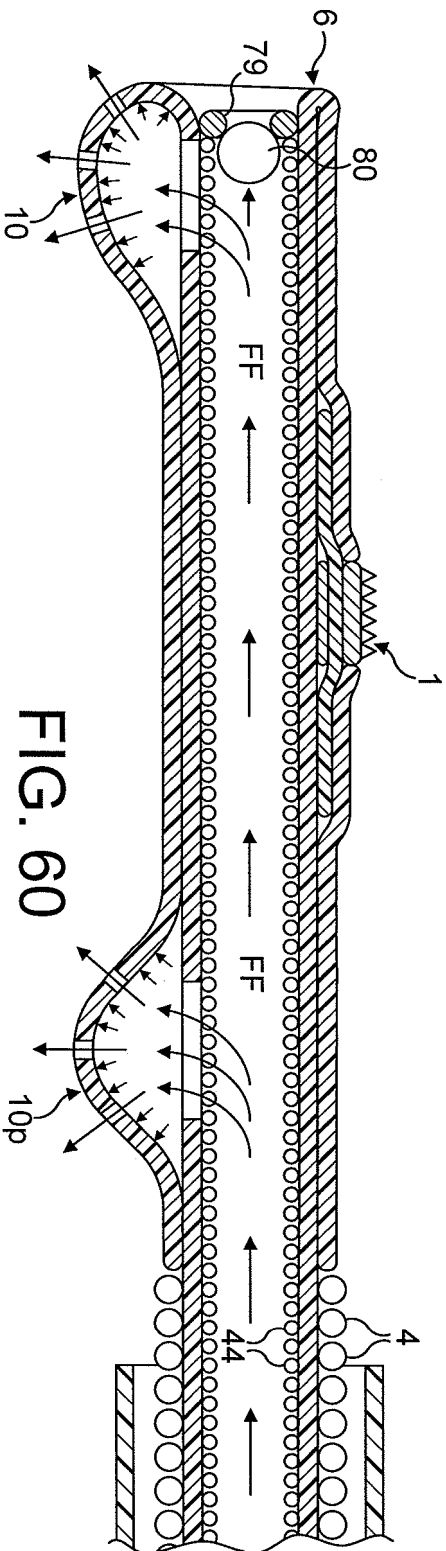
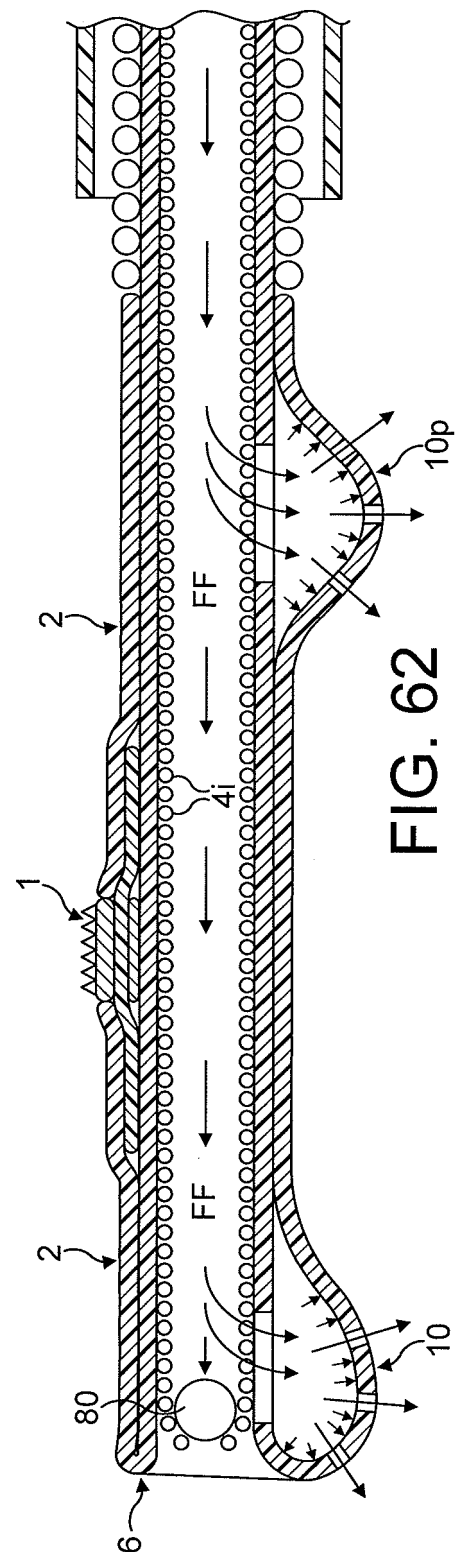
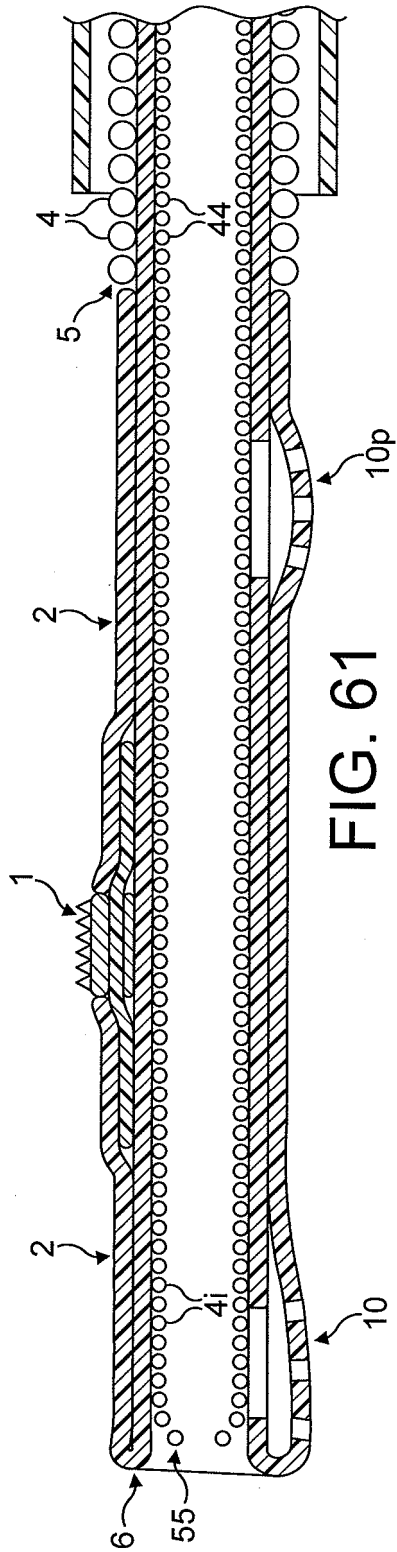
