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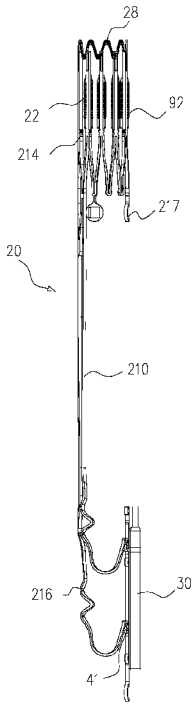
**(54) Title:** WIRELESS ENDOVASCULAR STENT-BASED ELECTRODES

FIG. 19A




**(57) Abstract:** Apparatus and methods are provided including a stent (20) configured to be placed in a blood vessel. The stent includes first (214) and second (216) strut portions at first and second ends of the stent, and a flexible central portion (210) of the stent. In the absence of any force being applied to the stent, the length of the central portion is more than 50 percent of a total length of the stent. At any given longitudinal location along the central portion, the central portion defines no struts around a continuous angular region of more than 180 degrees around a longitudinal axis of the stent. A control capsule (30), coupled to the second strut portion, drives a current into the blood vessel via an electrode (22), which is coupled to the stent. An antenna (28), coupled to the first strut portion, receives power and powers the control capsule.

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# WIRELESS ENDOVASCULAR STENT-BASED ELECTRODES

## CROSS-REFERENCES TO RELATED APPLICATIONS

The present application claims priority from the following US provisional patent applications, which are incorporated herein by reference:

- US Provisional Patent Application 61/641,388 to Dagan, filed May 02, 2012, entitled, "Wireless endovascular stent-based electrodes;"and
- US Provisional Patent Application 61/714,277 to Dagan, filed October 16, 2012, entitled, "Wireless endovascular stent-based electrodes.;" and
- US Provisional Patent Application 61/773,919 to Dagan, filed March 07, 2013, entitled, "Wireless endovascular stent-based electrodes."

The present application is related to International application PCT/IL2012/000336 (published as WO 13/035092), filed September 09, 2012, entitled "Wireless endovascular stent-based electrodes," which claims priority from US Provisional Patent Application 61/532,660 to Dagan, filed September 09, 2011, entitled, "Wireless endovascular stent-based electrodes."

The present application is related to US 13/210,778 to Dagan (published as US 2012/0035679), filed August 16, 2011, which is a continuation-in-part of US 12/957,799 to Gross (published as US 2011/0137370), filed December 01, 2010, entitled "Thoracic aorta and vagus nerve stimulation," which is a continuation-in-part of US 12/792,227 to Gross (published as US 2010/0305392), filed June 02, 2010, entitled "Thoracic aorta and vagus nerve stimulation," which claims the benefit of (a) US Provisional Patent Application 61/183,319 to Reisner, filed June 02, 2009, entitled "Thoracic aorta and vagus nerve stimulation," and (b) US Provisional Patent Application 61/331,453 to Dagan, filed May 05, 2010, entitled "Thoracic aorta and vagus nerve stimulation."

All of the above-referenced applications are incorporated herein by reference.

## FIELD OF EMBODIMENTS OF THE INVENTION

Some applications of the present invention generally relate to medical apparatus. Specifically, some applications of the present invention relate to stent-based electrodes for placement in a blood vessel.

## BACKGROUND

Heart failure is a condition in which a problem with the structure or function of the heart impairs its ability to supply sufficient blood flow to meet the body's needs. The condition impairs quality of life and is a leading cause of hospitalizations and mortality in the western world. Treatment of heart failure is typically aimed at removal of precipitating causes, prevention of deterioration in cardiac function, and control of congestive state.

Hypertension, or chronic high blood pressure, is an extremely prevalent medical condition, which can lead to strokes, heart attacks, and heart failure. There are a variety of treatments that are available for treating hypertension, including lifestyle changes, and medication.

## SUMMARY OF EMBODIMENTS

For some applications of the present invention a stent is placed inside a blood vessel of a subject. The stent defines first and second strut portions, each of the strut portions defining a plurality of struts that are arranged such as to define a generally circular cross-section. The first and second strut portions are coupled to one another by a flexible central portion of the stent. In the absence of any force being applied to the stent, a length of the flexible central portion is more than 50 percent of a total length of the stent, at any given longitudinal location along the flexible central portion. The flexible central portion defines no struts around a continuous angular region of more than 180 degrees around a longitudinal axis of the stent. An electrode and an antenna are typically coupled to the first strut portion of the stent. The antenna is configured to receive power from outside the blood vessel by RF energy being transmitted toward the antenna. The antenna powers a control capsule that is typically coupled to the second strut portion of the stent. The control capsule drives a current into the blood vessel via the electrode, using the power provided to the control capsule by the antenna.

Typically the stent is placed inside the subject's aorta such that the distal end of the stent is in the vicinity of the subject's aortic arch. For some applications, the stent is placed such that the electrodes are disposed between the bifurcation of the aorta with the left subclavian artery and the bifurcation of the aorta with the fifth intercostal artery. For some applications, the control capsule drives the electrodes to drive a current into the subject's aorta, e.g., in order to treat the subject for a condition such as congestive heart failure, diastolic heart failure, and/or hypertension, e.g., as described in US 13/210,778 (published as US 2012/0035679), US 12/957,799 to Gross (published as US 2011/0137370), and/or US 12/792,227 to Gross (published as US 2010/0305392), all of which applications are incorporated herein by reference.

Typically, the portion of the aorta into which the stent is placed is curved. The flexible central portion of the stent is configured to facilitate bending of the first and second strut portions with respect to one another, and to allow the stent to curve such as to conform with the curvature of the aorta.

It is noted that in the context of the present application, the terms "proximal" and "distal" are to be understood to be with respect to an access point of the stent into the subject's body. Thus, the distal end of the stent is the end of the stent that is further from the access point, and the proximal end of the stent is the end of the stent that is closest to the access point. For applications in which the stent is placed inside the subject's aorta, the term "distal" typically means the portion of the stent or the aorta that is closer to the subject's left ventricle, and the term "proximal" means the portion of the stent or the aorta that is further from the subject's left ventricle.

There is therefore provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, including:

a stent configured to be placed in the blood vessel, the stent including:

a first strut portion at a first end of the stent, the first strut portion defining a plurality of struts that are arranged such that the first strut portion defines a generally circular cross-section;

a second strut portion at a second end of the stent, the second strut portion defining a plurality of struts that are arranged such that the second strut portion defines a generally circular cross-section; and

a flexible central portion of the stent, the first and second strut portions being coupled to one another by the flexible central portion of the stent,

in the absence of any force being applied to the stent, a length of the flexible central portion being more than 50 percent of a total length of the stent, and at any given longitudinal location along the flexible central portion, the flexible central portion defining no struts around a continuous angular region of more than 180 degrees around a longitudinal axis of the stent;

an electrode that is coupled to the stent;

an antenna coupled to the first strut portion; and

a control capsule coupled to the second strut portion,

the control capsule being configured to drive a current into the blood vessel via the electrode, and the antenna being configured to receive power and to power the control capsule using the received power.

For some applications, the length of the flexible central portion of the stent includes more than 75 percent of the total length of the stent.

For some applications, at any given longitudinal location along the flexible central portion, the flexible central portion is configured to define no rigid or semi-rigid components thereof within the continuous angular region of more than 180 degrees.

For some applications, the flexible central portion is configured to facilitate bending of the first and second strut portions with respect to one another.

For some applications, the stent is configured to be placed inside a curved blood vessel and the flexible central portion is configured to allow the stent to curve such as to conform with a curvature of the curved blood vessel.

For some applications, the stent is configured to be placed within a curved portion of an aorta of the subject, and the flexible central portion is configured to allow the stent to curve such as to conform with a curvature of the portion of the aorta.

For some applications, at any given longitudinal location along the flexible central portion, the flexible central portion defines no struts around a continuous angular region of more than 225 degrees around the longitudinal axis of the stent.

For some applications, at any given longitudinal location along the flexible central portion, the flexible central portion defines no struts around a continuous angular region of more than 270 degrees around the longitudinal axis of the stent.

For some applications, the length of the flexible central portion of the stent is more than 15 mm.

For some applications, the length of the flexible central portion of the stent is more than 20 mm.

For some applications, the length of the flexible central portion of the stent is more than 30 mm.

For some applications, the flexible central portion of the stent defines one or more generally elongate struts, each of the struts having a length of more than 15 mm.

For some applications, at least one of the elongate struts of the central portion of the stent is shaped to define straightened portions of the strut, and a curved portion

of the strut between the straightened portions of the strut, the curved portion of the strut being configured to act as a joint about which the straightened portions bend.

For some applications, the stent is configured to be inserted into the blood vessel via a catheter, and the stent defines coupling elements at a proximal end of the first strut portion configured to facilitate coupling of the first strut portion to the catheter.

For some applications, the stent does not define coupling elements coupled to the second strut portion configured to facilitate coupling of the second strut portion to the catheter.

For some applications, the elongate struts are disposed helically between the first and second strut portions of the stent.

For some applications, the stent defines a plurality of rings that are coupled to the elongate elements, and the apparatus further includes a reinforcement element configured to reinforce the central portion of the stent by coupling the first strut portion of the stent to the second strut portion of the stent by being threaded through the rings.

There is further provided, in accordance with some applications of the present invention, a method for use with a blood vessel of a subject, including:

providing:

a stent that defines:

a first strut portion at a first end of the stent, the first strut portion defining a plurality of struts that are arranged such that the first strut portion defines a generally circular cross-section;

a second strut portion at a second end of the stent, the second strut portion defining a plurality of struts that are arranged such that the second strut portion defines a generally circular cross-section; and

a flexible central portion of the stent, the first and second strut portions being coupled to one another by the flexible central portion of the stent,

in the absence of any force being applied to the stent, a length of the flexible central portion being more than 50 percent of a total

length of the stent and, at any given longitudinal location along the flexible central portion, the flexible central portion defining no struts around a continuous angular region of more than 180 degrees around a longitudinal axis of the stent;

an electrode that is coupled to the stent;

an antenna coupled to the first strut portion; and

a control capsule coupled to the second strut portion,

the control capsule being configured to drive a current into the blood vessel via the electrode, and the antenna being configured to receive power and to power the control capsule using the received power; and

placing the stent inside the blood vessel.

For some applications, placing the stent inside the blood vessel includes:

inserting the stent into the blood vessel via a catheter the stent being coupled to the catheter via coupling elements that are coupled to the first strut portion,

releasing the stent from the catheter by decoupling the first strut portion from the catheter and allowing the first strut portion to become coupled to the blood vessel by retracting the catheter; and

subsequently, allowing the second strut portion to become coupled to the blood vessel by further retracting the catheter.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject and a delivery system, the apparatus including:

a stent configured to be inserted into the blood vessel via the delivery system, the stent:

when in a radially-constrained state thereof inside the delivery system, being configured to define a plurality of cells having lengths of at least 5 mm, each of the cells being defined by a pair of substantially elongate struts that define boundaries of the cell,

when in a non-constrained state thereof, being configured such that at least a portion of each of the elongate struts forms a helix around a circumference of the stent; and

a control capsule coupled to the stent such that when the stent is in the constrained state thereof more than 20 percent of a length of the capsule is accommodated inside one of the elongate cells.

For some applications, the stent is configured such that when in the non-constrained state thereof, at least 30 percent of a length of each of the elongate struts forms a helix around the circumference of the stent.

For some applications, the stent is configured such that, when in the radially-constrained state thereof inside the delivery system, the plurality of cells are configured to have lengths of at least 10 mm.

For some applications, the control capsule is coupled to the stent such that, when the stent is in the constrained state thereof, more than 40 percent of the length of the capsule is accommodated inside one of the elongate cells.

For some applications, the control capsule is coupled to the stent such that, when the stent is in the constrained state thereof, more than 60 percent of the length of the capsule is accommodated inside one of the elongate cells.

There is additionally provided, in accordance with some applications of the present invention, a method for use with a blood vessel of a subject and a delivery system, the method including:

inserting a stent into the blood vessel via the delivery system,

the stent, when in a radially-constrained state thereof inside the delivery system, defining a plurality of cells having lengths of at least 5 mm, each of the cells being defined by a pair of substantially elongate struts that define boundaries of the cell, and

a control capsule being coupled to the stent such that, when the stent is in the constrained state thereof, more than 20 percent of a length of the capsule is accommodated inside one of the elongate cells; and

causing at least a portion of each of the elongate struts to form a helix around a circumference of the stent, by releasing the stent into the blood vessel from the delivery system.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject and a delivery system, the apparatus including:

a stent configured to be inserted into the blood vessel via the delivery system, the stent being shaped to define struts;

at least one electrode coupled to the stent;

a control capsule configured to drive the electrode to drive a current into the blood vessel; and

a dynamic coupling mechanism configured to couple the control capsule to the stent such that:

when the coupling mechanism is in a constrained state thereof inside the delivery system, the coupling mechanism maintains the control capsule at a first location with respect to the stent, and

in response to the coupling mechanism assuming a non-constrained state thereof by being released from the delivery system, the coupling mechanism moves the control capsule to a second location with respect to the stent.

For some applications, the coupling mechanism is configured:

by maintaining the control capsule at a first location with respect to the stent, to maintain the control capsule adjacent to a portion of the stent within which the struts of the stent are relatively spaced from each other, and

by moving the control capsule to the second location with respect to the stent, to move the control capsule to a location that is adjacent to a portion of the stent within which the struts of the stent are relatively close each other.

For some applications, the coupling mechanism is configured, by moving the control capsule to the second location with respect to the stent, to move the control capsule toward the electrode.

For some applications, the dynamic coupling mechanism, by coupling the control capsule to the stent such that, when the coupling mechanism is in the constrained state thereof inside the delivery system, the control capsule is maintained at the first location with respect to the stent, is configured to reduce a minimum diameter to which the stent may be radially-constrained relative to if the coupling

mechanism were to couple the control capsule to the stent such that when the coupling mechanism is in the constrained state thereof inside the delivery system the control capsule were to be disposed at the second location with respect to the stent.

There is further provided, in accordance with some applications of the present invention, a method for use with a blood vessel of a subject and a delivery system, the method including:

providing:

a stent that is shaped to define struts,

an electrode coupled to the stent, and

a control capsule configured to drive the electrode to drive a current into the blood vessel, the control capsule being coupled to the stent via a dynamic coupling mechanism;

maintaining the control capsule at a first location with respect to the stent, by maintaining the coupling mechanism in a constrained configuration thereof, by inserting the stent via the delivery system, the delivery system being sized such as to constrain the coupling mechanism; and

subsequently, moving the control capsule to a second location with respect to the stent, by causing the coupling mechanism to assume a non-constrained state thereof, by releasing the coupling mechanism from the delivery system.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, including:

a stent configured to be placed in the blood vessel, the stent including:

a first strut portion including struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

a second strut portion including struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

the first and second strut portions being coupled to one another by at least one helical member,

the stent being configured such that, in the absence of force being applied to the stent, the first and second strut portions, and the helical member define a common longitudinal axis; and

at least one electrode disposed on at least an outer surface of the stent.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, and a delivery system, the apparatus including:

a stent configured to be placed in the blood vessel via the delivery system, the stent defining a generally cylindrical shape, in the absence of force being applied to the stent, and the stent being configured to assume a compressed configuration while inside the delivery system and to expand radially upon protruding from the delivery system;

a control capsule coupled to the stent;

an antenna configured to be placed in the blood vessel via the delivery system, and, while inside the blood vessel to receive electrical power from outside the subject's body, and to provide power to the control capsule, the antenna defining a generally cylindrical shape, in the absence of force being applied to the antenna,

the antenna being configured to assume a compressed configuration while inside the delivery system and to expand radially upon protruding from the delivery system such that radial expansion of the antenna is limited by a circumference of the blood vessel, even while the stent is in its compressed state due to being disposed entirely within the delivery system.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, including:

a coiled antenna configured to be placed inside the blood vessel and configured to receive power by RF energy being transmitted toward the antenna, such as to generate an inductive current through the antenna;

a control capsule;

an electrode, the control capsule being configured to use the inductive current to drive a current into the blood vessel via the electrode;

a switch configured to switch the antenna between:

a first configuration thereof, in which first configuration the coiled antenna defines a first number of turns, and

a second configuration thereof, in which the coiled antenna defines a second number of turns, the second number being different from the first number.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, including:

a coiled antenna configured to be placed inside the blood vessel and configured to receive power by RF energy being transmitted toward the antenna, such as to generate an inductive current through the antenna,

the antenna being configured such that, in response to a diameter of the antenna increasing, an inductance of the antenna remains substantially constant, by a pitch of the antenna decreasing; and

a transmitter configured to be disposed outside of the blood vessel, the transmitter being configured to transmit RF energy toward the antenna.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, including:

an antenna configured to be placed inside the blood vessel;

a transmitter configured to generate an inductive current in the antenna, by transmitting RF energy toward the antenna; and

a control unit configured to measure the inductive current in the antenna, and, in response thereto, to determine a change in a concentration of an electrolyte in blood of the subject.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, including:

a stent configured to be placed in the blood vessel, the stent defining cells that are defined by proximal and distal pairs of struts, a compliance of the proximal pair of struts being different from a compliance of the distal pair of struts.

There is further provided, in accordance with some applications of the present invention, a method for use with a blood vessel of a subject, including:

providing:

a stent that includes:

a first strut portion including struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

a second strut portion including struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

the first and second strut portions being coupled to one another by at least one helical member,

the stent being configured such that, in the absence of force being applied to the stent, the first and second strut portions, and the helical member define a common longitudinal axis; and

placing the stent inside the blood vessel.

There is further provided, in accordance with some applications of the present invention, a method for use with a blood vessel of a subject, including:

inserting into the blood vessel via a delivery system, a stent and an antenna, the stent and the antenna both defining generally cylindrical shapes, in the absence of a force being applied thereto, and the stent and the antenna assuming compressed configuration while disposed within the delivery system, a control capsule being coupled to the stent and being configured to receive electrical power via the antenna;

causing the antenna to radially expand such that radial expansion of the antenna is limited by a circumference of the blood vessel, by advancing the antenna out of delivery system, while the stent is in its compressed configuration due to being disposed entirely within the delivery system.

There is further provided, in accordance with some applications of the present invention, a method for use with a coiled antenna that is placed inside a blood vessel, the method including:

operating a control unit to:

provide electrical current to a control capsule that is electrically coupled to the antenna, by transmitting RF energy toward the antenna; and

compensate for changes in an impedance of the control capsule, by switching the antenna from a first configuration thereof, in which the coiled antenna defines a first number of turns, to a second configuration thereof, in which the coiled antenna defines a second number of turns.

There is further provided, in accordance with some applications of the present invention, a method for use with a blood vessel of a subject, including:

providing a coiled antenna configured to receive power by RF energy being transmitted toward the antenna, such as to generate an inductive current through the antenna, the antenna being configured such that, in response to a diameter of the antenna increasing, an inductance of the antenna remains substantially constant, by a pitch of the antenna decreasing; and

placing the antenna inside the subject's blood vessel.

There is further provided, in accordance with some applications of the present invention, a method for use with an antenna that has been placed in a blood vessel, the method including:

generating an inductive current in the antenna, by transmitting RF energy toward the antenna;

measuring the inductive current in the antenna; and

in response thereto, determining a change in a concentration of an electrolyte in blood of the subject.

There is further provided, in accordance with some applications of the present invention, apparatus for use with a blood vessel of a subject, the apparatus including:

a stent configured to be placed in the blood vessel, the stent including:

a first portion thereof;

a second portion thereof;

a flexible central portion thereof, a compliance of the flexible central portion of the stent being greater than compliances of the first and second strut portions of the stent; and

coupling elements,

the first portion, the flexible central portion, and the second portion being modularly formed, and being coupled to each other via the coupling elements such that the flexible central portion is disposed between the first and second portions;

an antenna coupled to at least one of the first and second portions;

one or more electrodes coupled to at least one of the first and second portions; and

a control capsule coupled to one of the first and second portions, the control capsule being configured to drive a current into the blood vessel via the electrode, and the antenna being configured to receive power and to power the control capsule using the received power.

For some applications, the coupling elements comprise threads configured to tie the first portion to the central portion, and the central portion to the second portion.

For some applications, the coupling elements comprise wires configured to tie the first portion to the central portion, and the central portion to the second portion.

The present invention will be more fully understood from the following detailed description of embodiments thereof, taken together with the drawings, in which:

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is schematic illustrations of a stent placed inside a subject's aorta, electrodes being disposed on the stent, in accordance with some applications of the present invention;

Figs. 2A-C are schematic illustrations of a stent, in accordance with respective applications of the present invention;

Fig. 3A is a schematic illustration of a post of a stent, in accordance with some applications of the present invention;

Fig. 3B is a schematic illustration of a coiled electrode disposed on a post of a stent, in accordance with some applications of the present invention;

Fig. 4 is a schematic illustration of an electrode configured to be coupled to a stent, in accordance with some applications of the present invention;

Fig. 5 is a schematic illustration of a mechanism for facilitating coupling of an electrode to a stent, in accordance with some applications of the present invention;

Figs. 6A-B are schematic illustrations of a stent that defines a stent body with posts protruding from a distal end of the stent body, in accordance with some applications of the present invention;

Figs. 7A-B are schematic illustrations of a stent that defines a stent body with posts protruding from a distal end of the stent body, in accordance with some additional applications of the present invention;

Figs. 7C-D are schematic illustrations of a barb of a stent, in accordance with some applications of the present invention;

Fig. 7E is a schematic illustration of a stent that defines a stent body with posts protruding from a distal end of the stent body, in accordance with some additional applications of the present invention;

Figs. 8A-B are schematic illustrations of a construction for coupling a coiled electrode to a post of a stent, in accordance with some applications of the present invention;

Figs. 9A-E are schematic illustration of respective steps of the opening of a stent that defines two junctions, in accordance with some applications of the present invention;

Figs. 10A-E are schematic illustration of respective steps of the opening of a stent that defines three junctions, in accordance with some applications of the present invention;

Fig. 11 is a graph showing experimental results that demonstrate a correlation between the variation with time of an inductive voltage that was measured in an antenna, and a component of the subject's blood pressure signal that relates to the subject's cardiac cycle, in accordance with some applications of the present invention;

Fig. 12 is a graph showing experimental results that demonstrate a correlation between the variation with time of the inductive voltage that was measured in the antenna, and a component of the subject's blood pressure signal that relates to the subject's respiratory cycle, in accordance with some applications of the present invention;

Figs. 13A-C are schematic illustrations of a stent that defines cells that are defined by pairs of struts having respective compliances, in accordance with some applications of the present invention;

Fig. 13D is a schematic illustration of a stent that defines cells that are defined by pairs of struts having respective compliances, in accordance with some additional applications of the present invention;

Fig. 14 is a schematic illustration of a stent that defines strut portions that are coupled to each other by at least one helical-shaped member, in accordance with some applications of the present invention;

Figs. 15A-B are schematic illustrations of a radially self-expandable antenna, in accordance with some applications of the present invention;

Fig. 15C is a schematic illustration of a radially self-expandable antenna, in accordance with some additional applications of the present invention;

Fig. 16 is a schematic illustration of a stent that includes a stent body that is braided, and a stent head that is formed of at least partially rigid struts, in accordance with some applications of the present invention;

Fig. 17 is a schematic illustration of a stent that includes graft material, in accordance with some applications of the present invention;

Figs. 18A-B are schematic illustrations of a stent that is shaped to define a flexible central portion thereof, in accordance with some applications of the present invention;

Figs. 19A-B are schematic illustrations of a stent that is shaped to define a flexible central portion thereof, in accordance with some alternative applications of the present invention;

Figs. 20A-B are schematic illustrations of a stent that is shaped to define a flexible central portion thereof, in accordance with some further alternative applications of the present invention;

Fig. 21 is a schematic illustration of a stent that is shaped to define a flexible central portion thereof, in accordance with some still further alternative applications of the present invention;

Figs. 22A-B are schematic illustrations of a stent that is shaped to define elongate cells, respectively, while the stent is in partially constrained and non-constrained states thereof, in accordance with some applications of the present invention; and

Figs. 23A-B are schematic illustrations of a control capsule coupled to a stent via a dynamic coupling mechanism, in accordance with some applications of the present invention.

## DETAILED DESCRIPTION OF EMBODIMENTS

Reference is now made to Fig. 1, which is a schematic illustration of a stent 20 placed inside a subject's blood vessel 21, at least one electrode 22 (Fig. 2A), and typically, a plurality of electrodes, being disposed on the stent, in accordance with some applications of the present invention. Reference is also made to Fig. 2A, which is a schematic illustration of the stent in the absence of the subject's anatomy, in accordance with some applications of the present invention.

It is noted that Fig. 1 shows stent 20 disposed inside the subject's aorta. However, the scope of the present invention includes placing the stent in any blood vessel of the subject, e.g., the subject's carotid artery, pulmonary artery, and/or renal artery. For example, the stent may be placed in the renal artery, in order to treat renal dysfunction, and/or in the pulmonary artery, in order to treat pulmonary hypertension. Alternatively or additionally, the stent may be placed in the pulmonary artery and/or the carotid artery in order to be used for vagal stimulation (e.g., vasovagal stimulation), for example, in order to treat gastroesophageal reflux disease (GERD). Similarly, although Fig. 1 shows a portion of the stent disposed in the aortic arch, and a portion of the stent disposed in the descending aorta, the scope of the present invention includes placing the stent at any location within the aorta, such as in the ascending aorta, the descending aorta, the aortic arch, or a combination thereof.

For some applications, electrodes 22 are placed in contact with an aortic site, which is typically as described in US 13/210,778 (published as US 2012/0035679), US 12/957,799 to Gross (published as US 2011/0137370), and/or US 12/792,227 to Gross (published as US 2010/0305392), all of which applications are incorporated herein by reference. The aortic site is typically between the bifurcation of the aorta with the left subclavian artery and the bifurcation of the aorta with the fifth intercostal artery. Further typically, the aortic site is between the bifurcation of the aorta with the left subclavian artery and the bifurcation of the aorta with the fourth intercostal artery, e.g., between the bifurcation of the aorta with the left subclavian artery and the bifurcation of the aorta with the first intercostal artery. For some applications, the aortic site is between the bifurcations of the aorta with the first and fifth intercostal arteries.

For some applications, a current is driven into the subject's aorta, e.g., in order to treat the subject for a condition such as congestive heart failure, diastolic heart failure, and/or hypertension, e.g., as described in US 13/210,778 (published as US 2012/0035679), US 12/957,799 to Gross (published as US 2011/0137370), and/or US 12/792,227 to Gross (published as US 2010/0305392), all of which applications are incorporated herein by reference. For some applications, the subject's cardiac cycle is determined by detecting an electrical signal from the subject's aorta, via electrodes 22, and deriving the subject's ECG and/or blood pressure from the electrical signal detected at the aorta, e.g., in accordance with techniques described in US 12/792,227 to Gross (published as US 2010/0305392). For some applications, electrical stimulation is applied to the aorta in coordination with the subject's cardiac cycle, based upon the electrical signal detected at the aorta. For some applications, in response to detecting that a subject is undergoing an epileptic seizure, the subject's vagus nerve is stimulated by driving a current into the subject's aorta. For some applications, a current is driven into the subject's aorta in order to treat the subject for sleep apnea.

For some applications, electrodes are placed at a different location (e.g., a different location within the aorta, or within a different blood vessel of the subject, as described hereinabove), and a current is driven into the different location via the electrodes, or an electrical signal is detected from the different location via the electrodes. For example, a current may be driven into the different location in order to treat the subject for congestive heart failure and/or hypertension.

Typically, the compliance of stent 20 varies along the length of the stent. For some applications, the compliance of the stent varies along the length of the stent in a manner that conforms with local stresses exerted on the stent by collagen fibers of the blood vessel. For some applications, the compliance of the stent varies along the length of the stent in a manner that facilitates placement of the stent in a curved blood vessel, the stent being configured to conform with the local shape of the blood vessel.

Typically, stent 20 includes a plurality of strut portions along the length of the stent, and the strut portions are coupled to each other at junctions 37, for example, junctions that include springs 38. Typically, the compliance of the stent at the junctions is greater than the compliance of the stent at the strut portions. For some

applications, the stent is configured to be placed in a curved blood vessel. For some applications, the compliance of the stent at the junctions facilitates curvature of the stent that conforms with the curvature of the blood vessel. For example, the compliance of the stent at the junctions may facilitate curvature of the stent such that local longitudinal axes of respective strut portions of the stent are aligned with local longitudinal axes of a curved blood vessel. For some applications, the compliance of the stent at the junctions provides flexibility to the stent while the stent is being advanced through a delivery system (such as a catheter).

For example, with reference to Fig. 2A, in order to facilitate placement of electrodes 22 at an aortic site as described hereinabove, a first strut portion 32 (e.g., a first row of struts) of stent 20 is placed at the aortic arch, and a second strut portion 34 (e.g., a second row of struts) of the stent is placed in the descending aorta. Alternatively, the second portion is placed in a portion of the aortic arch that is downstream of the aortic arch with respect to the first portion. Upon placement of the first and second portions within the aorta as described, the local longitudinal axis of the first portion of the stent is disposed at an angle from that of the second portion of the stent. As described hereinabove, in order to facilitate placement of the stent such that the positions of the first and second portions of the stent are as described, the stent defines a junction 37A, e.g., a junction that include springs 38, configured to facilitate bending of the stent, between the first and second portions of the stent. Thus, the junction acts as a joint that facilitates bending of the strut portions with respect to one another about the joint. For some applications, the stent defines additional junctions, e.g., additional springs, between other portions of the stent. For example (as shown in Figs. 2A-C), the stent may define a third strut portion 36 (e.g., a third row of struts) configured to be placed downstream of the second portion, a control capsule 30 being coupled to the third portion. For some applications, a length of the control capsule is more than 6 mm, less than 30 mm (e.g., less than 25 mm), and/or 6-30 mm (e.g., 6-25 mm). Typically, the width and depth of the capsule are each greater than 1 mm (e.g., greater than 2 mm), less than 5 mm (e.g., less than 3 mm), and/or 1-5 mm (e.g., 2-3 mm). Springs 38 disposed at junction 37B, between the second and third strut portions of the stent, facilitate bending of the stent between the second and third portions. Thus, springs 38, disposed between the second and

third strut portions of the stent, act as a joint that facilitates bending between the second and third strut portions.

It is noted that in the context of the present application, the term "spring" should not necessarily be understood to be limited to denoting an object having a particular shape. Rather, the term "spring" should be understood to denote a portion of the stent that stores potential energy when the portion is bent and releases the potential energy when a restraining force that causes the portion to bend is removed. It is further noted that, in Fig. 2A, the junctions at which the strut portions of stent 20 are connected to one another are shown as being formed as waved strips that act as springs. However, the scope of the present inventions includes using other elements at the junctions, in order to facilitate bending of the strut portions with respect to one another. For example, the struts of the stent at the junctions may be shaped such that the compliance of the stent at the junctions is greater than the compliance of the stent at the strut portions, as described hereinbelow with reference to Fig. 7E. Alternatively or additionally, the junctions may be shaped as joints at which pairs of struts of the stent are coupled to each other by sinusoidally shaped strips, such as junction 37B of stent 20 as shown in Fig. 2C.

Stent 20 is typically configured to be placed inside the blood vessel (e.g., the aorta) percutaneously using a delivery system, e.g., using a 12 Fr - 20 Fr catheter (e.g., a 16 Fr catheter). Typically, upon being placed inside the blood vessel, the stent is partially deployed, such that (a) electrodes 22 contact the wall of the blood vessel at a given location within the blood vessel, and (b) a proximal portion of the stent is disposed inside the catheter, such that the stent may be retrieved into the catheter. The response of the subject to electrical stimulation of the blood vessel at the current location of the electrodes within the blood vessel is determined. In response thereto, the stent is (a) fully deployed at the current location of the stent, (b) retrieved into the catheter and redeployed at a different location within the blood vessel, or (c) retrieved into the catheter and removed from the subject's body (e.g., if the subject does not respond in a suitable manner to electrical stimulation of the blood vessel at any locations at which the stent is deployed). For some applications, the junctions of the stent facilitate the partial deployment of the stent such that (a) electrodes 22 contact the wall of the blood vessel at a given location within the blood vessel, and (b) a proximal portion of the stent is disposed inside the catheter, such that the stent may be

retrieved into the catheter, as described in further detail below with reference to Figs. 9A-E and 10A-E.

Typically, the compliance of stent 20 is such that pulsation of the blood vessel is substantially maintained upon the stent being deployed inside the blood vessel. Further typically, the stent and components coupled thereto (such as control capsule 30) are shaped such as to substantially maintain blood flow through the blood vessel upon deployment of the stent inside the blood vessel.

For some applications, stent 20 is cut from a nitinol tube (or a tube made from a different material, such as stainless steel) having a wall thickness of more than 0.3 mm (e.g., more than 0.4 mm), and/or less than 0.7 mm (e.g., less than 0.6 mm). For some applications the length of the stent is more than 25 mm (e.g., more than 30 mm), and/or less than 100 mm (e.g., less than 40 mm). For some applications, the stent has an outer diameter of more than 10 mm (e.g., more than 15 mm), and/or less than 35 mm (e.g., less than 25 mm). Typically, the stent has a crimped profile of less than 18 Fr (e.g., 12 Fr or less), and/or more than 8 Fr (e.g., 10 Fr or more).

For some applications, a transmitter 24 (Fig. 1) is placed in a vein 26 that is in the vicinity of the blood vessel in which the stent is placed, e.g., in accordance with techniques described in US 12/957,799 to Gross (published as US 2011/0137370), which is incorporated herein by reference. A signal and/or power is typically transmitted to the electrodes by the transmitter driving the electrodes to drive a current into the subject's blood vessel. An antenna 28 that is disposed on stent 20 receives the signal, and control capsule 30 that is disposed on the stent drives the electrodes to drive the current into the blood vessel, in response to the antenna receiving the signal. For some applications, a different type of transmitter from transmitter 24 (shown in Fig. 1) is used to transmit a signal and/or power toward antenna 28.

For some applications, one or more portions of stent 20 function as antenna 28. For example, the stent may be cut from a nitinol tube and a portion of the tube functions as the antenna. Alternatively, an antenna may be coupled to the stent, e.g., using techniques described herein. For some applications, the diameter of the blood vessel at the antenna and/or hemodynamic parameters are measured using the antenna, as described in further detail hereinbelow, with reference to Figs. 11-12.

For some applications, capsule 30 is coupled to the stent mechanically, e.g., using a locking mechanism, using adhesive (e.g., epoxy), using suturing, and/or by pressing the capsule against struts of the stent, such that the capsule becomes coupled to the stent by deforming to conform with the shape of the stent struts. For some applications, the capsule is coupled to a fabric sleeve (e.g., by being printed onto the sleeve) and the sleeve is coupled (e.g., sutured) to the stent, e.g., as described hereinbelow.

For some applications, a control unit for driving electrodes 22 is disposed in a subcutaneously implanted housing 50 (Fig. 1). The control unit is coupled, via a lead 52, to transmitter 24 (e.g., a transmitting coil, as shown) that is implanted in vein 26 that is in the vicinity of the blood vessel (e.g., the aorta). For example, the transmitter may be placed in the innominate vein (also called the left brachiocephalic vein), placement of the transmitter in the innominate vein being performed via the left subclavian vein. The control unit wirelessly drives the electrodes, receives a signal from the electrodes, and/or powers circuitry associated with the electrodes (e.g., circuitry of control capsule 30) by transmitting a wireless signal to antenna 28, via transmitter 24. Typically, the transmitter is placed inside the vein such that it is at a distance from the intra-arterial electrodes of more than 2 cm and/or less than 5 cm (e.g., 2-5 cm), or more than 5 cm and/or less than 20 cm (e.g., 5-20 cm). For example, the transmitter may be placed in the pulmonary vein, innominate vein, vena cava, jugular vein, and/or subclavian vein.

For some applications, housing 50, which houses the control unit, is implanted (e.g., implanted subcutaneously) in the vicinity of electrode 22, e.g., within 10 cm of the electrode. For some applications, housing 50 is disposed on a chest belt that is worn on the subject's chest, such that the housing is outside the subject's body, but within 15 cm of the electrode. The control unit wirelessly drives the electrode, receives a signal from the electrode, and/or powers circuitry associated with the electrode (e.g., circuitry of control capsule 30), by transmitting a wireless signal to antenna 28.

For some applications, the control unit is disposed inside housing 50 and is implanted subcutaneously within the subject's body, as described hereinabove. Parameters of the control unit may be adjusted by transmitting a signal to the control

unit from outside the subject's body. Alternatively or additionally, electrical power may be supplied to the subcutaneously implanted control unit, by transmitting a signal to the control unit from outside the subject's body.

For some applications, transmitter 24 is mounted on a support structure (such as a nitinol ring) in order to orient the transmitter in a suitable orientation for transmitting a signal to antenna 28, which is coupled to the electrode. For example, the transmitter may include a coil that is mounted on the support structure such that a plane that is defined by the coil is at an angle of greater than 10 degrees from a plane that is perpendicular to the local longitudinal axis of the vein in which the transmitter is placed. Alternatively, the transmitter coil is oriented with respect to the support structure such that the plane defined by the coil is generally perpendicular to the local longitudinal axis of the vein.

For some applications, transmitter coil 24 is placed inside the vein such that the plane defined by the coil is at an angle of greater than 10 degrees from a plane that is perpendicular to the local longitudinal axis of the vein, without mounting the coil on a support structure. Alternatively, the coil is placed inside the vein such that the plane defined by the coil is generally perpendicular to the local longitudinal axis of the vein, without mounting the coil on a support structure. Typically, the transmitter coil is placed in the vein (by being mounted on a support structure, or not by being mounted on a support structure) such that the plane defined by the transmitter coil is generally perpendicular to the plane defined by antenna 28, which is placed in the subject's artery.

Reference is now made to Figs. 2B-C, which are schematic illustrations of stent 20, in accordance with respective applications of the present invention.

Figs. 2B-C are schematic illustrations of respective stents that define three junctions 37, in accordance with respective applications of the present invention. The stents shown in Figs. 2B and Fig. 2C differ from one another in that (a) springs 38 of second junction 37B of the spring shown in Fig. 2C are a different shape from the springs of the second junction of the stent shown in Fig. 2B, and (b) the shapes of the struts of the strut portions of the respective stents are different. In all other aspects, the stents shown in Figs. 2B and 2C are generally similar to one another.

Stent 20 as shown in Figs. 2B and 2C includes first strut portion 32 and second strut portion 34 that are coupled to one another at first junction 37A, the first junction being configured to facilitate bending of the first strut portion with respect to the second strut portion, such that the local longitudinal axis of the first strut portion of the stent may be disposed at an angle from that of the second strut portion of the stent. The stent additionally includes third strut portion 36 coupled to second strut portion 34 at second junction 37B, the second junction being configured to facilitate bending of the second strut portion with respect to the third strut portion, such that the local longitudinal axis of the second strut portion of the stent may be disposed at an angle from that of the third strut portion of the stent. The stent further includes fourth strut portion 39 coupled to third strut portion at third junction 37C, the third junction being configured to facilitate bending of the third strut portion with respect to the second strut portion, such that the local longitudinal axis of the third strut portion of the stent may be disposed at an angle from that of the fourth strut portion of the stent.

For some applications, the first, second and third junctions of the stent facilitate the partial deployment of the stent such that (a) electrodes 22 contact the wall of the blood vessel at a given location within the blood vessel, and (b) a proximal portion of the stent is disposed inside the catheter, such that the stent may be retrieved into the catheter, as described in further detail below with reference to Figs. 10A-E. Stent 20 as shown in Figs. 2B-C is generally similar to stent 20 as shown in Fig. 2A except that (a) stent 20 as shown in Figs. 2B-C defines an additional strut portion, and a corresponding additional junction, as compared with stent 20 of Fig. 2A, and (b) stent 20 as shown in Figs. 2B-C has posts 64 (to which coiled electrodes 22 are couplable) coupled only to the first strut portion of the stent, whereas stent 20 as shown in Fig. 2A has posts 64 coupled to the first and second strut portions.

It is noted that for some applications, a stent having more than three junctions (and correspondingly, more than four strut portions) is used. Typically, the number of junctions that the stent defines increases as the length of the stent increases. For some applications, the length of the stent that is used increases as the diameter of the vessel in which the stent is to be placed increases, in order to facilitate greater radial expansion of the distal end of the stent during partial deployment of the stent. In addition, the length of the stent that is used increases as the curvature of the vessel in which the stent is to be placed increases, in order to facilitate greater radial expansion

of the distal end of the stent during partial deployment of the stent. In a curved vessel, it may be necessary to radially expand the stent to a greater diameter than is necessary in a similarly sized straight vessel, in order to bring the electrodes into contact with a portion of the vessel wall that is curving away from the distal end of the delivery system. Furthermore, in a curved vessel, the distal end of the delivery system (e.g., the catheter), via which the stent is inserted, is typically disposed closer to the wall on one side of the vessel, and is not disposed in the center of the vessel, due to the delivery system distal end (e.g., the catheter tip) typically being substantially straight, and the vessel being curved. Therefore, in a curved vessel, it may be necessary to radially expand the stent to a greater diameter than is necessary in a similarly sized straight vessel, in order to bring the electrodes into contact with the wall that is further from the distal end of the delivery system.

As shown in Fig. 2C, stent 20 typically defines coupling elements 41 (e.g., holes) for facilitating coupling of control capsule 30 to the stent. Although in Fig. 2C, the coupling elements are shown as being disposed on the proximal half of the stent, for some applications, the coupling elements are disposed on the distal half of the stent, e.g., as shown in Fig. 7A.

Reference is now made to Fig. 3A, which is a schematic illustration of a post 64 that is defined by stent 20, in accordance with some applications of the present invention. Reference is also made to Fig. 3B, which is a schematic illustration of electrode 22 coupled to stent 20 by being placed on post 64, in accordance with some applications of the present invention. For some applications, electrode 22 is a coiled electrode. Typically, the coiled electrode is disposed on an insulation tube 60, as shown in Fig. 3B. For example, the electrode may be coupled to the insulation tube using ultraviolet (UV) (e.g., UV tape), or using adhesive, such as an epoxy adhesive. For some applications, stent 20 is shaped to define at least one post 64, as shown in Fig. 3A. The coiled electrode (typically coupled to the insulation tube) is coupled to the stent by being placed on the post. For some applications, the post is coupled to the stent at an intersection of two struts 65 of the stent, and the post protrudes radially outwardly from the stent with respect to the struts, in order to facilitate contact between the electrode and the subject's blood vessel, upon placement of the stent inside the blood vessel. For example, the post may be disposed at an angle of more than 5 degrees with respect to a plane defined by the struts at the intersection of which

the post is coupled. Alternatively, the post does not protrude radially outwardly from the stent with respect to the struts. Typically, the electrode is fixedly coupled to the post by an electrode-fixation member, for example, by placing a cap 66 on the post, such as to hold the electrode on the post. For some applications, the cap is fixedly coupled to the post, e.g., using UV, or using adhesive, such as an epoxy adhesive. For some applications, posts that are electrical insulators protrude from a distal end of the stent body, and a coiled electrode is coupled to the posts, as described in further detail hereinbelow.

For some applications, one or more posts 64 are defined by first strut portion 32 of stent 20, the first strut portion being configured to be placed in the subject's aortic arch, for example, as shown in Figs. 2A-C. Alternatively or additionally, one or more posts 64 are defined by second portion 34 of the stent, which is placed downstream of the aorta with respect to the first portion of the stent, for example, as shown in Fig. 2A. Coiled electrodes are coupled to posts 64, e.g., as described hereinabove. For some applications, the second strut portion of the stent is placed in the descending aorta, or in a portion of the aortic arch that is downstream of the aortic arch with respect to the first portion, and coiled electrodes are disposed on posts defined by the second strut portion.

Reference is now made to Fig. 4, which is a schematic illustration of electrode 22 coupled to a strut 65 of stent 20, in accordance with some applications of the present invention. For some applications, electrode 22 is mechanically coupled to strut 65 of stent 20. Alternatively or additionally, electrode 22 is coupled to post 64 (shown in Fig. 3A) of the stent. Typically, the electrode is disposed on an inner insulation tube 72. An outer insulation tube 73 is disposed over the electrode such as to insulate a first area of the electrode and such that a second area 74 of the electrode is exposed by the outer insulation tube. The second area of the electrode functions as the active area of the electrode.

Reference is now made to Fig. 5, which is a schematic illustration of a mechanism 80 for facilitating coupling of electrode 22 to stent 20, in accordance with some applications of the present invention. For some applications, as shown, at an intersection 82 at which two struts 65 meet, the struts are separable from one another. A coiled electrode (e.g., as described hereinabove) is placed on one of the struts by

separating the struts from one another and sliding the coiled electrode onto the strut. Subsequently, the struts are fixedly coupled to one another at the intersection, such as to fixedly couple the electrode to the strut. For example, the struts are coupled to one another by using laser welding, and/or sutures.

For some applications, stent 20 includes first, second, third, and fourth strut portions, and, correspondingly three junctions 37A, 37B, and 37C, e.g., as described herein with reference to Figs. 2B-C, 6A-B, and 7E of the present application. For some applications, stent 20 includes first, second, and third strut portions, and, correspondingly two junctions 37A, and 37B, e.g., as shown in Fig. 2A and in Figs. 7A-B of the present application. Alternatively, the stent may define first and second strut portions 32 and 34 that are coupled to each other at a single junction 37A, but may not include a third strut portion coupled to the second portion via springs (embodiment not shown).