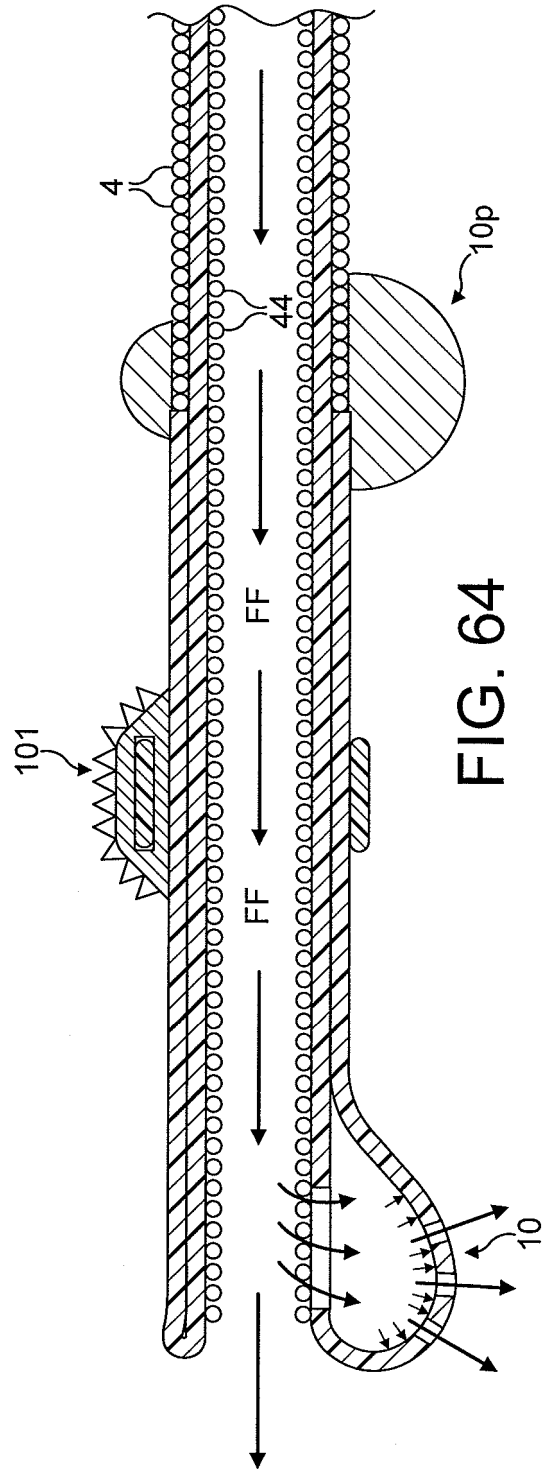
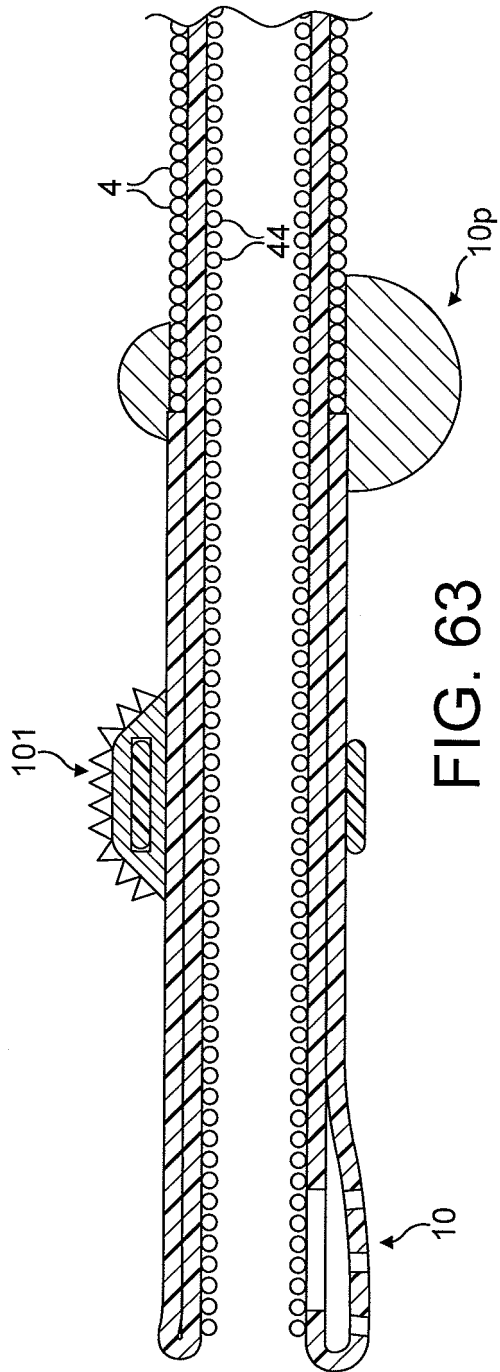