For some applications, both first and second strut portions of the stent define posts, to which coiled electrodes 22 are couplable, e.g., as shown in Fig. 2A of the present application. Alternatively, only the first portion (i.e., the upstream-most, i.e., the distal-most portion) of the stent defines posts, to which coiled electrodes 22 are couplable, e.g., as shown in Figs. 2B-C, 6A-B, 7A-B, and 7E of the present application.

In accordance with respective applications, a single antenna 28 is coupled to the stent (as shown in Figs. 2A-B, and Fig. 6B of the present application), or a plurality of antennas (e.g., two antennas) are coupled to the stent (embodiment not shown).

In general, the scope of the present invention includes stents having any number of strut portions coupled to each other at junctions (e.g., via springs), and any number of antennas, posts for supporting electrodes, and/or electrodes (e.g., coiled electrodes, as shown in Fig. 3B and Fig. 8A-B, or electrodes as shown in Fig. 4) coupled to the stent at any location on the stent, as would be obvious to one skilled in the art based upon the present disclosure, mutatis mutandis. The scope of the present invention further includes stents having strut portions having sets of rings, such as sets of two to ten rings, e.g., two to six rings. In general, the term "strut portions" should be interpreted as meaning portions of the stent that provide resistance against

longitudinal compression of the stent, that permit radial compression of the stent, that permit transverse flexibility of the stent, and that are less compliant than the junctions of the stent.

For some applications, one or more components are coupled to stent 20, by coupling the components to a cuff (e.g., by printing the components on the cuff, by adhering the components to the cuff using adhesive, and/or by suturing the components to the cuff) and coupling the cuff to the stent (e.g., by suturing the cuff to the stent, or adhering the cuff to the stent using adhesive), e.g., as described in US Provisional Patent Application 61/532,660 to Dagan, which is incorporated herein by reference. For example, antenna 28, electrodes 22, and/or capsule 30 may be coupled to the stent in the aforementioned manner. For some applications, a cuff is used that is configured to be coupled to the stent along substantially the entire length of the stent. Alternatively, a cuff is used that is configured to be coupled to a portion of the length of the stent, e.g., first strut portion 32 of the stent.

Reference is now made to Figs. 6A-B, which are schematic illustrations of stent 20, stent 20 defining a stent body 90 with posts 92 protruding longitudinally from a distal end of the stent body, in accordance with some applications of the present invention. Fig. 6A shows the stent and posts without the electrical components of the stent (such as electrodes 22, antenna 28 or capsule 30) disposed on the stent, and Fig. 6B shows the stent and posts with the aforementioned electrical components disposed thereon. As shown in Fig. 6B, antenna 28 is disposed annularly on distal portions of the posts, e.g., by being threaded through holes 94 defined by the distal portions of the posts. Thus, the posts longitudinally separate the antenna from the distal end of the stent body (e.g., from the distal-most closed loop of struts of the stent body).

For some applications, the posts at least partially electrically insulate the antenna from the stent body, due to electrical resistance provided by the posts or portions thereof. For some applications, posts 92, or at least portions thereof, are formed from a material that is an electrical insulator, such as a plastic. Typically, the posts are formed of nitinol, and the nitinol posts provide electrical resistance that is such that the current from the antenna to the stent body, through the posts, is relatively low, e.g., negligible, and/or substantially zero.

As described hereinabove, for some applications antenna 28 is used to receive electrical power for powering the control capsule 30 to drive a current via electrodes 22. Typically, the antenna receives power via inductive coupling, e.g., by transmitter 24 (shown in Fig. 1), or a different transmitter, transmitting RF energy toward antenna 28, such as to generate a magnetic field through the antenna. The magnetic field passing through antenna 28 generates an inductive current through antenna 28. The current through antenna 28 in turn generates a magnetic field, which can generate an inductive current through stent body 90, which may interfere with the antenna current, and reduce the efficiency of the electrical powering of the control capsule. For some applications, by separating the antenna from the distal end of the stent body, the posts reduce the strength of the inductive current that is generated in the stent body, thereby increasing the efficiency of the electrical powering of the control capsule, via the inductive current that is generated through the antenna.

For some applications, a length L (Fig. 6A) of each of posts 92 is less than 20 mm, e.g., less than 15 mm, and/or greater than 1 mm, e.g., greater than 5 mm.

Typically, coiled electrodes 22 are coupled to stent 20 by being placed around posts 92, for example, by using a construction as shown in Figs. 8A-B. For some applications, the stent is shaped to define protrusions at the joints between the stent body and the posts. The protrusions act as stoppers 96 to support the electrode constructions, and to prevent the electrode constructions from sliding proximally with respect to the stent body.

Typically, antenna 28 is wiredly coupled to control capsule 30 (wires not shown), and the control capsule is powered using the inductive current of the antenna. For some applications, the inductive current of the antenna is the only source of power for the control capsule. The control capsule is typically configured to drive a current into the blood vessel via electrode 22 (e.g., to stimulate the blood vessel), and/or to receive an electrical parameter of the blood vessel via the electrode. For some applications, stent body 90 includes a wire holder 98 that is configured to hold in place, with respect to the stent body, the wires that couple the antenna to the control capsule, by the wires being threaded through slots defined by the wire holder.

Reference is now made to Figs. 7A-B, which are schematic illustrations of stent 20, stent 20 defining a stent body 90 with posts 92 protruding from a distal end of the stent body, in accordance with some applications of the present invention.

Stent 20 as shown in Fig. 7A is generally similar to stent 20 as shown in Fig. 6A except for the following differences. Stent 20 as shown in Fig. 7A defines only two junctions 37A and 37B (and correspondingly three strut portions 32, 34, and 36), whereas stent 20 as shown in Fig. 6A defines three junctions 37A, 37B, and 37C (and correspondingly four strut portions 32, 34, 36, and 39). In addition, on the stent shown in Fig. 7A, coupling elements 41 for facilitating coupling of the control capsule to the stent are disposed on the distal half of the stent, whereas on the stent shown in Fig. 6A, coupling elements 41 for facilitating coupling of the control capsule to the stent are disposed on the proximal half of the stent. Furthermore, stent 20 as shown in Fig. 7A defines a pair of anchoring barbs 93 and 95, which protrude from struts of the stent and are, respectively, proximally-facing and distally-facing. In accordance with some applications of the present invention, a stent is used that defines a pair of anchoring barbs 93 and 95, which protrude from struts of the stent and are, respectively, proximally-facing and distally-facing, for example, as shown in Fig. 7A. The barbs typically facilitate anchoring of the stent to the blood vessel upon expansion of the stent within the blood vessel, by the barbs becoming embedded into the wall of the blood vessel.

Stent 20 as shown in Fig. 7B is generally similar to stent 20 as shown in Fig. 7A, except that barbs 93 and 95 of the stent shown in Fig. 7B are coupled to the stent at (or in the vicinity of) respective intersections between pairs of struts of the stent, whereas barbs 93 and 95 of the stent shown in Fig. 7A are coupled to the stent such that barbs 93 and 95 protrude from the side of respective struts of the stent.

Reference is now made to Figs. 7C-D, which are schematic illustrations of respective views of barb 93 of stent 20, barb 93 being as shown in Fig. 7B. As can be seen from Fig. 7C, which shows a top view of the barb, the barb protrudes from the vicinity of an intersection of two struts 65 of the stent. As can be seen from Fig. 7D, which shows a side view of the barb, the stent is typically configured such that when the stent is open, the barb is raised with respect to a plane that is defined by struts 65. Typically the barb is raised such that a height h of the tip of the barb from the plane

defined by the struts is greater than 0.5 mm (e.g., greater than 0.8 mm), and/or less than 2 mm (e.g., less than 1.5 mm). Further typically, the barb curves away from the plane defined by the struts, a radius of curvature r of the barb being greater than 2 mm (e.g., greater than 4 mm), and/or less than 12 mm (e.g., less than 8 mm). Typically the height and curvature of the barb are such that when the stent is opened inside the blood vessel the barb becomes automatically embedded in the wall of the blood vessel without requiring distal or proximal movement of the stent with respect to the blood vessel in order to cause the barb to become embedded.

Reference is now made to Fig. 7E, which is a schematic illustration of stent 20, stent 20 defining a stent body 90 with posts 92 protruding from a distal end of the stent body, in accordance with some applications of the present invention. Stent 20 as shown in Fig. 7E is generally similar to stent 20 as shown in Fig. 6A except that the junctions of the stent shown in Fig. 7E are different from the junctions as shown in Fig. 6A. Junctions 37A-C of stent 20 as shown in Fig. 7E comprise longitudinal locations along the stent body at which the struts of the stent are shaped such as to facilitate bending of the stent at those locations.

Reference is now made to Figs. 8A-B, which are schematic illustrations of an electrode construction 100 for coupling coiled electrodes 22 to posts 92 of stent 20, in accordance with some applications of the present invention. Typically, the electrode construction is configured such that electrode 22 is electrically isolated from the antenna and from the stent body.

For some applications, the coiled electrode is disposed around an insulating layer 102. For example, the insulating layer may be composed of polyether ether ketone (PEEK), and/or another plastic. The insulating layer is typically hollow, such that the insulating layer can be placed on post 92 of stent 20. For some applications, the insulating layer is shaped to define an inner cross-section having a square shape. The square-shaped cross-section of the inner surface is configured to prevent rotation of the electrode construction about post 92. The insulating layer acts in a generally similar manner to insulation tube 60 described hereinabove, with reference to Fig. 3B.

Typically, electrode construction 100 defines a tip-encapsulation portion 106 configured to hold the distal end of coiled electrode 22 in place with respect to insulating layer 102, by encapsulating the distal end of electrode 22. Further

typically, electrode construction 100 defines a base-encapsulation portion 104 configured to hold the proximal end of coiled electrode 22 in place with respect to insulating layer 102, by encapsulating the proximal end of electrode 22. Typically, a proximal end 109 of the coiled electrode passes through the base-encapsulation portion. A wire from the control capsule is electrically coupled to the proximal end of the coiled electrode.

For some applications, the electrode construction defines an outer insulating layer 108. The outer insulating layer is placed around the side of the coiled electrode that faces the inside of the stent, in order to electrically insulate the electrode from the subject's blood.

Reference is now made to Figs. 9A-E, which are schematic illustrations of respective steps of the opening of stent 20, the stent defining two junctions 37A and 37B, in accordance with some applications of the present invention. First and second strut portions 32 and 34 of the stent are flexibly coupled to one another at first junction 37A, and second and third strut portions 34 and 36 are flexibly coupled to one another at second junction 37B. By way of illustration, Figs. 9A-E show the opening of a stent that is as shown in Fig. 7A, although the manner of the opening of any of the stents that define two or more junctions that are described herein would be generally similar.

As described hereinabove, stent 20 is typically configured to be placed inside the blood vessel (e.g., the aorta) percutaneously, e.g., using a 12 Fr - 20 Fr catheter (e.g., a 16 Fr catheter). Typically, upon being placed inside the blood vessel, the stent is partially deployed, such that (a) electrodes 22 (not shown, but which are typically coupled to first, distal-most strut portion 32) contact the wall of the blood vessel at a given location within the blood vessel, and (b) a proximal portion of the stent is disposed inside the catheter, such that the stent may be retrieved into the catheter. The response of the subject to electrical stimulation of the blood vessel at the current location of the electrodes within the blood vessel is determined. In response thereto, the stent is (a) fully deployed at the current location of the stent, (b) retrieved into the catheter and redeployed at a different location within the blood vessel, or (c) retrieved into the catheter and removed from the subject's body (e.g., if the subject does not

respond in a suitable manner to electrical stimulation of the blood vessel at any locations at which the stent is deployed).

For some applications, junctions 37 of stent 20 are configured to cause at least a portion of the outer surface of the stent to assume a convex profile upon protruding from the catheter. For example, as shown in the transition from Fig. 9B to Fig. 9C and from Fig. 9C to Fig. 9D, first junction 37A causes at least a portion of the outer surface of stent 20 to assume a convex profile upon protruding from the catheter (as indicated by arrow 110). Typically, causing the outer surface of the stent to assume the convex profile causes the angle that the outer surface of the stent makes with the vessel wall, as the stent protrudes from the catheter, to be less than if the stent were to assume a straight profile upon protruding from the catheter. For some applications, by reducing the angle that the outer surface of the stent makes with the vessel wall, damage to the vessel wall that could be caused by the distal end of the stent contacting the vessel wall is reduced. For some applications, the assumption of the convex profile by the outer surface of the stent brings the electrodes into contact with the vessel wall.

For some applications, junctions 37 of the stent are configured to facilitate retrieval of the stent into the catheter. For example, as shown in the transition from Fig. 9A to Fig. 9B, the flexible coupling between first strut portion 32 and second strut portion 34 that is provided by junction 37A allows first strut portion 32 to radially expand, while second strut portion 34 may remain substantially compressed inside the catheter. Similarly, as shown in the transition from Fig. 9D to Fig. 9E, the flexible coupling between second strut portion 34 and third strut portion 36 that is provided by junction 37B allows second strut portion 34 to radially expand, while third strut portion 36 may remain substantially compressed inside the catheter. In order to retrieve the stent into the catheter, the proximal end of the stent is pulled, such as to cause second portion 34 to become compressed by flexing about junction 37B. The proximal end of the stent then continues to be pulled, such as to cause first portion 32 to become compressed by flexing about junction 37A.

For some applications, first junction 37A of stent 20 is configured to reduce an angle that posts 92 of the stent make with the blood vessel wall as the posts protrude from the distal end of the delivery device, relative to the angle that the posts

would make with the blood vessel wall in the absence of the junction. For some applications, in this manner, the first junction reduces injury to the blood vessel wall that may be caused by the posts, relative to if the posts were to make a larger angle with the blood vessel wall. For some applications, the first junction includes waved strips of nitinol (or another alloy or metal) that function as springs, each of the strips having a width that is greater than 0.1 mm, and/or less than 1mm (e.g., less than 0.6 mm).

Reference is now made to Figs. 10A-E, which are schematic illustration of respective steps of the opening of stent 20, stent 20 defining three junctions 37A, 37B, and 37C, in accordance with some applications of the present invention. First and second strut portions 32 and 34 of the stent are flexibly coupled to one another at first junction 37A, second and third strut portions 34 and 36 are flexibly coupled to one another at second junction 37B, and third and fourth strut portions 36 and 39 are flexibly coupled to one another at third junction 37C. By way of illustration, Figs. 10A-E show the opening of a stent that is as shown in Fig. 2C, although the manner of the opening of any of the stents that define three or more junctions that are described herein would be generally similar.

As described hereinabove, with reference to Figs. 9A-E, junctions 37 of stent 20 are configured to cause at least a portion of the outer surface of the stent to assume a convex profile upon protruding from catheter. For some applications, causing the outer surface of the stent to assume the convex profile reduces damage to the vessel wall that could be caused by the distal end of the stent contacting the vessel wall, relative to if the stent were to assume a straight profile upon protruding from the catheter. For some applications, the assumption of the convex profile by the outer surface of the stent brings the electrodes into contact with the vessel wall. For some applications, junctions 37 of the stent are configured to facilitate retrieval of the stent into the catheter, as described with reference to Figs. 9A-E.

As described hereinabove, typically, the number of junctions that the stent defines increases as the length of the stent increases. For some applications, the length of the stent that is used increases as the diameter of the vessel in which the stent is to be placed increases, in order to facilitate greater radial expansion of the distal end of the stent during partial deployment of the stent. In addition, the length of

the stent that is used increases as the curvature of the vessel in which the stent is to be placed increases, in order to facilitate greater radial expansion of the distal end of the stent during partial deployment of the stent. In a curved vessel, it may be necessary to radially expand the stent to a greater diameter than is necessary in a similarly sized straight vessel, in order to bring the electrodes into contact with a portion of the vessel wall that is curving away from the distal end of the delivery system. Furthermore, in a curved vessel, the distal end of the delivery system via which the stent is inserted is typically disposed closer to the wall on one side of the vessel, and not disposed in the center of the vessel, due to the catheter tip typically being substantially straight, and the vessel being curved. Therefore, in a curved vessel, it may be necessary to radially expand the stent to a greater diameter than is necessary in a similarly sized straight vessel, in order to bring the electrodes into contact with the wall that is further from the distal end of the delivery system.

Reference is now made to Figs. 11 and 12. Fig. 11 is a graph showing experimental results that demonstrate a relationship between the variation with time of an inductive voltage that was measured in an antenna, and a component of the subject's blood pressure signal that relates to the subject's cardiac cycle, in accordance with some applications of the present invention. Fig. 12 is a graph showing experimental results that demonstrate a correlation between the variation with time of the inductive voltage that was measured in the antenna, and a component of the subject's blood pressure signal that relates to the subject's respiratory cycle, in accordance with some applications of the present invention.

An antenna that was disposed on a stent was placed inside the aorta of a sheep. A transmitter that was disposed outside the sheep's body was used to transmit RF energy toward the antenna. Wires were used to connect the antenna to a computer that was disposed outside of the sheep's body, in order to record the inductive voltage that was generated at the antenna, as a result of the RF energy that was transmitted toward the antenna. Simultaneously with the detection of the inductive voltage at the antenna, the sheep's blood pressure was measured using a sphygmomanometer that was connected to a leg of the sheep.

The bottom curve of the graph of Fig. 11 shows the variation of the inductive voltage of the antenna with time, the x-axis of the graph measuring 1 second time

periods. The top curve of the graph of Fig. 11 shows the simultaneously-measured blood pressure of the sheep. It may be observed that the inductive voltage signal is correlated to the blood pressure signal. The inventors of the present invention hypothesize that the variation of the inductive voltage of the antenna that corresponds with the blood pressure signal is due to variations in the circumference of the antenna over the course of the subject's cardiac cycle. Since the antenna is disposed on a stent and the radial expansion of the stent is limited by the circumference of the blood vessel, the circumference of the antenna varies over the course of the subject's cardiac cycle, as the circumference of the blood vessel varies, and in turn, the circumference of the stent varies.

The bottom curve of the graph of Fig. 12 shows the variation of the inductive voltage of the antenna with time, the x-axis of the graph measuring 5 second time periods. The top curve of the graph of Fig. 12 shows the simultaneously-measured blood pressure of the sheep. It may be observed that in both the inductive voltage signal and in the blood pressure signal there is an envelope having a period of approximately 5 seconds. For example, in the top graph of Fig. 12, the envelope peaks at around 20 seconds, and then peaks again at around 24.5 seconds. The envelope of the blood pressure signal is indicative of the subject's respiratory cycle. It may be observed that the envelope of inductive voltage signal is correlated to the envelope of the blood pressure signal. The inventors hypothesize that the variation of the inductive voltage of the antenna that corresponds with the envelope blood pressure signal is due to the antenna moving with respect to the transmitter, as the subject's abdomen undergoes movement due to the subject's breathing. It is noted that, in Fig. 12, the troughs in the inductive voltage signal correspond to peaks in the blood pressure signal, whereas, in Fig. 11, the troughs in the inductive voltage signal correspond to troughs in the blood pressure signal. The inventors hypothesize that this is because the effect on the inductive voltage of the antenna moving with respect to the transmitter over the course of the subject's respiratory cycle, overrides the effect on the inductive voltage of the subject's blood pressure envelope varying over the course of the respiratory cycle.

Therefore, in accordance with some applications of the present invention, an annular antenna is placed inside a blood vessel on a stent, such that the radial expansion of the stent (and therefore the antenna) is limited by the circumference of

the blood vessel. Alternatively, a stent, or at least a portion thereof, is configured to act as an antenna, the stent being placed inside a blood vessel such that the radial expansion of the stent is limited by the circumference of the blood vessel. An inductive current is generated in the antenna by transmitting RF energy toward the antenna. For some applications, RF energy is directed toward the antenna, the RF energy having a frequency of more than 50 kHz (e.g., more than 90 kHz), and/or less than 100 MHz (e.g., less than 60 MHz). The inductive current that is generated at the antenna is measured. Variations in the inductive current that are measured at the antenna are interpreted as being caused by variations in the geometry of the antenna over the course of the subject's cardiac cycle. For example, variations in the inductive current having a frequency of more than 0.5 Hz and/or less than 1.5 Hz are interpreted as being caused by variations in the geometry of the antenna over the course of the subject's cardiac cycle. For some applications, variations in the inductive current having a frequency of more than 0.05 Hz and/or less than 0.3 Hz are interpreted as being caused by variations in the geometry of the antenna over the course of the subject's respiratory cycle. In response to variations in the inductive current of the antenna, physiological parameters of the subject, e.g., hemodynamic physiological parameters of the subject, are derived. For example, the subject's cardiac rate, respiratory rate, blood pressure, blood vessel pulsation, and/or other parameters of the subject may be derived.

For some applications, the inductive current that is generated at the antenna varies as a result of changes in the concentration of an electrolyte in the subject's blood. For some applications, the inductive current in the antenna is measured, and, in response thereto, a change in the concentration of an electrolyte in the subject's blood is determined. The inventors of the present application have observed that the inductive current at the antenna is sensitive to the environment in which the antenna is placed, when RF power is transmitted to the antenna at a frequency of more than 20 MHz, e.g., more than 25 MHz. Therefore, for some applications, an inductive current is generated at antenna 28 by transmitting toward the antenna RF power at a frequency of more than 20 MHz, e.g., more than 25 MHz. The inductive current in the antenna is measured, and, in response thereto, a change in the concentration of an electrolyte in the subject's blood is determined.

It is noted that, although some applications of the present invention have been described as being used in conjunction with a stent, the scope of the present invention includes applying the apparatus and methods described herein to a stent graft, mutatis mutandis. For example, a stent graft that defines strut portions and junctions may be used, and/or an antenna may be coupled to the body of a stent graft via posts that longitudinally separate the antenna from a distal end of the body of the stent graft, in accordance with the techniques described hereinabove.

Reference is now made to Figs. 13A-B, which are schematic illustrations of stent 20, the stent defining cells 120 that are defined by proximal and distal pairs of struts, the proximal and distal pairs having respective compliances that are different from one another, in accordance with some applications of the present invention. Fig. 13A shows a flattened profile of the stent, and Fig. 13B shows the stent, as the stent is shaped while the stent is in a crimped state inside a delivery device. As shown, the stent defines first strut portion 32 and second strut portion 34, the strut portions defining cells. Cells of the strut portions are defined by a distal pair of struts 124, which define a v-shape, and a proximal pair of struts 126. The proximal pair of struts are shaped such that, in the absence of any force being applied to the stent, the proximal pair of struts define a v-shape that points in the same direction as the v-shape defined by the distal pair of struts. Thus, at rest, in combination, the proximal and distal pairs of struts define a concave kite shape (i.e., a dart shape), e.g., as shown in Fig. 13A. The compliance of the proximal pair of struts is greater than that of the distal pair of struts. For example, as shown, the proximal pair of struts may be thinner than the distal pair of struts. In order to crimp the stent, the stent is stretched, such that the proximal pair of struts become inverted with respect to the distal pair of struts, such that the proximal pair of struts defines a v-shape that faces in the opposite direction to the v-shape defined by the distal pair of struts, and such that, in combination, the proximal and distal pairs of struts define a convex kite shape, as shown in Fig. 13B.

The stent shown in Figs. 13A-B is configured such that, when the stent is placed inside a curved blood vessel, cells that are on the side of the vessel that is on the outside of the curve assume a convex kite shape, and such that cells that are on the side of the vessel that is on the inside of the curve assume a concave kite shape. Thus, the stent becomes curved such as to conform with the curvature of the blood vessel.

Reference is now made to Fig. 13C, which is a schematic illustration of stent 20, the stent defining cells 120 that are defined by proximal and distal pairs of struts, the proximal and distal pairs of struts having respective compliances that are different from one another in accordance with some additional applications of the present invention. Fig. 13C shows stent 20 in the absence of any force being applied to the stent. As shown, for some applications, stent 20 is configured such that, in the absence of any force being applied to the stent, cells 120 of the stent define spade shapes, the proximal pair of struts of the cell forming a straight line, and the distal pair 126 of struts forming a v-shape. As described above with reference to Figs. 13A-B, the compliance of the proximal pair of struts is greater than that of the distal pair of struts. For example (not shown), the proximal pair of struts may be thinner than the distal pair of struts. The stent shown in Figs. 13C is configured, such that when the stent is placed inside a curved blood vessel, cells that are on the side of the vessel that is on the outside of the curve assume a convex kite shape, by the proximal pair of struts flexing with respect to the distal pair of struts. Cells that are on the side of the vessel that are on the inside of the curve maintain a spade shape, or assume a concave kite shape. Thus, the stent becomes curved such as to conform with the curvature of the blood vessel.

It is noted that although a stent has been described that defines cells in which the proximal pair of struts of the cell has a greater compliance than the distal pair of struts, and in which the proximal pair of struts is configured to flex (e.g., by becoming inverted) with respect to the distal pair of struts, the scope of the present invention includes using a stent that defines cells in which the distal pair of struts of the cell has a greater compliance than the proximal pair of struts, and in which the distal pair of struts is configured to flex (e.g., by becoming inverted) with respect to the proximal pair of struts, mutatis mutandis. In general, stents as described with reference to Figs. 13A-C are configured such that cells of the stent, by being defined by proximal and distal pairs of struts having respective compliances that are different from one another, are configured to impart flexibility to individual cells of the stent. Furthermore, stents as described with reference to Figs. 13A-C are configured to conform with the curvature of a blood vessel in which the stent is placed, at least in part by pairs of struts of given cells of the stent flexing with respect to corresponding

pairs of struts of the cells, due to the respective pairs of struts of the cells having respective compliances.

Reference is again made to Figs. 13A-B. First strut portion 32 and second strut portion 34 of stent 20, as shown in Figs. 13A-B, are coupled to one another at first junction 37A. Junction 37A is generally similar to junction 37A described hereinabove, e.g., as described with reference to Figs. 2A-C. In addition, stent 20 as shown in Figs. 13A-B defines a stent body 90 with posts 92 protruding longitudinally from a distal end of the stent body. Posts 92 are generally similar to posts 92 described hereinabove, e.g., as described with reference to Figs. 6A-B.

For some applications, stent 20 is shaped to define a waved ring 130 that extends around the proximal ends of posts 92. The ring is typically configured such that upon protruding from the delivery system (e.g., the catheter) the ring expands such as to exert a radial force on proximal ends of posts 92 that is sufficient to cause the posts to move apart from each other. As described hereinabove, antenna 28 (not shown in Figs. 13A-B) is typically coupled to the distal ends of posts 92. Ring 130 typically expands such as to exert a radial force on proximal ends of posts 92 that facilitates expansion of the antenna, by causing the distal ends of the posts to move apart from each other.

Reference is now made to Fig. 13D, which is a schematic illustration of stent 20, the stent defining cells 120 that are defined by pairs of struts having respective compliances, in accordance with some applications of the present invention. Cells 120 of second strut portion 34 of stent 20 shown in Fig. 13D are generally similar to cells 120 of first and second strut portions of stent 120 shown in Figs. 13A-B. Stent 20 as shown in Fig. 13D differs from stent 20 as shown in Figs. 13A-B in that the stent shown in Fig. 13D comprises a distal portion 132 and a proximal portion 134 that are formed (e.g., cut from nitinol tubes) separately from one another, and/or are separately heat treated from one another. The proximal and distal portions are subsequently coupled to one another at a coupling location 136. For some applications, the proximal and distal portions of the stent are heat treated such that the proximal and distal portions have different respective compliances from one another, and/or such that the proximal and distal portions exert different respective radial

forces on the blood vessel. For some applications, stent 20, as shown in Fig. 13D, or at least a portion thereof, is configured to be balloon-expandable.

Reference is now made to Fig. 14, which is a schematic illustration of stent 20, stent 20 defining first and second strut portions 32 and 34 that are coupled to each other by at least one helical member 140, in accordance with some applications of the present invention. For some applications, a plurality of helical members couple the first and second strut portions to one another, as shown. Typically, the plurality of helical members act as a junction about which strut portions flex with respect to one another, in accordance with the techniques described hereinabove. The helical members are typically longitudinally stretched and radially compressed during insertion of stent 20 into the subject's blood vessel, via a delivery system (e.g., via a catheter). The helical members are configured to self-expand upon being advanced out of the delivery system. Thus, the helical members act as junctions between the strut portions of the stent, which junctions cause their own radial expansion, rather than being radially expanded solely due to radial expansion of the strut portions of the stent. For some applications, the two ends of each of the helical members are coupled to cells of the first and second strut portions, the cells being opposite to one another. Alternatively, the two ends of each of the helical member are coupled to cells of the first and second strut portions that are disposed at different locations around the circumference of the stent from one another. For example, the first end of a helical member may be coupled to a cell of the first strut portion, and a second end of the helical member may be coupled to a cell of the second strut portion, the cell of the second strut portion being on an opposite side of the stent (e.g., disposed at a 180 degree angle around the longitudinal axis of the stent) with respect to the cell of the first strut portion.

Reference is now made to Figs. 15A-B, which are schematic illustrations of antenna 28, antenna 28 being radially self-expandable, in accordance with some applications of the present invention. For some applications, the antenna and stent 20 are inserted into the subject's blood vessel via a delivery system (e.g., a catheter), while the antenna and the stent are in radially compressed configurations. The antenna is advanced out of the distal end of the delivery system (e.g., the catheter), while the stent is still in its radially compressed state inside the delivery system, e.g., while the stent is in its compressed state due to being disposed entirely within the

delivery system. The antenna self-expands such as to become coupled to the inner wall of the blood vessel. Subsequently, the stent is advanced out of the distal end of the delivery system, such that the stent self expands such as to become coupled to the inner wall of the blood vessel. For some applications, the aforementioned technique is used for implanting the antenna and the stent in a curved blood vessel, such as the aorta. The antenna and the stent are implanted at implantation locations that are separated from one another, such that the combined length of the stent and the antenna does not need to curve to conform with the curvature of the blood vessel, but rather, the antenna may be placed at a first location within the blood vessel and the stent may be placed at a second location within the blood vessel that is disposed at an angle with respect to the first location.

Fig. 15A shows a cross-sectional view of antenna 28, both in the compressed configuration of the antenna (on the inside of Fig. 15A), and in the expanded configuration of the antenna (Fig. 15B). The antenna is configured to expand, by an outer end 150 of the antenna spiraling outwardly with respect to an inner end 152 of the antenna, as indicated by arrow 154. The antenna is configured to become compressed by the outer end of the antenna spiraling inwardly toward the inner end of the antenna. Fig. 15B shows a three-dimensional view of the antenna, both in the compressed configuration of the antenna (on the inside of Fig. 15B), and in the expanded configuration of the antenna (on the outside of Fig. 15B).

Reference is now made to Fig. 15C, which is a schematic illustration of antenna 28, antenna 28 being radially self-expandable, in accordance with some additional applications of the present invention. For some applications, as shown, antenna 28 is formed as a self-expandable stent that may be caused to radially expand separately from stent 20 (not shown), in accordance with the technique described above with reference to Figs. 15A-B. Alternatively, the antenna may be coupled to a stent that is separate from stent 20 on which the control capsule is disposed, and the stent to which the antenna is coupled may be caused to radially expand separately from stent 20 (not shown), in accordance with the technique described above with reference to Figs. 15A-B.

For some applications, antenna 28 is a coiled antenna. Typically, as described hereinabove, the antenna receives power from a transmitter (e.g., transmitter 24,

shown in Fig. 1) that is disposed outside of the blood vessel in which the antenna is placed, and the power that the antenna receives is used to power control capsule 30 (Fig. 1). Control capsule 30 (Fig. 1) typically drives a current into the blood vessel via electrodes 22 (Fig. 1). For some applications, the control capsule operates in at least two modes: a standby mode in which the control capsule is on standby to receive a signal from the transmitter, and a stimulation mode, in which the control capsule actively drives a current through the electrodes. Typically, the power consumption of the circuitry of the control capsule when operating in standby mode differs from the power consumption of the control capsule circuitry when operating in stimulation mode, and therefore the input impedance of the circuitry of the control capsule in the two modes is different. For some applications, in order to facilitate an efficient transfer of power from the transmitter to the control capsule in each of the modes in which the control capsule operates, in response to the control capsule changing mode (or in preparation for the control capsule changing mode), the configuration of the antenna is changed from a first configuration to a second configuration, so as to compensate for the change in the input impedance of the circuitry of the control capsule. For example, subsequent to, or in preparation for, the control capsule being switched from standby mode to stimulation mode, a switch may switch the antenna from a first configuration thereof, in which the coiled antenna defines a first number of turns, to a second configuration thereof, in which the coiled antenna defines a second number of turns, the second number typically being less than the first number. An inductive current is then generated in the antenna that is used to drive the control capsule to drive a current into the blood vessel via the electrodes. Upon terminating, or in preparation for terminating, the driving of the current into the blood vessels, the control capsule is switched back into standby mode, and the switch switches the antenna back to the first configuration from the second configuration.

For example, the inventors of the present application conducted an experiment in which a coiled antenna having four turns was placed inside a container. An inductive current was generated at the antenna by directing an RF field toward the antenna from a transmitter that was placed outside the container. The antenna was used to power a control capsule, both when the control capsule was in stimulation mode, and when the control capsule was in standby mode. When the control capsule was in stimulation mode, the impedance of the control capsule circuitry was

approximately 1 kOhm, and when the control capsule was in standby mode, the impedance of the control capsule circuitry was approximately 4 kOhm. The transfer power efficiency of the antenna when inductive current was generated through all four turns of the antenna was measured during the operation of the control capsule in each of the modes. The transfer power efficiency was calculated by measuring, as a percentage, the power ratio of the transmitter coil to the antenna load. Subsequently, a lead was extracted from the antenna, such that the inductive current that was used to power the control capsule was generated through only two of the turns of the antenna. The Q factor of the antenna when inductive current was generated through two of the turns of the antenna was measured during the operation of the control capsule in each of the modes. The results of the experiment are shown in the below table:

| **Number of turns in antenna** | **2** | **4** |
|---|---|---|
| Transfer power efficiency when control capsule was in stimulation mode [%] | 18 | 13 |
| Transfer power efficiency when control capsule was in standby mode [%] | 12 | 24 |

The above results indicate that it may be most efficient to generate the inductive current through the antenna while the antenna is in a first configuration, in order to power the control capsule in the stimulation mode of the control capsule, but to generate the inductive current through the antenna while the antenna is in a second configuration, in order to power the control capsule in the standby mode of the control capsule. In particular, it may be most efficient to configure the antenna to have fewer turns when the antenna is being used to power the control capsule in stimulation mode, than when the antenna is being used to power the control capsule in standby mode.

It is noted that, when the control capsule is operating in stimulation mode, the input impedance of the control capsule may vary, since the input impedance is dependent on the impedance of the tissue and on the stimulation amplitude. In such cases, the parameters of the antenna are typically selected such as to provide a wide transfer function to provide sufficient system tolerance.

For some applications, rather than switching the antenna into configurations that are suitable for respective modes in which the control capsule is operating, the antenna operates in a single configuration, but the configuration of the antenna is chosen such the overall transfer of power from the transmitter to the antenna (both when the control capsule is operating in standby mode, and in stimulation mode) is optimized.

For some applications, the inductive current in the antenna changes as a result of changes in shape in the antenna that are caused by the blood vessel changing shape over the course of the cardiac cycle. As described hereinabove, for some applications, radial expansion of the antenna is limited by the circumference of the blood vessel. Therefore, during systole, as the blood vessel expands, the antenna expands, and during diastole, as the blood vessel contracts, the antenna contracts. For some applications, the antenna is configured such that, in response to the diameter of the antenna increasing, the inductance of the antenna remains substantially constant, by the pitch of the antenna decreasing such as to compensate for the change in the diameter of the antenna. For some applications, a braided scaffold is inserted into the blood vessel, a coiled portion of the braided scaffold being configured to act as the antenna. The scaffold is braided in a manner such that increases in the diameter of the scaffold cause the pitch of the coiled portion of the scaffold to decrease, thereby compensating for changes in the antenna's inductance due to the diameter change.

Reference is now made to Fig. 16, which is a schematic illustration of stent 20, stent 20 including a stent body 160 that is braided, and a stent head 162 that is formed from at least partially rigid struts 164, in accordance with some applications of the present invention. For some applications, as shown, a portion of stent 20 (i.e., stent body 160) that is configured to be placed in the descending aorta and to support control capsule 30 is formed of braided wires. Control capsule 30 is coupled to the stent body using coupling elements 163, which may include, for example, sutures, pins, and/or adhesive. For some applications, coupling elements 163 are additionally used to couple, to the stent body, the wiring that electrically couples the control capsule to the antenna and/or to the electrode. For some applications (not shown), the housing of the control capsule is formed from the braided wires of the stent body. Stent head 162 is generally similar to the portions of stent 20 as shown in Fig. 6B that are distal to junction 37A. Typically, the stent head includes at least partially rigid

struts 164, and posts 92 to which electrodes 22 and antenna 28 are coupled, in accordance with the techniques described hereinabove. Alternatively (not shown), the stent head may also be formed from braided wires. For such applications, posts 92 are typically formed from wires that protrude from the stent head. Stent body 160 and stent head 162 are typically formed separately from one another and are coupled to each other before being placed inside the subject's body. For example, the stent body may be tied to the stent head, e.g., using thread, or wire (e.g., nitinol wire).

It is noted that, in general, the scope of the present invention includes using a stent having any number of portions that are formed (e.g., cut from nitinol tubes) separately from each other, and/or are separately heat-treated from one another. Respective portions are typically defined by struts, by braided wire (e.g., braided nitinol wire), by helical members, by springs, and/or by members having other shapes. Respective portions may be heat treated such that the portions have different respective compliances from one another, and/or such that the portions exert different respective radial forces on the blood vessel. For some applications, having been separately formed, the portions are coupled to one another by threading the portions through one another, or by tying the portions to each other, e.g., using thread, as described with reference to Fig. 16. Typically, antenna 28 is coupled to one of the portions of the stent, and/or control capsule 30 is coupled to another one of the portions of the stent.

For some applications of the present invention, a stent is used that includes a distal portion, a central portion, and a proximal portion. Electrodes 22 and antenna 28 are typically coupled to the distal portion of the stent. The central portion of the stent is typically relatively flexible (the compliance of the central portion typically being greater than the compliances of the distal and proximal portions of the stent), such that the stent is able to conform with the curvature of a curved blood vessel (such as the aorta) in which the stent is placed. Capsule 30 is typically coupled to the proximal portion of the stent. For some applications, coupling elements (e.g., coupling elements that are similar to coupling elements 209 shown in Figs. 18A-B) that are configured to couple the stent to a delivery system are coupled to the proximal portion of the stent. The distal, central, and proximal portions of the stent may be formed (e.g., cut from nitinol tubes) separately from each other (i.e., the portions may be modularly formed), and/or are separately heat-treated from one another.

Respective portions are typically defined by struts, by braided wire (e.g., braided nitinol wire), by helical members, by springs, and/or by members having other shapes. Respective portions may be heat treated such that the portions have different respective compliances from one another, and/or such that the portions exert different respective radial forces on the blood vessel. For some applications, having been separately formed, the portions are coupled to one another using coupling elements, e.g., by threading the portions through one another, or by tying the portions to each other, e.g., using thread or wire (such as nitinol wire), as described with reference to Fig. 16.

As described hereinabove, typically electrodes 22 and antenna 28 are coupled to the distal portion of the stent. For some applications, electrodes 22 and antenna 28 are coupled to the proximal portion of the stent. Alternatively, one or more of the electrodes is coupled to the proximal portion of the stent, and one or more of the electrodes is coupled to the distal portion of the stent. Alternatively or additionally, a first portion of the antenna (e.g., one or more rings of the antenna) is coupled to the proximal portion of the stent, and a second portion of the antenna (e.g., one or more rings of the antenna) is coupled to the distal portion of the stent.

As described hereinabove, typically control capsule 30 is coupled to the proximal portion of the stent. For some applications, control capsule 30 is coupled to the distal portion of the stent. For some applications, control capsule 30 is disposed within two separate housings, each of which is coupled to the stent. For example, the first housing may house a battery (and/or a chain of capacitors that function as a battery), and the second housing may house circuitry that controls the driving of the current into the blood vessel, via the electrodes. For some applications, a battery is housed within the control capsule housing such that the control capsule is able to store electrical energy. In this manner, the control capsule is able to drive current through the electrodes even when the control capsule is not receiving power via the antenna in real-time.

For some applications of the present invention, stent 20 is configured such as to mimic the behavior of collagen. For some applications, the stent is configured such that when implanted into a blood vessel having a given diameter, the stent applies sufficient radial force to the inner wall of the blood vessel to become coupled to the

blood vessel, but does not apply a substantial amount of radial force to the blood vessel wall above that amount. The strain curve of collagen fibers is such that, when the collagen fibers are stretched by a small amount, the collagen fibers have a low stiffness, but when the collagen fibers are stretched by a greater amount, the fibers have a higher stiffness. For some applications, by not applying a substantial amount of radial force to the blood vessel wall beyond the force that is required to couple the stent to the blood vessel wall, the stent reduces stretching of collagen fibers of the blood vessel relative to if the stent were to apply a greater amount of radial force to the blood vessel wall. For some applications, the compliance of the vessel is thus greater than if the stent were to apply a greater amount of radial force to the blood vessel wall, since the stiffness of the collagen fibers in the blood vessel wall is lower than if the stent were to apply a greater amount of radial force to the blood vessel wall. For some applications, stent 20 is shaped such that struts of the stent are shaped as waves that are distributed along the length of the stent and along each cross section of the stent. For some applications, by shaping the stent in the aforementioned manner, the stent mimics properties of collagen.

It is noted that for some applications, as shown in Fig. 16, electrodes 22 are not disposed on all of posts 92 of stent head 162. For some applications, as described hereinabove, stent 20 is placed inside the subject's aorta in the vicinity of the subject's aortic arch, and the control capsule is configured to drive a current into the subject's aorta. For some applications, the control capsule is configured to stimulate the subject's vagus nerve by driving the current via the electrodes into the subject's aorta. Therefore, for some applications, the electrodes are disposed only on posts that will be disposed at a circumferential location within the aorta that is adjacent to the subject's vagus nerve. In general, the scope of the present invention includes placing electrodes on only a portion of posts 92 of any one of the configurations of stent 20 described herein as defining posts 92. Typically, posts 92 are evenly spaced around the distal end of stent 20. For soma applications, electrodes are disposed on less than 75 percent, e.g., less than 50 percent of posts 92.

Reference is now made to Fig. 17, which is a schematic illustration of stent 20, stent 20 including graft material 170, in accordance with some applications of the present invention. For some applications, stent 20 includes a distal portion 172 to which antenna 28 and electrodes 22 are coupled. Electrodes 22 are coupled to the

distal portion 172 by being coupled to graft material 170 of the distal portion, e.g., by being coupled to the graft material via sutures, or via adhesive. Stent 20 additionally defines one or more proximal portions 174. Typically, the distal portion and the one or more proximal portions of the stent are coupled to each other via junctions 176 that facilitate flexing of adjacent portions with respect to each other, in accordance with the techniques described hereinabove. Control capsule 30 is coupled to graft material 170 of one of the proximal portions of the stent, e.g., by being coupled to the graft material via sutures, or via adhesive.

As described hereinabove, stent 20 is typically configured to be placed inside the blood vessel (e.g., the aorta) percutaneously using a delivery system, e.g., using a 12 Fr - 20 Fr catheter (e.g., a 16 Fr catheter). Typically, stent 20 as shown in Fig. 17 defines coupling elements 178 at a proximal end of the stent. During insertion of the stent via the catheter, the stent is coupled to the catheter via the coupling elements. In order to place the stent inside the blood vessel at a deployment location, the stent is advanced out of the distal end of the catheter at the deployment location, and the stent becomes anchored to the blood vessel via radial expansion of the stent against the inner wall of the blood vessel. Subsequently, the coupling elements are decoupled from the catheter, and the catheter is withdrawn from the blood vessel. For some applications, stent 20 defines a ring 180 at a proximal end thereof that is reinforced with respect to other portions of the stent. For example, stent 20 may be formed of wire (e.g., nitinol wire), and a thickness of ring 180 may be greater than the thickness of the wire in other portions of the stent. Coupling elements 178 are coupled to the proximal end of the stent via ring 180.

Reference is now made to Figs. 18A-B, 19A-B, 20A-B, and 21, all of which show stent 20 in accordance with applications of the present invention in which stent 20 comprises proximal and distal strut portions that are configured to anchor the stent to a blood vessel (e.g., to the aorta) by expanding radially against the inner wall of the blood vessel. Each of the first and second strut portions typically defines a plurality of struts that are arranged such that the strut portion defines a generally circular cross-section. The stent further comprises a flexible central portion that is configured to impart flexibility to the stent. Typically, the flexible central portion permits the stent to be placed within a curved blood vessel (such as within a curved portion of the aorta), such that the proximal and distal strut portions are disposed at respective

locations around the curve. Furthermore, the flexible central portion facilitates adaptation by the stent to changes in the shape of the vessel, by the flexible central portion flexing to conform with changes in the shape of the vessel. Typically, antenna 28 and/or electrode 22 is coupled to a first one of the strut portions (typically, the distal strut portion), and capsule 30 is coupled to the second one of the strut portions (typically, the proximal strut portion). The flexible central portion of the stent couples the proximal and distal strut portions to one another and is used to support wiring that electrically couples the capsule to the antenna, and/or to the electrode.