FIG. 60





INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2007/056521

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B17/22

ADD. A61B17/32

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)

A61B A61M

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 99/44513 A2 (SCIMED LIFE SYSTEMS INC [US]) 10 September 1999 (1999-09-10) figure 2 pages 8,9; figures 2c,2d,4b	1-26, 42-52
Y	US 5 217 474 A (ZACCA NADIM M [US] ET AL) 8 June 1993 (1993-06-08) figure 6 column 11, line 64 - column 12, line 27	1-26, 42-52
A	US 5 314 438 A (SHTURMAN LEONID [US]) 24 May 1994 (1994-05-24) figures 1,8 column 5, lines 30-35 column 10, lines 5-43	1-26, 42-52
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☒ See patent family annex.

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Date of the actual completion of the international search

23 October 2007

Date of mailing of the international search report

31/10/2007

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INTERNATIONAL SEARCH REPORT

International application No

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 98/50101 A (APPLIED MED RESOURCES [US]; HART CHARLES C [US]; CHI SING EDUARDO [US]) 12 November 1998 (1998-11-12) figures 5,10	14
A	US 2003/199889 A1 (KANZ BILL [US] ET AL) 23 October 2003 (2003-10-23) paragraphs [0017], [0052]	1,12,13, 21
A	US 2005/154416 A1 (HERWECK STEVE A [US] ET AL) 14 July 2005 (2005-07-14) figure 12 abstract	
A	US 5 273 526 A (DANCE CREG W [US] ET AL) 28 December 1993 (1993-12-28) figures 1,4 column 6, line 14 - column 8, line 31	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2007/056521

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 9944513	A2	10-09-1999	CA 2322651 A1	10-09-1999
			EP 1059885 A2	20-12-2000
			JP 2003504090 T	04-02-2003
			US 6096054 A	01-08-2000
			US 6416526 B1	09-07-2002
			US 6685718 B1	03-02-2004
US 5217474	A	08-06-1993	AU 1152892 A	23-02-1993
			WO 9301849 A1	04-02-1993
			US 5308354 A	03-05-1994
US 5314438	A	24-05-1994	AU 5955194 A	04-07-1994
			WO 9413217 A1	23-06-1994
WO 9850101	A	12-11-1998	DE 69819489 D1	11-12-2003
			DE 69819489 T2	02-09-2004
			EP 0981387 A1	01-03-2000
			JP 2001523142 T	20-11-2001
			US 5868708 A	09-02-1999
US 2003199889	A1	23-10-2003	NONE	
US 2005154416	A1	14-07-2005	US 6955661 B1	18-10-2005
US 5273526	A	28-12-1993	AU 2253492 A	25-01-1993
			CA 2110982 A1	07-01-1993
			DE 69229048 D1	02-06-1999
			DE 69229048 T2	23-09-1999
			EP 0590065 A1	06-04-1994
			WO 9300119 A1	07-01-1993