The flexible central portion of each of the stents shown in Figs. 18A-B, 19A-B, 20A-B, and 21 defines one or more generally elongate struts (and, typically, two or more generally elongate struts). For some applications, the central portion has a length of more than 15 mm (e.g., more than 20 mm, or more than 30 mm), less than 80 mm (e.g., less than 70 mm), and/or 15-80 mm (e.g., 20-70 mm, or 30-70 mm), when the stent is in a non-constrained configuration thereof. Typically, the length of the flexible central portion of the stent comprises more than 20 percent (e.g., more than 50 percent, or more than 75 percent) of the total length of the stent, when the stent is in the non-constrained configuration thereof. Further typically, at any given longitudinal location along the length of the central portion of the stent, the flexible central portion of the stent defines no struts (and, typically, no other rigid or semi-rigid components) around a continuous angular region of more than 180 degrees (e.g., more than 225 degrees, or more than 270 degrees) around the longitudinal axis of the stent.

Figs. 18A-B are schematic illustrations of stent 20, stent 20 being shaped to define a flexible central portion 200 thereof, in accordance with some applications of the present invention. Fig 18B shows a view of the stent that is rotated through 90 degrees about the longitudinal axis of the stent, with respect to the view of the stent shown in Fig. 18A. Typically, the stent defines a first strut portion 202 and second strut portion 204, the strut portions being generally similar to the strut portions (such as portions 32 and 34) described hereinabove. Typically, each of the strut portions defines a plurality of struts that are arranged such that the strut portions define generally circular cross-sections. Further typically, the stent defines posts 92 which protrude from the first strut portion, to which posts antenna 28 and electrodes 22 are typically coupled, as described hereinabove. Still further typically, control capsule 30

is coupled to the second strut portion, e.g., via coupling elements 41. For some applications, the control capsule is coupled to the second strut portion via suturing (e.g., by coupling the control capsule to a supporting layer of fabric and suturing the fabric to the second strut portion), and/or using an adhesive.

The first and second strut portions are coupled to one another via flexible central portion 200, the flexible central portion being configured to facilitate bending of the first and second strut portions with respect to one another. By facilitating bending of the first and second strut portions with respect to one another, flexible central portion 200 facilitates placement of the stent within a curved blood vessel, such as within a curved portion of the aorta, by allowing the stent to curve such as to conform with the curvature of the blood vessel. Thus, for example, in order to facilitate placement of electrodes 22 at an aortic site as described hereinabove, first strut portion 202 may be placed in the vicinity of the aortic arch, and the second strut portion to which the control capsule is coupled may be placed in the descending aorta. Upon placement of the first and second strut portions within the aorta as described, the local longitudinal axis of the first strut portion of the stent is typically disposed at an angle from that of the second strut portion of the stent.

For some applications, flexible central portion 200 of stent 20 defines one or more generally elongate struts 206. Typically, the flexible central portion of the stent defines two or more generally elongate struts 206, as shown. Typically, elongate struts 206 have lengths LI of more than 15 mm (e.g., more than 20 mm, or more than 30 mm), less than 80 mm (e.g., less than 70 mm), and/or 15-80 mm (e.g., 20-70 mm, or 30-70 mm), when the stent is in a non-constrained configuration thereof (i.e., the configuration of the stent in the absence of any force being applied to the stent). For some applications, the central portion has length L2 of more than 15 mm (e.g., more than 20 mm, or more than 30 mm), less than 80 mm (e.g., less than 70 mm), and/or 15-80 mm (e.g., 20-70 mm, or 30-70 mm), when the stent is in the non-constrained configuration thereof. Typically, length L2 of the flexible central portion of the stent comprises more than 20 percent, e.g., more than 50 percent, of a total length LT of the stent, when the stent is in the non-constrained configuration thereof. For some applications, lengths LI and length L2 are equal to one another, as shown. Alternatively, lengths LI and L2 may be different from one another, for example, in cases in which the elongate struts are disposed helically, and/or are curved. Further

typically, at any given longitudinal location along length L2 of the central portion of the stent, the flexible central portion of the stent defines no struts (and, typically, no other rigid or semi-rigid components) around a continuous angular region of more than 180 degrees (e.g., more than 225 degrees, or more than 270 degrees) around the longitudinal axis of the stent. For example, as shown in Fig. 18B, the central portion of the stent defines only two elongate struts 206. At any given longitudinal location along the flexible central portion of the stent, the elongate struts define an angle alpha about the longitudinal axis. Thus, along the length of the flexible central portion of the stent, the central portion of the stent defines no struts (and, typically, no other rigid or semi-rigid components) around an angle of (360 - alpha) degrees. Typically (360 - alpha) is greater than 180 degrees (e.g., more than 225 degrees, or more than 270 degrees). Typically, angle alpha is at least 40 degrees, e.g., at least 60 degrees.

As described hereinabove, stent 20 is typically configured to be placed inside the blood vessel (e.g., the aorta) percutaneously using a delivery system, e.g., using a 12 Fr - 20 Fr catheter (e.g., a 16 Fr catheter). Typically, stent 20 as shown in Figs. 18A-B defines coupling elements 209 at a proximal end of second strut portion 204 of the stent. During insertion of the stent via the catheter, the stent is coupled to the catheter via the coupling elements. In order to place the stent inside the blood vessel at a deployment location, the stent is advanced out of the distal end of the catheter at the deployment location, and the stent becomes anchored to the blood vessel via radial expansion of the strut portions against the inner wall of the blood vessel. Subsequently, the coupling elements are decoupled from the catheter, and the catheter is withdrawn from the blood vessel.

Reference is now made to Figs. 19A-B, which are schematic illustrations of a stent 20, stent 20 being shaped to define a flexible central portion 210 thereof, in accordance with some alternative applications of the present invention. Fig 19B shows a view of the stent that is rotated through 90 degrees about the longitudinal axis of the stent, with respect to the view of the stent shown in Fig. 19A. As shown, the flexible central portion of stent 20 shown in Figs. 19A-B defines four elongate struts 212 that couple a first strut portion 214 of the stent to a second strut portion 216 of the stent. Stent 20 shown in Figs. 19A-B is generally similar to stent 20 shown in Figs. 18A-B. For example, first strut portion 214 defines posts 92 to which antenna 28 and electrodes 22 are typically coupled, as described hereinabove, and control capsule 30

is typically coupled to the second strut portion 216, e.g., via coupling elements 41. Flexible central portion 210 is configured to facilitate bending of the first and second strut portions with respect to one another, as described hereinabove with reference to the flexible central portion of stent 20 shown in Figs. 18A-B. As described with reference to Figs. 18A-B, at any given longitudinal location along the central portion of the stent, the stent defines no struts around an angle of more than 180 degrees around the longitudinal axis of the stent.

As described hereinabove, stent 20 is typically configured to be placed inside the blood vessel (e.g., the aorta) percutaneously using a delivery system, e.g., using a 12 Fr - 20 Fr catheter (e.g., a 16 Fr catheter). Typically, stent 20 as shown in Figs. 19A-B defines coupling elements 217 coupled to a proximal end of first strut portion 214 of the stent. During insertion of the stent via the catheter, the stent is coupled to the catheter via the coupling elements. In order to place the stent inside the blood vessel at a deployment location, initially, the first strut portion of the stent is advanced out of the distal end of the catheter at the deployment location, and the stent becomes anchored to the blood vessel via radial expansion of the first strut portion of the stent against the inner wall of the blood vessel. Subsequently, coupling elements 217 are decoupled from the catheter. Subsequent to the decoupling of the coupling elements from the catheter, the catheter is retracted such as to release the flexible central portion of the stent from the catheter. As described hereinabove, the flexible central portion of the stent facilitates curving of the stent to conform with curvature of the blood vessel in which the stent is deployed. The catheter is further retracted, such as to release second strut portion 216 of the stent, the second strut portion of the stent becoming anchored to the blood vessel by radially expanding against an inner wall of the blood vessel. Typically, the second strut portion of the stent does not include coupling elements coupled thereto, for coupling the second strut portion to the catheter. Thus, the second strut portion is typically released from the catheter by virtue of the catheter being retracted, without requiring any further action to decouple the stent from the catheter.

Reference is now made to Figs. 20A-B, which are schematic illustrations of a stent 20, stent 20 being shaped to define a flexible central portion 220 thereof, in accordance with some alternative applications of the present invention. Fig 20B shows a view of the stent that is rotated through 90 degrees about the longitudinal axis

of the stent, with respect to the view of the stent shown in Fig. 20A. As shown, the flexible central portion of stent 20 shown in Figs. 20A-B defines generally elongate struts 222 that couple a first strut portion 224 of the stent to a second strut portion 226 of the stent. The elongate struts are shaped to define straightened portions 228 of the elongate strut, and a curved portion 230 between the straightened portions of the elongate strut. The curved portion of the elongate struts is configured to act as a joint about which the straightened portions of the elongate strut bend. Stent 20 shown in Figs. 20A-B is generally similar to stent 20 shown in Figs. 18A-B. For example, first strut portion 224 defines posts 92 to which an antenna and electrodes are typically coupled (antenna and electrodes not shown), as described hereinabove, and a control capsule (not shown) is typically coupled to the second strut portion 226, e.g., via coupling elements 41. Flexible central portion 220 is configured to facilitate bending of the first and second strut portions with respect to one another, as described hereinabove with reference to the flexible central portion of stent 20 shown in Figs. 18A-B.

As described hereinabove, stent 20 is typically configured to be placed inside the blood vessel (e.g., the aorta) percutaneously using a delivery system, e.g., using a 12 Fr - 20 Fr catheter (e.g., a 16 Fr catheter). Typically, stent 20 as shown in Figs. 20A-B defines coupling elements 231 at a proximal end of first strut portion 224 of the stent. During insertion of the stent via the catheter, the stent is coupled to the catheter via the coupling elements. In order to place the stent inside the blood vessel at a deployment location, initially, the first strut portion of the stent is advanced out of the distal end of the catheter at the deployment location, and the stent becomes anchored to the blood vessel via radial expansion of the first strut portion of the stent against the inner wall of the blood vessel. Subsequently, coupling elements 231 are decoupled from the catheter. Subsequent to the decoupling of the coupling elements from the catheter, the catheter is retracted such as to release the flexible central portion of the stent from the catheter. As described hereinabove, the flexible central portion of the stent facilitates curving of the stent to conform with curvature of the blood vessel in which the stent is deployed. The catheter is further retracted, such as to release second strut portion 226 of the stent, the second strut portion of the stent becoming anchored to the blood vessel by radially expanding against an inner wall of the blood vessel. Typically, the second strut portion of the stent does not include

coupling elements coupled thereto, for coupling the second strut portion to the catheter. Thus, the second strut portion is typically released from the catheter by virtue of the catheter being retracted without requiring any further action to decouple the stent from the catheter.

Reference is now made to Fig. 21, which is a schematic illustration of stent 20 that is shaped to define a flexible central portion 235 thereof, in accordance with some still further alternative applications of the present invention. As shown, the flexible central portion of stent 20 shown in Fig. 21 defines generally helical elongate struts 237 that couple a first strut portion 239 of the stent to a second strut portion 241 of the stent. Stent 20 shown in Fig. 21 is generally similar to stent 20 shown in Figs. 18A-B. For example, first strut portion 239 defines posts 92 to which antenna 28 and electrodes (electrodes not shown) are typically coupled, as described hereinabove, and control capsule 30 is typically coupled to the second strut portion 241. Flexible central portion 235 is configured to facilitate bending of the first and second strut portions with respect to one another, as described hereinabove with reference to the flexible central portion of stent 20 shown in Figs. 18A-B.

As described hereinabove, typically stent 20 is placed in a curved blood vessel, such as the subject's aorta. Typically, elongate struts 237, by being helically shaped, are configured to enhance coupling of central portion 235 of stent 20 to the blood vessel walls, by conforming with the local shape of the blood vessel walls. Further typically, the elongate struts, by being helically shaped, impart rotational flexibility to first and second strut portions 239 and 241 with respect to one another, by facilitating rotation of the first and second strut portions with respect to one another, about the longitudinal axis of the stent.

As shown, for some applications, control capsule 30 is disposed on stent 20 such that at least a portion of the capsule is disposed within the flexible central portion of the stent. In general, control capsule 30 may be coupled to stent 20 as described with reference to any one of Figs. 18A-B, 19A-B, 20A-B, or 21 such that at least a portion of the capsule overlaps with the flexible central portion of the stent.

For some applications, rings 247 are coupled to helical elongate struts 237. For some applications, control capsule 30 is coupled to stent 20 by suturing the control capsule to rings 247, or by suturing the control capsule to fabric and suturing

the fabric to the rings. Alternatively or additionally, one or more reinforcement elements 249 (e.g., threads or wires) couple the first strut portion of the stent to the second strut portion of the stent by being threaded through the rings. The threads or wires are configured to reinforce central portion 235 of stent 20, e.g., by increasing the stiffness of the central portion. For some applications, the reinforcement elements reduce the strain that is applied to elongate struts 237 due to movement of the blood vessel (e.g., pulsation of the blood vessel due to the subject's cardiac cycle), by the reinforcement elements reducing movement of the first and second strut portions with respect to each other as a result of the blood vessel movement.

Reference is now made to Figs. 22A-B, which are schematic illustrations of stent 20, stent 20 being shaped to define elongate cells 240, respectively, in a partially constrained state of the stent (Fig. 22A) and in a non-constrained state of the stent (Fig. 22B), in accordance with some applications of the present invention. It is noted that Figs. 22A and 22B are not shown to scale, and that, in reality, when stent 20 is in its partially constrained state, the stent is longer and narrower than when the state is in its non-constrained state. As described hereinabove, stent 20 is typically configured to be placed inside the blood vessel (e.g., the aorta) percutaneously using a delivery system, e.g., using a 12 Fr - 20 Fr catheter (e.g., a 16 Fr catheter). Typically, during insertion of the stent via the catheter, the stent is maintained in a radially-constrained state (e.g., a crimped state) by the catheter. In the radially-constrained state of the stent, each of the elongate cells (each of which is defined by a pair of substantially elongate struts 242 that define boundaries of the cell) has a length L3 of more than 5 mm (e.g., more than 6 mm, or more than 10 mm). Typically, control capsule 30 is coupled to the stent (control capsule not shown in Figs. 22A-B), e.g., via coupling elements 41, as described hereinabove. For some applications, a length of the control capsule is more than 10 mm, less than 30 mm (e.g., less than 25 mm), and/or 10-30 mm (e.g., 10-25 mm). Typically, the width and depth of the capsule are each greater than 1 mm (e.g., greater than 2 mm), less than 5 mm (e.g., less than 3 mm), and/or 1-5 mm (e.g., 2-3 mm). Further typically, the lengths of the elongate cells are such that more than 20 percent (e.g., more than 40 percent, or more than 60 percent) of the length of the control capsule can be accommodated within one of the elongate cells. For some applications, by accommodating the aforementioned percentage of the length of the control capsule within one of the elongate cells, the minimum diameter

to which the stent may be radially-constrained is decreased relative to if only a smaller percentage of the capsule were to be accommodated within the cells of the stent, or if the cells of the stent were unable to accommodate any portion of the length of the capsule, in the radially constrained state of the stent.

It is noted that Fig. 22A does not show stent 20 in the fully radially-constrained state of the stent. Rather, for illustrative purposes, Fig. 22A shows the shape of the stent when the stent is partially-radially constrained. For example, stent 20 will typically be in the state shown in Fig. 22A when the distal end of the stent has been advanced out of the distal end of the catheter through which the stent is inserted into the subject's body. Fig. 22B shows stent 20 when the stent is in a non-constrained state thereof (i.e., the state of the stent when no external forces are acting on the stent). As shown in Fig. 22B, when the stent is in the non-constrained state thereof, the stent is configured such that at least a portion 244 of struts 242 forms a helix by spiraling around the circumference of the stent. For some applications, portion 244 of strut 242 that is configured to form a helix by spiraling around the circumference of the stent when the stent is in the non-constrained state of the stent comprises at least 30 percent of length L3 of strut 242.

Typically, stent 20 as shown in Figs. 22A-B defines coupling elements 245 at a proximal end of the stent. During insertion of the stent via the catheter, the stent is coupled to the catheter via the coupling elements. In order to place the stent inside the blood vessel at a deployment location, the stent is advanced out of the distal end of the catheter at the deployment location, and the stent becomes anchored to the blood vessel via radial expansion of the stent against the inner wall of the blood vessel. Subsequently, the coupling elements are decoupled from the catheter, and the catheter is withdrawn from the blood vessel.

Reference is now made to Figs. 23A-B, which are schematic illustrations of control capsule 30 coupled to stent 20 via a dynamic coupling mechanism 250, in accordance with some applications of the present invention. For some applications, it is desirable that, during insertion of the stent into the blood vessel via a delivery system (e.g., a catheter), the control capsule be disposed adjacent to a portion of the stent within which struts of the stent are relatively spaced from each other. For example, by maintaining the control capsule adjacent to a portion of the stent within

which struts of the stent are relatively spaced from each other, the minimum diameter to which the stent may be radially-constrained within the delivery system may be decreased relative to if the control capsule were disposed adjacent to a portion of the stent within which struts of the stent are in closer proximity to each other. This is because, in the region of the stent in which the struts of the stent are relatively spaced from each other, the control capsule may be accommodated, or at least partially accommodated, within a space between struts of the stent while the stent is in the radially-constrained state.

Fig. 23A shows dynamic coupling mechanism 250 in a constrained state thereof. Typically during insertion of the stent into a blood vessel via the delivery system, the delivery system maintains the coupling mechanism in the constrained state of the coupling mechanism. In the constrained state of the coupling mechanism, the coupling mechanism maintains the control capsule adjacent to a portion of the stent within which struts of the stent are relatively spaced from each other.

Fig. 23B shows dynamic coupling mechanism 250 in a non-constrained state thereof. (It is noted that Figs. 23A and 23B are not shown to scale, and that, in reality, when stent 20 is in its constrained state, the stent is longer and narrower than when the state is in its non-constrained state.) Typically, when the stent advances out of the distal end of the delivery system, at least a portion of the coupling mechanism expands (e.g., in the direction of arrows 252). The expansion of the coupling mechanism is such as to change the location of the control capsule with respect to the stent, as shown in Fig. 23B. Typically, the coupling mechanism changes the location of the control capsule with respect to the stent, such that the control capsule is disposed adjacent to a portion of the stent within which struts of the stent are relatively close to each other. For some applications, the coupling mechanism pulls the control capsule toward the distal end of the stent (i.e., toward the electrodes and antenna) such that when the stent is disposed inside the blood vessel, the capsule is disposed in the vicinity of the electrodes and/or the antenna that are coupled to the stent and to which the capsule is electrically coupled. For some applications, the coupling mechanism includes wires 256 that are coupled to the control capsule, and/or that are coupled to a portion of the stent to which the control capsule is coupled. As shown in the transition from Fig. 23A to Fig. 23B, the expansion of the coupling mechanism, causes the wires to pull the control capsule toward the distal end of the

stent. In accordance with respective applications, wires 256 are made from an alloy (such as nitinol), or from string.

Typically, stent 20 as shown in Figs. 23A-B defines coupling elements 254 at a proximal end of the stent. During insertion of the stent via the catheter, the stent is coupled to the catheter via the coupling elements. In order to place the stent inside the blood vessel at a deployment location, the stent is advanced out of the distal end of the catheter at the deployment location, and the stent becomes anchored to the blood vessel via radial expansion of the stent against the inner wall of the blood vessel. Subsequently, the coupling elements are decoupled from the catheter, and the catheter is withdrawn from the blood vessel.

Although some applications of the present invention have been described with respect to placing stent 20 inside a subject's aorta, the scope of the present invention includes placing stent 20 inside other blood vessels of a subject's body, mutatis mutandis.

For some applications, the techniques described herein are practiced in combination with techniques described in WO 07/013065 to Gross, which is incorporated herein by reference. For some applications, the techniques described herein are practiced in combination with the techniques described in WO 09/095918, entitled "Peristaltic pump for treatment of erectile dysfunction," to Gross, which claims priority from US Patent Application 2009/0198097 to Gross, the PCT application and the US application being incorporated herein by reference. For some applications, the techniques described herein are practiced in combination with the techniques described in US Patent Application 2009/0198097 to Gross, which is incorporated herein by reference. For some applications, the techniques described herein are practiced in combination with the techniques described in US 2012/0035679 to Dagan, US 2011/0137370 to Gross, and/or in US 2010/0305392 to Gross, all of which applications are incorporated herein by reference.

For some applications, the methods described herein are performed in combination with the techniques described in WO 09/095920 to Gross, which is incorporated herein by reference.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather,

the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the foregoing description.

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## CLAIMS

1. Apparatus for use with a blood vessel of a subject, comprising:

a stent configured to be placed in the blood vessel, the stent comprising:

a first strut portion at a first end of the stent, the first strut portion defining a plurality of struts that are arranged such that the first strut portion defines a generally circular cross-section;

a second strut portion at a second end of the stent, the second strut portion defining a plurality of struts that are arranged such that the second strut portion defines a generally circular cross-section; and

a flexible central portion of the stent, the first and second strut portions being coupled to one another by the flexible central portion of the stent,

in the absence of any force being applied to the stent, a length of the flexible central portion being more than 50 percent of a total length of the stent, and at any given longitudinal location along the flexible central portion, the flexible central portion defining no struts around a continuous angular region of more than 180 degrees around a longitudinal axis of the stent;

an electrode that is coupled to the stent;

an antenna coupled to the first strut portion; and

a control capsule coupled to the second strut portion,

the control capsule being configured to drive a current into the blood vessel via the electrode, and the antenna being configured to receive power and to power the control capsule using the received power.

2. The apparatus according to claim 1, wherein the length of the flexible central portion of the stent comprises more than 75 percent of the total length of the stent.

3. The apparatus according to claim 1, wherein, at any given longitudinal location along the flexible central portion, the flexible central portion is configured to define no rigid or semi-rigid components thereof within the continuous angular region of more than 180 degrees.

4. The apparatus according to any one of claims 1-3, wherein the flexible central portion is configured to facilitate bending of the first and second strut portions with respect to one another.

5. The apparatus according to claim 4, wherein the stent is configured to be placed inside a curved blood vessel and wherein the flexible central portion is configured to allow the stent to curve such as to conform with a curvature of the curved blood vessel.

6. The apparatus according to claim 5, wherein the stent is configured to be placed within a curved portion of an aorta of the subject, and wherein the flexible central portion is configured to allow the stent to curve such as to conform with a curvature of the portion of the aorta.

7. The apparatus according to any one of claims 1-3, wherein, at any given longitudinal location along the flexible central portion, the flexible central portion defines no struts around a continuous angular region of more than 225 degrees around the longitudinal axis of the stent.

8. The apparatus according to claim 7, wherein, at any given longitudinal location along the flexible central portion, the flexible central portion defines no struts around a continuous angular region of more than 270 degrees around the longitudinal axis of the stent.

9. The apparatus according to any one of claims 1-3, wherein the length of the flexible central portion of the stent is more than 15 mm.

10. The apparatus according to claim 9, wherein the length of the flexible central portion of the stent is more than 20 mm.

11. The apparatus according to claim 10, wherein the length of the flexible central portion of the stent is more than 30 mm.

12. The apparatus according to any one of claims 1-3, wherein the flexible central portion of the stent defines one or more generally elongate struts, each of the struts having a length of more than 15 mm.

13. The apparatus according to claim 12, wherein at least one of the elongate struts of the central portion of the stent is shaped to define straightened portions of the strut, and a curved portion of the strut between the straightened portions of the strut, the curved portion of the strut being configured to act as a joint about which the straightened portions bend.

14. The apparatus according to claim 12, wherein the stent is configured to be inserted into the blood vessel via a catheter, and wherein the stent defines coupling elements at a proximal end of the first strut portion configured to facilitate coupling of the first strut portion to the catheter.

15. The apparatus according to claim 14, wherein the stent does not define coupling elements coupled to the second strut portion configured to facilitate coupling of the second strut portion to the catheter.

16. The apparatus according to claim 12, wherein the elongate struts are disposed helically between the first and second strut portions of the stent.

17. The apparatus according to claim 16, wherein the stent defines a plurality of rings that are coupled to the elongate elements, the apparatus further comprising a reinforcement element configured to reinforce the central portion of the stent by coupling the first strut portion of the stent to the second strut portion of the stent by being threaded through the rings.

18. A method for use with a blood vessel of a subject, comprising:

providing:

a stent that defines:

a first strut portion at a first end of the stent, the first strut portion defining a plurality of struts that are arranged such that the first strut portion defines a generally circular cross-section;

a second strut portion at a second end of the stent, the second strut portion defining a plurality of struts that are arranged such that the second strut portion defines a generally circular cross-section; and

a flexible central portion of the stent, the first and second strut portions being coupled to one another by the flexible central portion of the stent,

in the absence of any force being applied to the stent, a length of the flexible central portion being more than 50 percent of a total length of the stent and, at any given longitudinal location along the flexible central portion, the flexible central portion defining no struts around a continuous angular region of more than 180 degrees around a longitudinal axis of the stent;

an electrode that is coupled to the stent;

an antenna coupled to the first strut portion; and

a control capsule coupled to the second strut portion,

the control capsule being configured to drive a current into the blood vessel via the electrode, and the antenna being configured to receive power and to power the control capsule using the received power; and

placing the stent inside the blood vessel.

19. The method according to claim 18, wherein providing the stent comprises providing the stent, the stent being shaped such that the length of the flexible central portion of the stent comprises more than 75 percent of the total length of the stent.

20. The method according to claim 18, wherein providing the stent comprises providing the stent, the stent being shaped such that, at any given longitudinal location along the flexible central portion of the stent, the flexible central portion is configured to define no rigid or semi-rigid components thereof within the continuous angular region of more than 180 degrees.

21. The method according to claim 18, wherein placing the stent inside the blood vessel comprises:

inserting the stent into the blood vessel via a catheter the stent being coupled to the catheter via coupling elements that are coupled to the first strut portion,

releasing the stent from the catheter by decoupling the first strut portion from the catheter and allowing the first strut portion to become coupled to the blood vessel by retracting the catheter; and

subsequently, allowing the second strut portion to become coupled to the blood vessel by further retracting the catheter.

22. The method according to any one of claims 18-21, wherein providing the stent that defines the central flexible portion comprises, upon the stent being placed inside the blood vessel, facilitating bending of the first and second strut portions with respect to one another.

23. The method according to claim 22, wherein the blood vessel includes a curved blood vessel, and wherein providing the stent that defines the central flexible portion

comprises, upon the stent being placed inside the blood vessel, allowing the stent to curve such as to conform with a curvature of the curved blood vessel.

24. The method according to claim 23, wherein the blood vessel includes a curved portion of the aorta, and wherein providing the stent that defines the central flexible portion comprises, upon the stent being placed inside the blood vessel, allowing the stent to curve such as to conform with a curvature of the portion of the aorta.

25. The method according to any one of claims 18-21, wherein providing the stent comprises providing the stent, the stent being shaped such that, at any given longitudinal location along the flexible central portion, the flexible central portion defines no struts around a continuous angular region of more than 225 degrees around the longitudinal axis of the stent.

26. The method according to claim 25, wherein providing the stent comprises providing the stent, the stent being shaped such that, at any given longitudinal location along the flexible central portion, the flexible central portion defines no struts around a continuous angular region of more than 270 degrees around the longitudinal axis of the stent.

27. The method according to any one of claims 18-21, wherein providing the stent comprises providing the stent, the stent being shaped such that the length of the flexible central portion of the stent is more than 15 mm.

28. The method according to claim 27, wherein providing the stent comprises providing the stent, the stent being shaped such that the length of the flexible central portion of the stent is more than 20 mm.

29. The method according to claim 28, wherein providing the stent comprises providing the stent, the stent being shaped such that the length of the flexible central portion of the stent is more than 30 mm.

30. The method according to any one of claims 18-21, wherein providing the stent comprises providing the stent, the stent being shaped such that the flexible central portion of the stent defines one or more generally elongate struts, each of the struts having a length of more than 15 mm.

31. The method according to claim 30, wherein providing the stent comprises providing the stent, the stent being shaped such that at least some of the elongate

struts of the central portion of the stent are shaped to define straightened portions of the strut, and a curved portion of the strut between the straightened portions of the strut, the curved portion of the strut being configured to act as a joint about which the straightened portions bend.

32. The method according to claim 30, wherein providing the stent comprises providing the stent, the stent being shaped such that the elongate struts are disposed helically between the first and second strut portions of the stent.

33. The method according to claim 32, wherein providing the stent comprises providing the stent, the stent being shaped such that the stent defines a plurality of rings that are coupled to the elongate elements, and a reinforcement element configured to reinforce the central portion of the stent couples the first strut portion of the stent to the second strut portion of the stent by being threaded through the rings.

34. Apparatus for use with a blood vessel of a subject and a delivery system, the apparatus comprising:

a stent configured to be inserted into the blood vessel via the delivery system, the stent:

when in a radially-constrained state thereof inside the delivery system, being configured to define a plurality of cells having lengths of at least 5 mm, each of the cells being defined by a pair of substantially elongate struts that define boundaries of the cell,

when in a non-constrained state thereof, being configured such that at least a portion of each of the elongate struts forms a helix around a circumference of the stent; and

a control capsule coupled to the stent such that when the stent is in the constrained state thereof more than 20 percent of a length of the capsule is accommodated inside one of the elongate cells.

35. The apparatus according to claim 34, wherein the stent is configured such that when in the non-constrained state thereof, at least 30 percent of a length of each of the elongate struts forms a helix around the circumference of the stent.

36. The apparatus according to claim 34, wherein the stent is configured such that, when in the radially-constrained state thereof inside the delivery system, the plurality of cells are configured to have lengths of at least 10 mm.

37. The apparatus according to any one of claims 34-36, wherein the control capsule is coupled to the stent such that, when the stent is in the constrained state thereof, more than 40 percent of the length of the capsule is accommodated inside one of the elongate cells.

38. The apparatus according to claim 37, wherein the control capsule is coupled to the stent such that, when the stent is in the constrained state thereof, more than 60 percent of the length of the capsule is accommodated inside one of the elongate cells.

39. A method for use with a blood vessel of a subject and a delivery system, the method comprising:

inserting a stent into the blood vessel via the delivery system,

the stent, when in a radially-constrained state thereof inside the delivery system, defining a plurality of cells having lengths of at least 5 mm, each of the cells being defined by a pair of substantially elongate struts that define boundaries of the cell, and

a control capsule being coupled to the stent such that, when the stent is in the constrained state thereof, more than 20 percent of a length of the capsule is accommodated inside one of the elongate cells; and

causing at least a portion of each of the elongate struts to form a helix around a circumference of the stent, by releasing the stent into the blood vessel from the delivery system.

40. The method according to claim 39, wherein causing at least a portion of each of the elongate struts to form a helix around a circumference of the stent comprises causing at least 30 percent of a length of each of the elongate struts to form a helix around the circumference of the stent.

41. The method according to claim 39, wherein inserting the stent comprises inserting the stent such that, when the stent is in the radially-constrained state thereof inside the delivery system, the plurality of cells are configured to have lengths of at least 10 mm.

42. The method according to any one of claims 39-41, wherein inserting the stent comprises inserting the stent such that, when the stent is in the radially-constrained state thereof inside the delivery system, more than 40 percent of the length of the capsule is accommodated inside one of the elongate cells.

43. The method according to claim 42, wherein inserting the stent comprises inserting the stent such that, when the stent is in the radially-constrained state thereof inside the delivery system, more than 60 percent of the length of the capsule is accommodated inside one of the elongate cells.

44. Apparatus for use with a blood vessel of a subject and a delivery system, the apparatus comprising:

a stent configured to be inserted into the blood vessel via the delivery system, the stent being shaped to define struts;

at least one electrode coupled to the stent;

a control capsule configured to drive the electrode to drive a current into the blood vessel; and

a dynamic coupling mechanism configured to couple the control capsule to the stent such that:

when the coupling mechanism is in a constrained state thereof inside the delivery system, the coupling mechanism maintains the control capsule at a first location with respect to the stent, and

in response to the coupling mechanism assuming a non-constrained state thereof by being released from the delivery system, the coupling mechanism moves the control capsule to a second location with respect to the stent.

45. The apparatus according to claim 44, wherein the coupling mechanism is configured:

by maintaining the control capsule at a first location with respect to the stent, to maintain the control capsule adjacent to a portion of the stent within which the struts of the stent are relatively spaced from each other, and

by moving the control capsule to the second location with respect to the stent, to move the control capsule to a location that is adjacent to a portion of the stent within which the struts of the stent are relatively close each other.

46. The apparatus according to claim 44, wherein the coupling mechanism is configured, by moving the control capsule to the second location with respect to the stent, to move the control capsule toward the electrode.

47. The apparatus according to claim 44, wherein the dynamic coupling mechanism, by coupling the control capsule to the stent such that, when the coupling mechanism is in the constrained state thereof inside the delivery system, the control capsule is maintained at the first location with respect to the stent, is configured to reduce a minimum diameter to which the stent may be radially-constrained relative to if the coupling mechanism were to couple the control capsule to the stent such that when the coupling mechanism is in the constrained state thereof inside the delivery system the control capsule were to be disposed at the second location with respect to the stent.

48. A method for use with a blood vessel of a subject and a delivery system, the method comprising:

providing:

a stent that is shaped to define struts,

an electrode coupled to the stent, and

a control capsule configured to drive the electrode to drive a current into the blood vessel, the control capsule being coupled to the stent via a dynamic coupling mechanism;

maintaining the control capsule at a first location with respect to the stent, by maintaining the coupling mechanism in a constrained configuration thereof, by inserting the stent via the delivery system, the delivery system being sized such as to constrain the coupling mechanism; and

subsequently, moving the control capsule to a second location with respect to the stent, by causing the coupling mechanism to assume a non-constrained state thereof, by releasing the coupling mechanism from the delivery system.

49. The method according to claim 48, wherein maintaining the control capsule at the first location with respect to the stent comprises maintaining the control capsule adjacent to a portion of the stent within which the struts of the stent are relatively spaced from each other, and moving the control capsule to the second location with respect to the stent comprises moving the control capsule to a location that is adjacent

to a portion of the stent within which the struts of the stent are relatively close each other.

50. The method according to claim 48, wherein moving the control capsule to the second location with respect to the stent comprises moving the control capsule toward the electrode.

51. The method according to claim 48, wherein maintaining the control capsule at the first location with respect to the stent comprises reducing a minimum diameter to which the stent may be radially-constrained within the delivery system, relative to if the coupling mechanism were to couple the control capsule to the stent such that when the coupling mechanism is in the constrained state thereof inside the delivery system the control capsule were to be disposed at the second location with respect to the stent.

52. Apparatus for use with a blood vessel of a subject, comprising:

a stent configured to be placed in the blood vessel, the stent comprising:

a first strut portion comprising struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

a second strut portion comprising struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

the first and second strut portions being coupled to one another by at least one helical member,

the stent being configured such that, in the absence of force being applied to the stent, the first and second strut portions, and the helical member define a common longitudinal axis; and

at least one electrode disposed on at least an outer surface of the stent.

53. Apparatus for use with a blood vessel of a subject, and a delivery system, the apparatus comprising:

a stent configured to be placed in the blood vessel via the delivery system, the stent defining a generally cylindrical shape, in the absence of force being applied to the stent, and the stent being configured to assume a compressed configuration while inside the delivery system and to expand radially upon protruding from the delivery system;

a control capsule coupled to the stent;

an antenna configured to be placed in the blood vessel via the delivery system, and, while inside the blood vessel to receive electrical power from outside the subject's body, and to provide power to the control capsule, the antenna defining a generally cylindrical shape, in the absence of force being applied to the antenna,

the antenna being configured to assume a compressed configuration while inside the delivery system and to expand radially upon protruding from the delivery system such that radial expansion of the antenna is limited by a circumference of the blood vessel, even while the stent is in its compressed state due to being disposed entirely within the delivery system.

54. Apparatus for use with a blood vessel of a subject, comprising:

a coiled antenna configured to be placed inside the blood vessel and configured to receive power by RF energy being transmitted toward the antenna, such as to generate an inductive current through the antenna;

a control capsule;

an electrode, the control capsule being configured to use the inductive current to drive a current into the blood vessel via the electrode;

a switch configured to switch the antenna between:

a first configuration thereof, in which first configuration the coiled antenna defines a first number of turns, and

a second configuration thereof, in which the coiled antenna defines a second number of turns, the second number being different from the first number.

55. Apparatus for use with a blood vessel of a subject, comprising:

a coiled antenna configured to be placed inside the blood vessel and configured to receive power by RF energy being transmitted toward the antenna, such as to generate an inductive current through the antenna,

the antenna being configured such that, in response to a diameter of the antenna increasing, an inductance of the antenna remains substantially constant, by a pitch of the antenna decreasing; and

a transmitter configured to be disposed outside of the blood vessel, the transmitter being configured to transmit RF energy toward the antenna.

56. Apparatus for use with a blood vessel of a subject, comprising:

an antenna configured to be placed inside the blood vessel;

a transmitter configured to generate an inductive current in the antenna, by transmitting RF energy toward the antenna; and

a control unit configured to measure the inductive current in the antenna, and, in response thereto, to determine a change in a concentration of an electrolyte in blood of the subject.

57. Apparatus for use with a blood vessel of a subject, comprising:

a stent configured to be placed in the blood vessel, the stent defining cells that are defined by proximal and distal pairs of struts, a compliance of the proximal pair of struts being different from a compliance of the distal pair of struts.

58. A method for use with a blood vessel of a subject, comprising:

providing:

a stent that includes:

a first strut portion comprising struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

a second strut portion comprising struts that, in the absence of force being applied to the stent, are shaped to define a generally cylindrical shape;

the first and second strut portions being coupled to one another by at least one helical member,

the stent being configured such that, in the absence of force being applied to the stent, the first and second strut portions, and the helical member define a common longitudinal axis; and

placing the stent inside the blood vessel.

59. A method for use with a blood vessel of a subject, comprising:

inserting into the blood vessel via a delivery system, a stent and an antenna, the stent and the antenna both defining generally cylindrical shapes, in the absence of a force being applied thereto, and the stent and the antenna assuming compressed

configuration while disposed within the delivery system, a control capsule being coupled to the stent and being configured to receive electrical power via the antenna;

causing the antenna to radially expand such that radial expansion of the antenna is limited by a circumference of the blood vessel, by advancing the antenna out of delivery system, while the stent is in its compressed configuration due to being disposed entirely within the delivery system.

60. A method for use with a coiled antenna that is placed inside a blood vessel, the method comprising:

operating a control unit to:

provide electrical current to a control capsule that is electrically coupled to the antenna, by transmitting RF energy toward the antenna; and

compensate for changes in an impedance of the control capsule, by switching the antenna from a first configuration thereof, in which the coiled antenna defines a first number of turns, to a second configuration thereof, in which the coiled antenna defines a second number of turns.

61. A method for use with a blood vessel of a subject, comprising:

providing a coiled antenna configured to receive power by RF energy being transmitted toward the antenna, such as to generate an inductive current through the antenna, the antenna being configured such that, in response to a diameter of the antenna increasing, an inductance of the antenna remains substantially constant, by a pitch of the antenna decreasing; and

placing the antenna inside the subject's blood vessel.

62. A method for use with an antenna that has been placed in a blood vessel, the method comprising:

generating an inductive current in the antenna, by transmitting RF energy toward the antenna;

measuring the inductive current in the antenna; and

in response thereto, determining a change in a concentration of an electrolyte in blood of the subject.

63. Apparatus for use with a blood vessel of a subject, the apparatus comprising:

a stent configured to be placed in the blood vessel, the stent comprising:

a first portion thereof;

a second portion thereof;

a flexible central portion thereof, a compliance of the flexible central portion of the stent being greater than compliances of the first and second strut portions of the stent; and

coupling elements,

the first portion, the flexible central portion, and the second portion being modularly formed, and being coupled to each other via the coupling elements such that the flexible central portion is disposed between the first and second portions;

an antenna coupled to at least one of the first and second portions;

one or more electrodes coupled to at least one of the first and second portions; and

a control capsule coupled to one of the first and second portions, the control capsule being configured to drive a current into the blood vessel via the electrode, and the antenna being configured to receive power and to power the control capsule using the received power.

64. The apparatus according to claim 63, wherein the coupling elements comprise threads configured to tie the first portion to the central portion, and the central portion to the second portion.

65. The apparatus according to claim 63, wherein the coupling elements comprise wires configured to tie the first portion to the central portion, and the central portion to the second portion.

FIG. 1

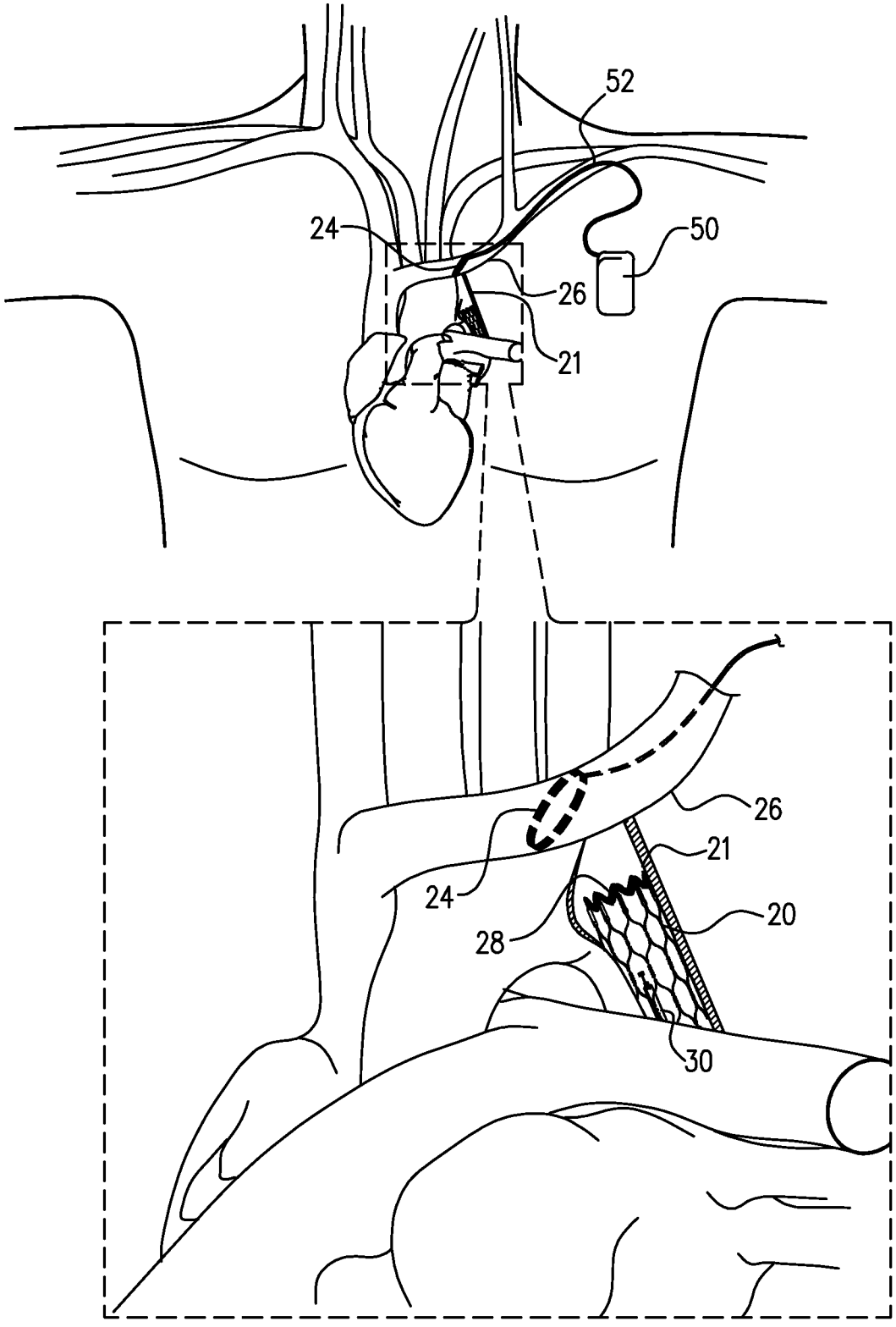

FIG. 2A

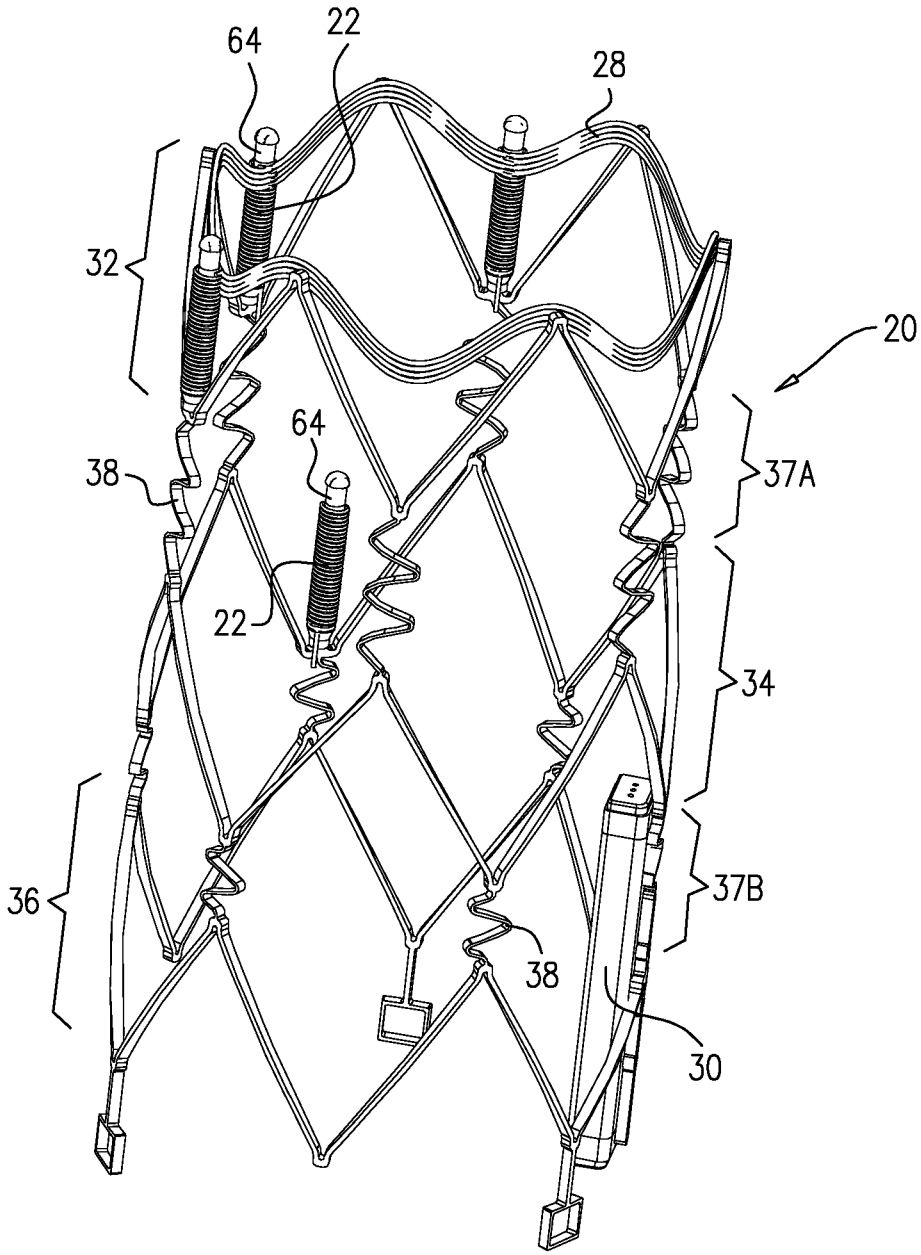

FIG. 2B

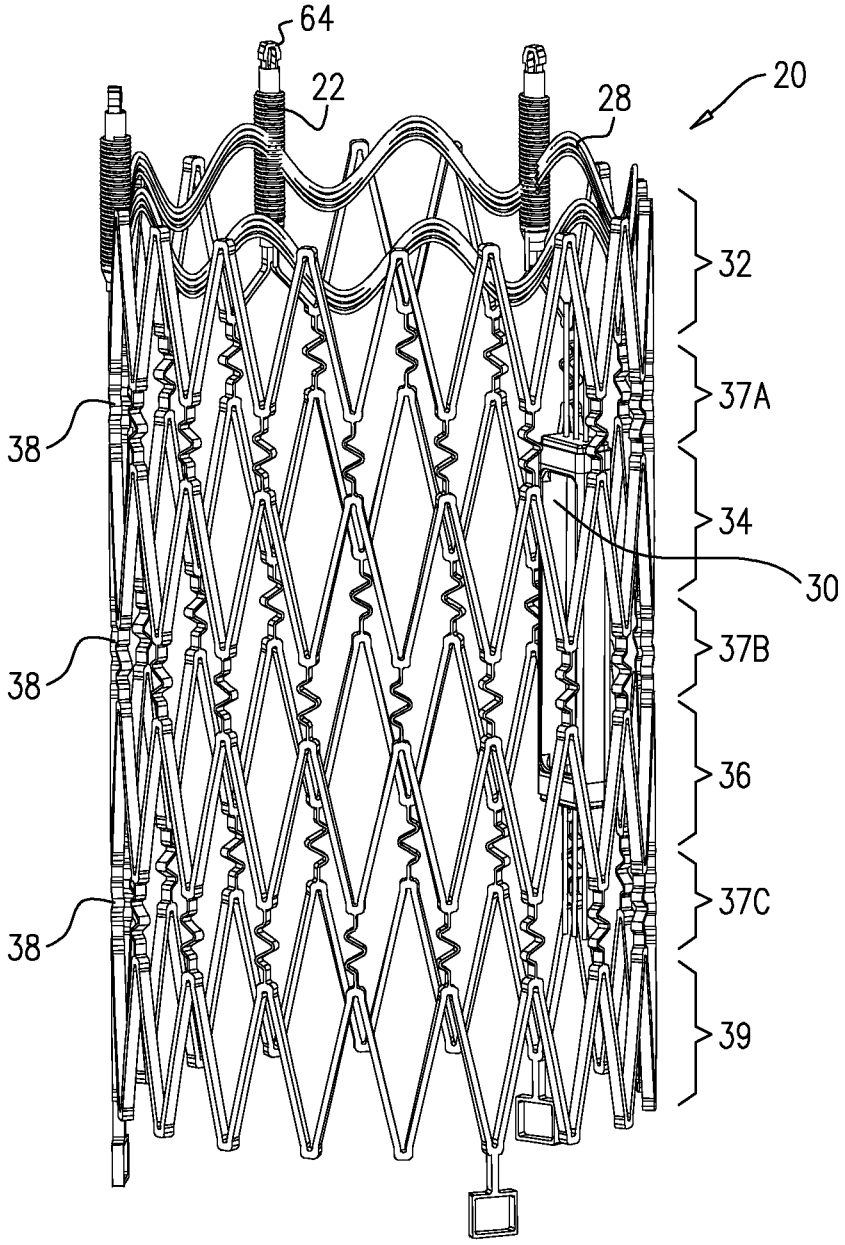

FIG. 2C

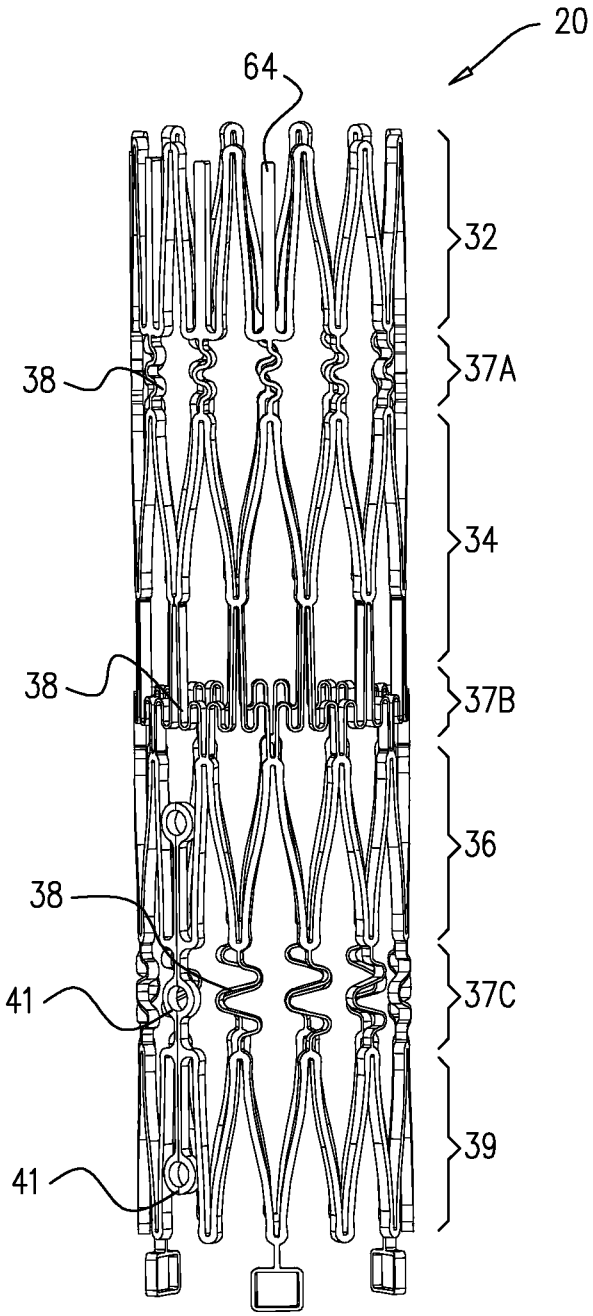

FIG. 3A

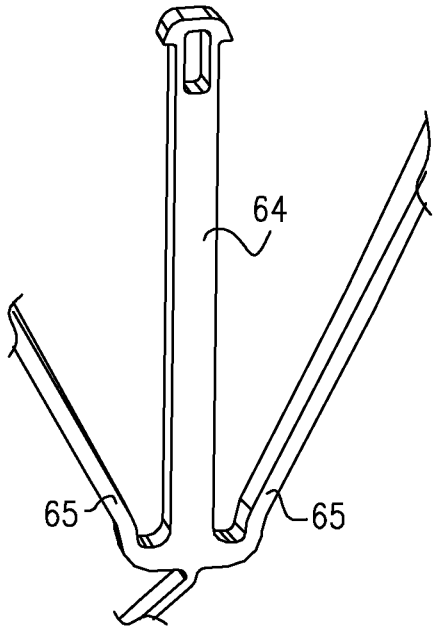


FIG. 3B

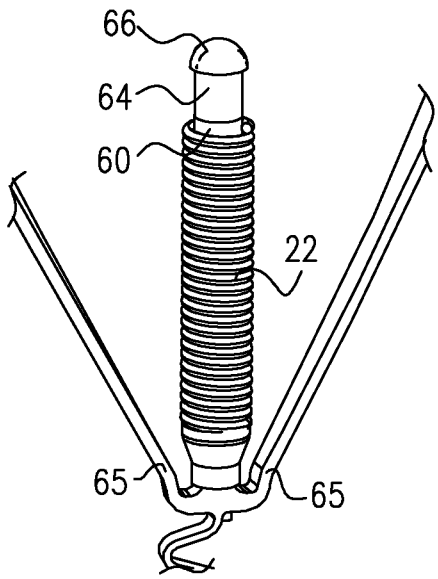


FIG. 4

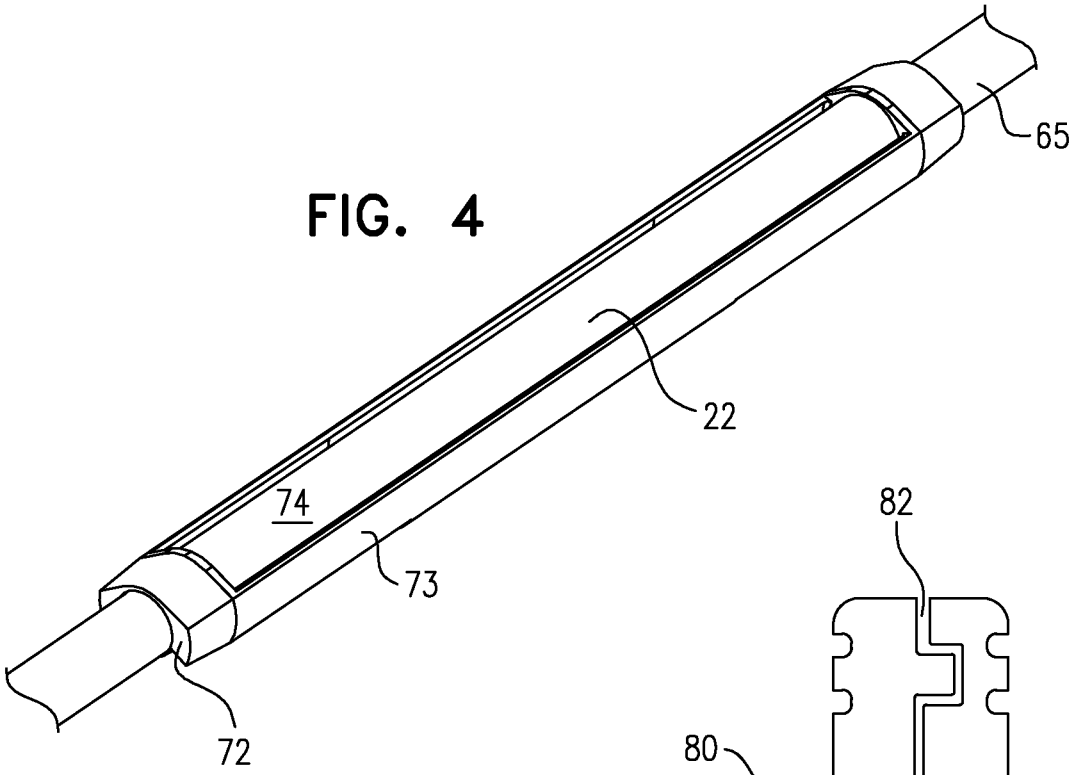


FIG. 5

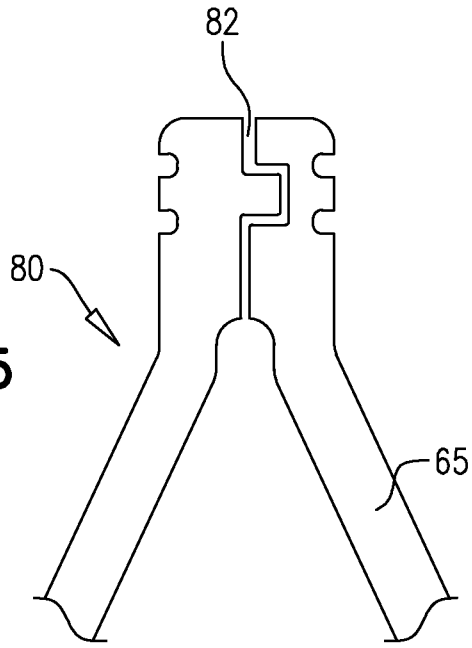

FIG. 6A

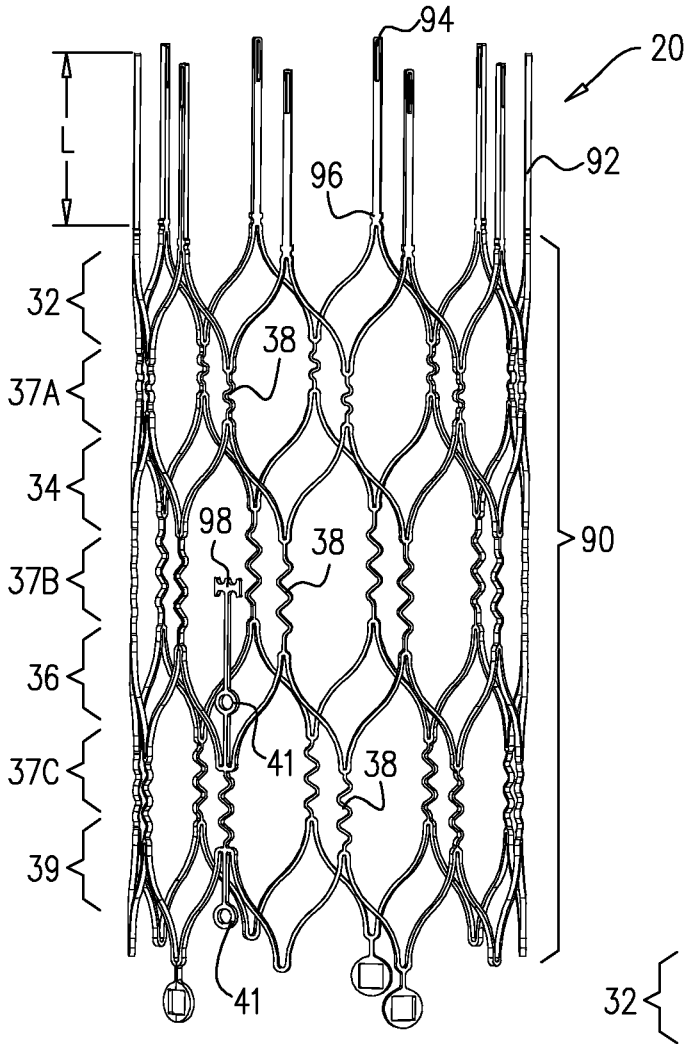
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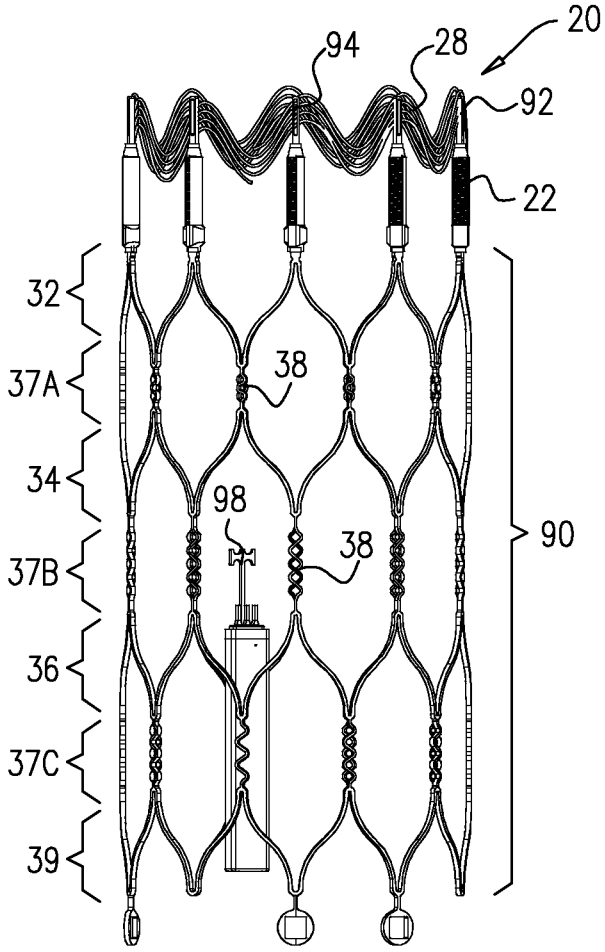
FIG. 6B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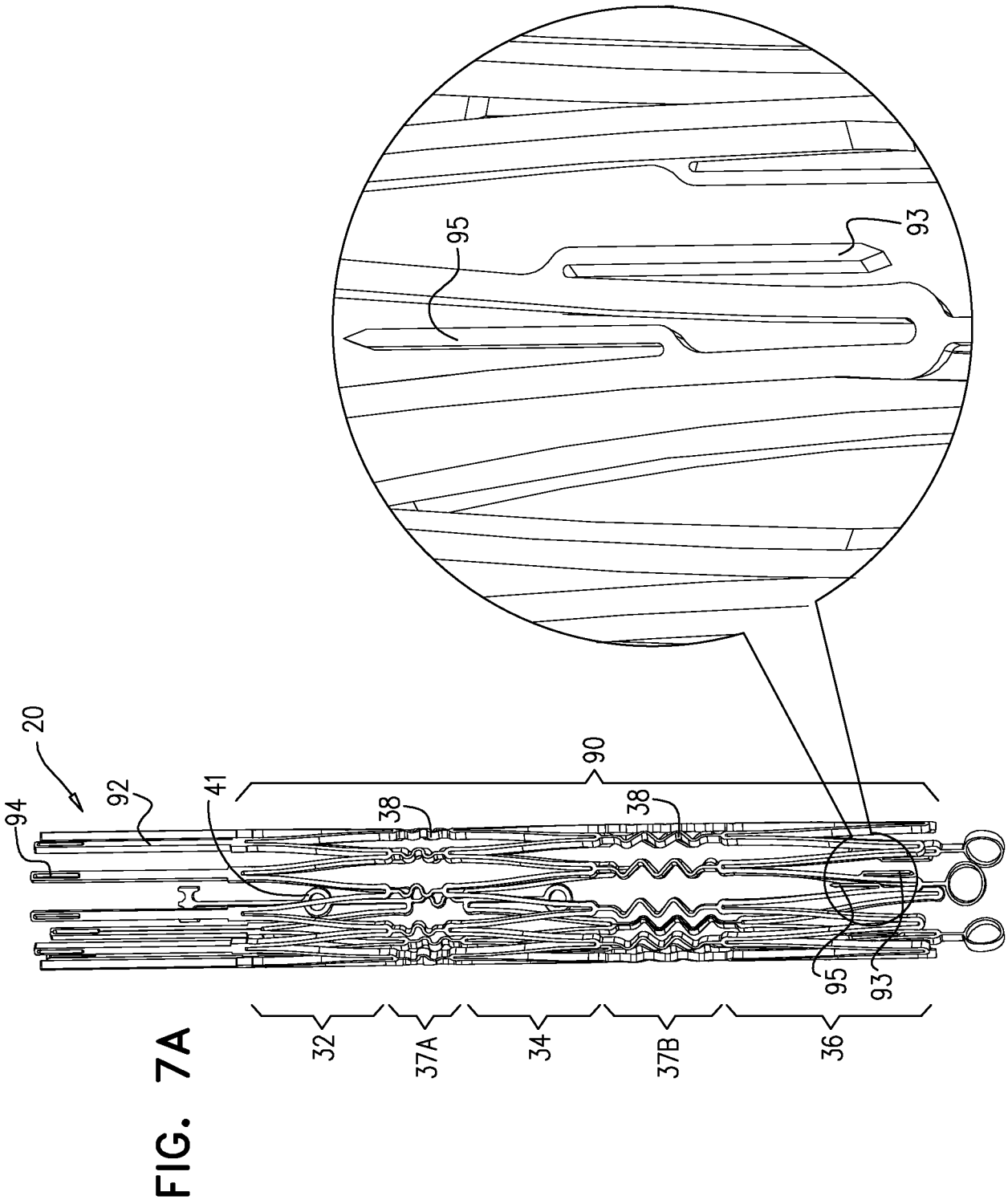



FIG. 7A

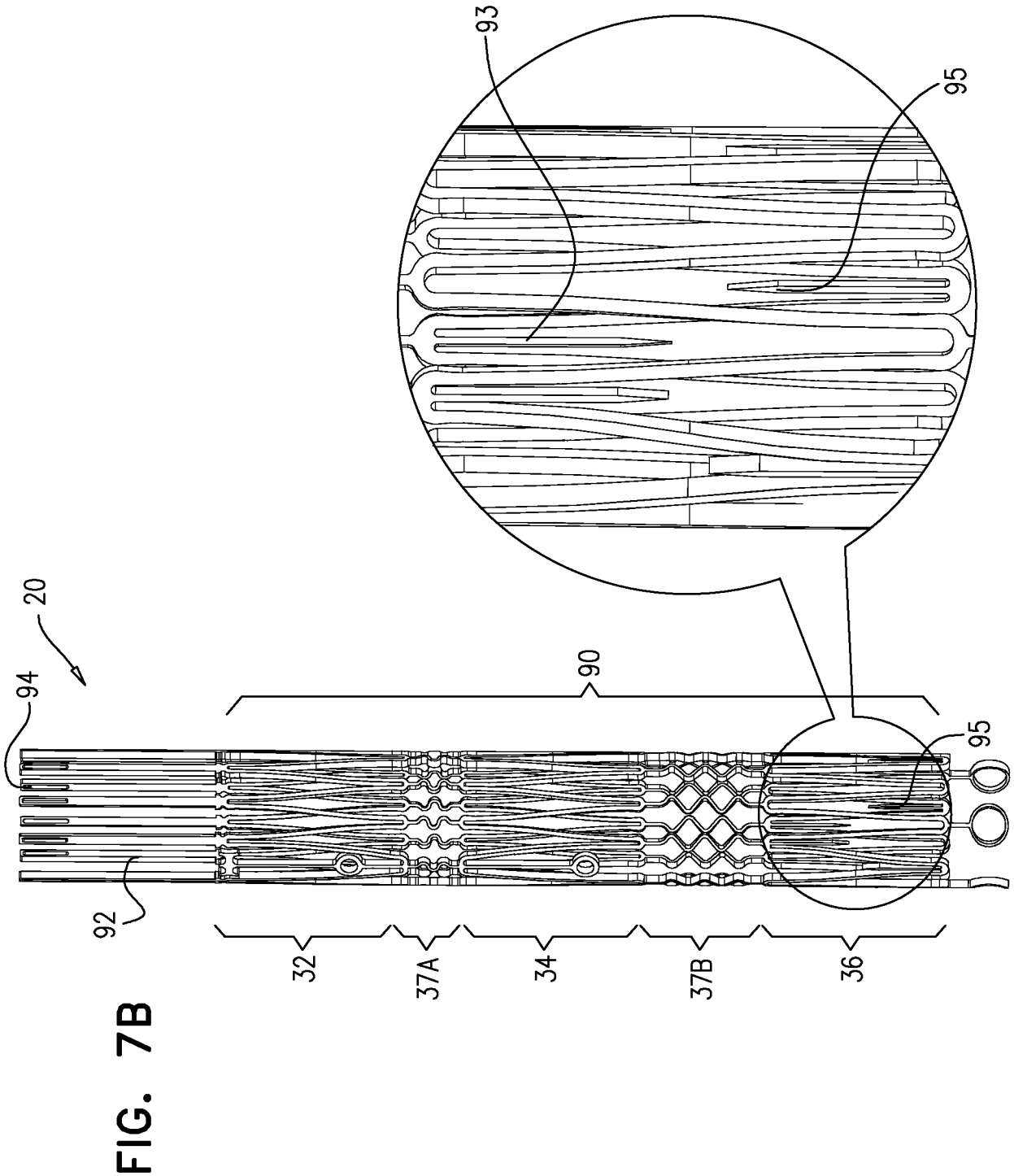
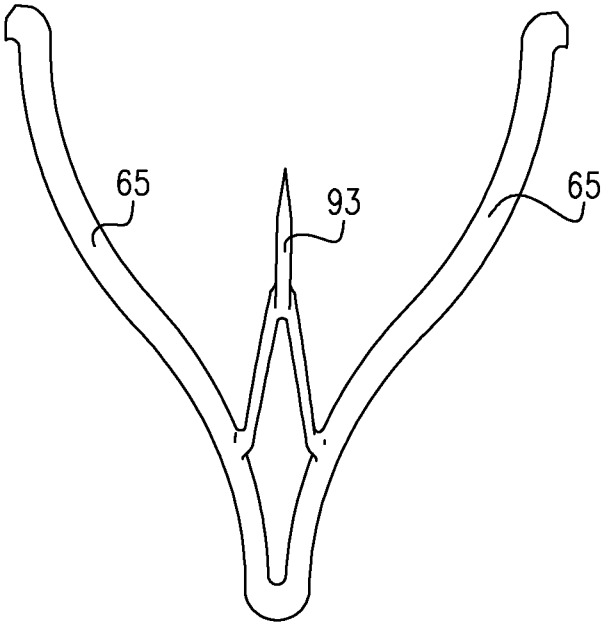



FIG. 7B

FIG. 7C



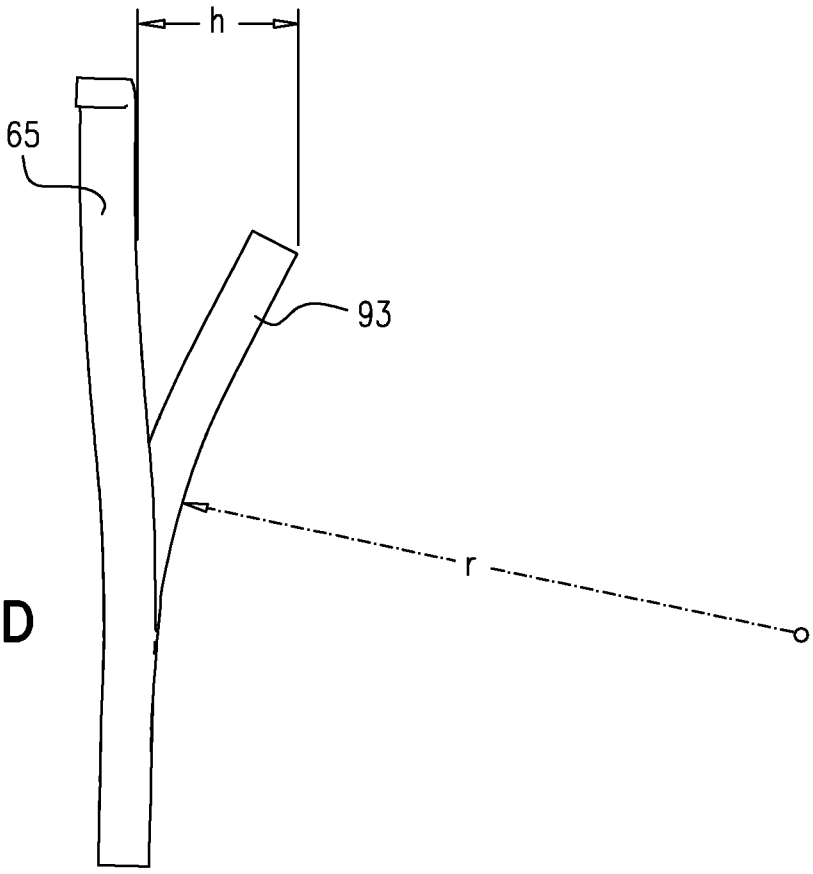
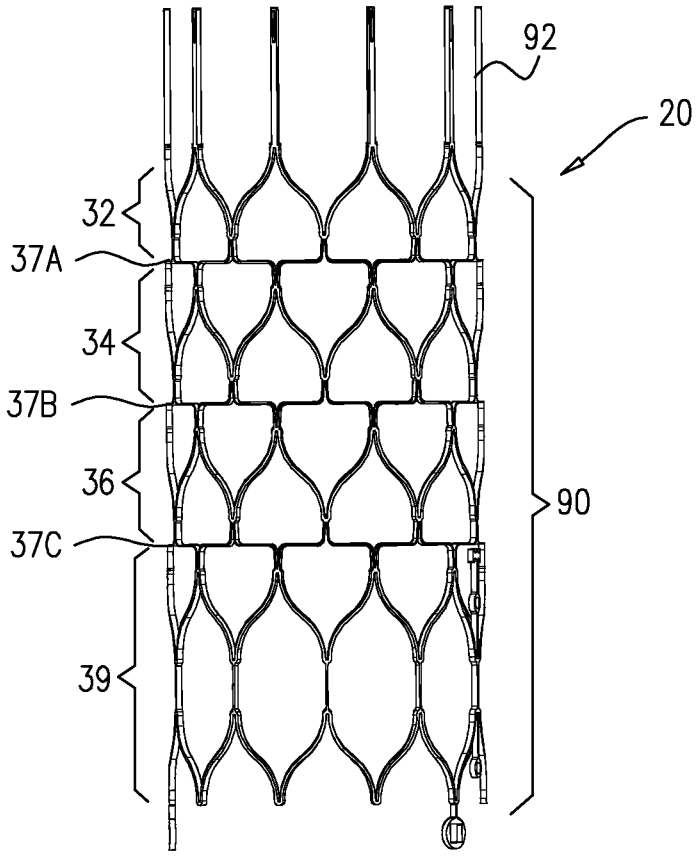




FIG. 7D

FIG. 7E



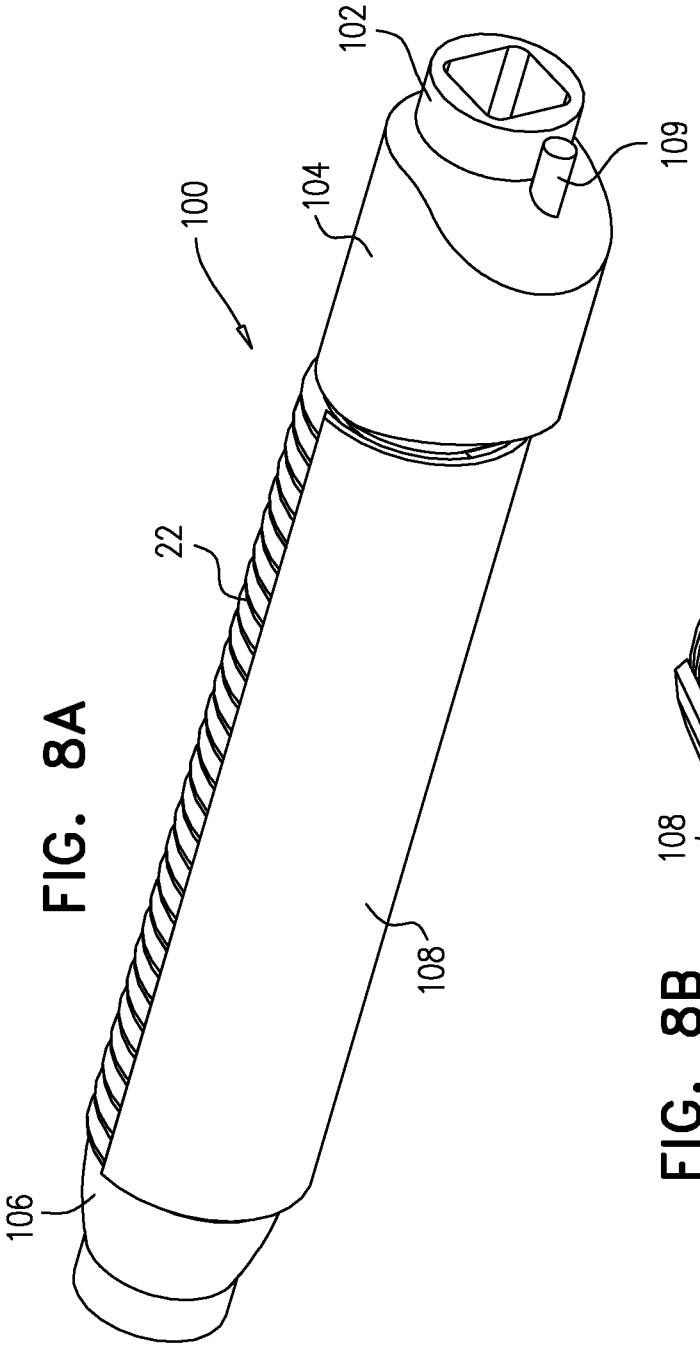



FIG. 8A

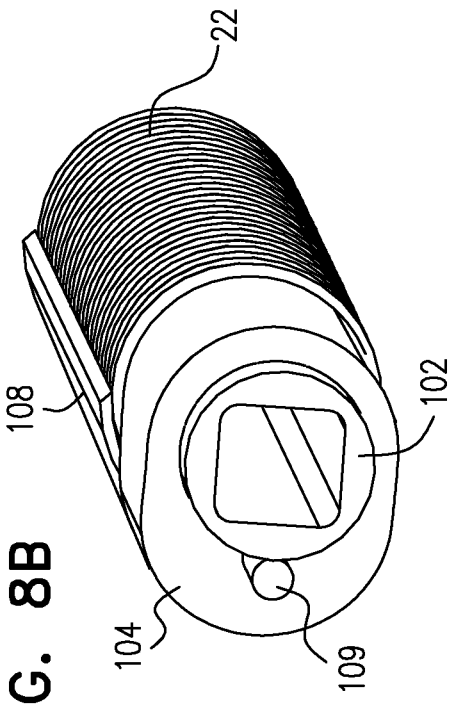



FIG. 8B

FIG. 9A

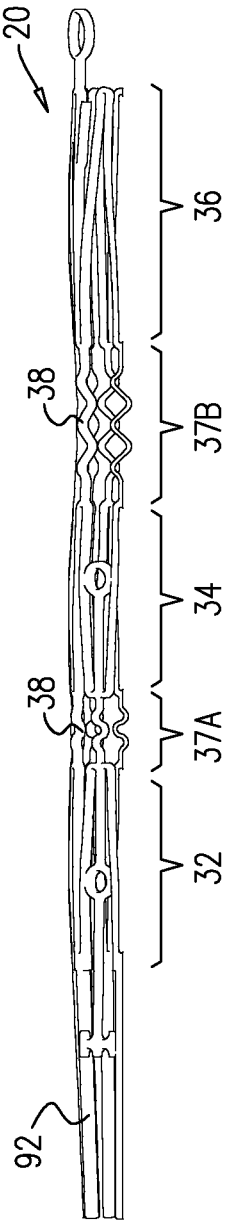



FIG. 9B

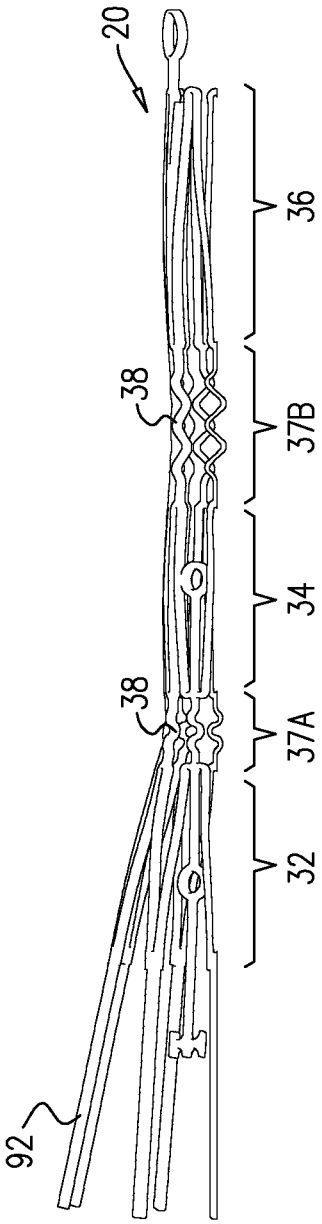



FIG. 9C

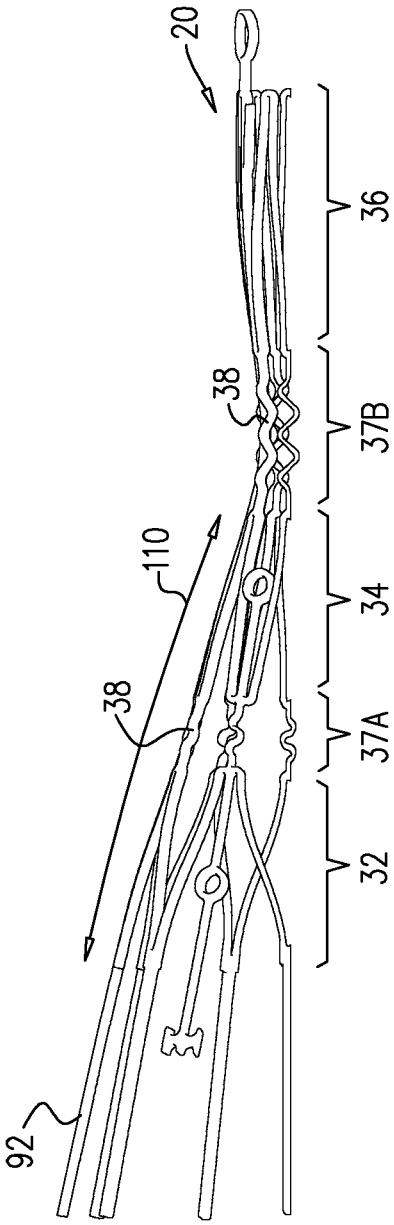


FIG. 9D

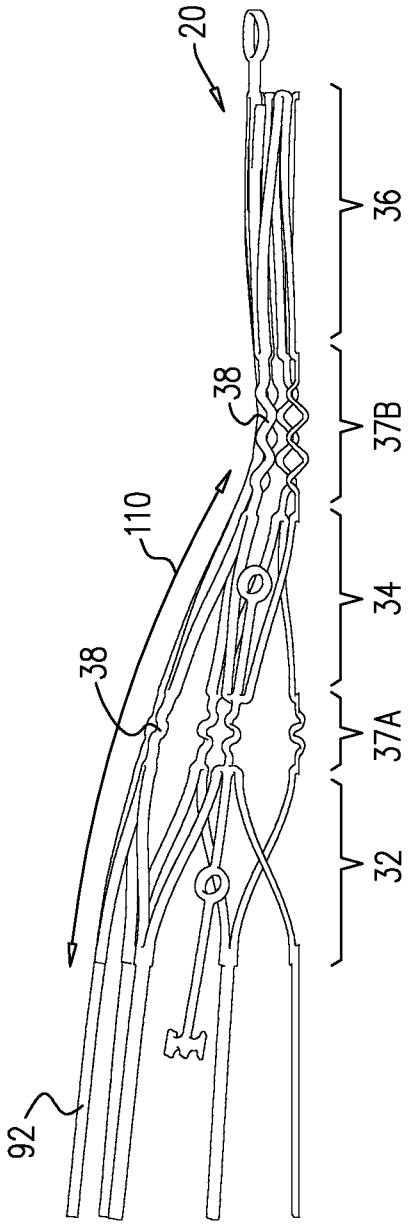



FIG. 9E

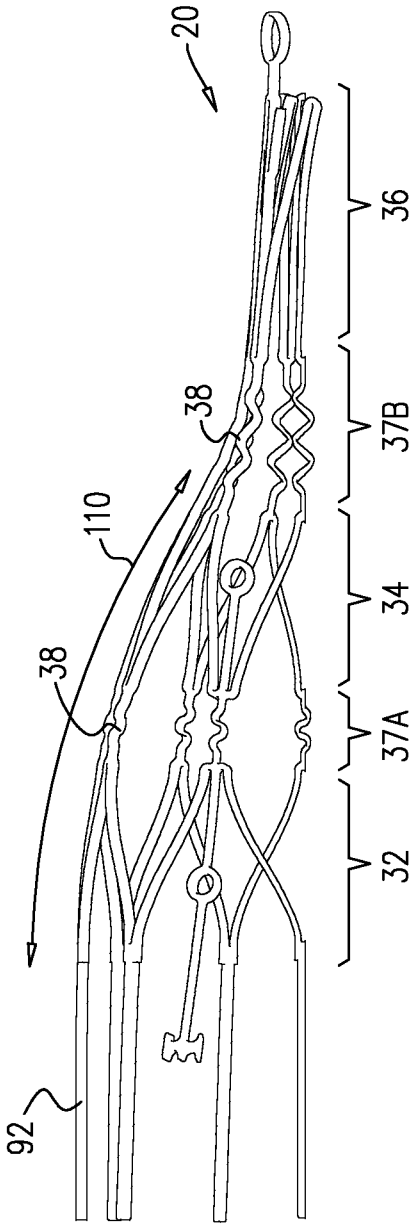


FIG. 10A

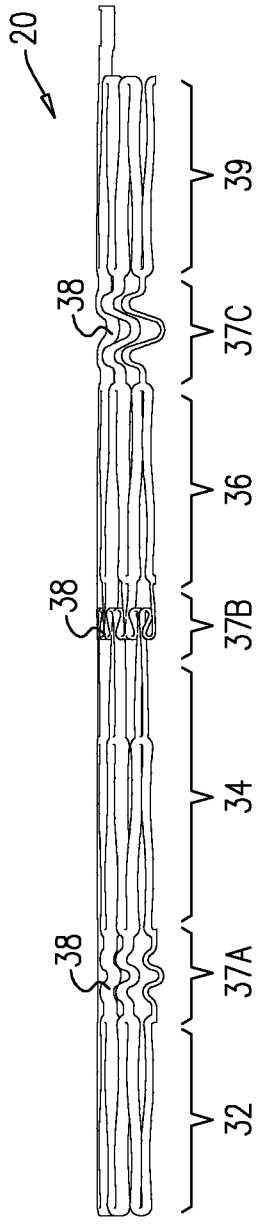



FIG. 10B

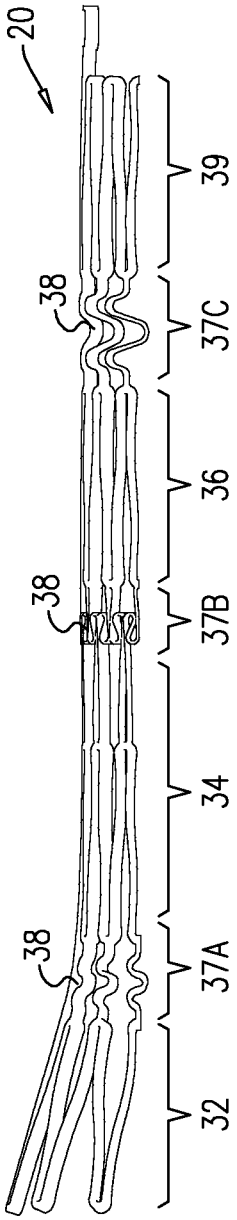



FIG. 10C

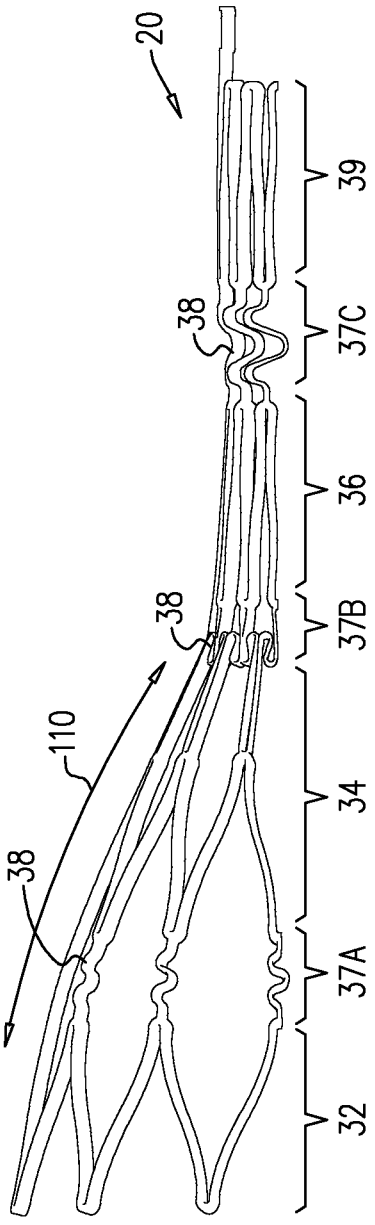


FIG. 10D

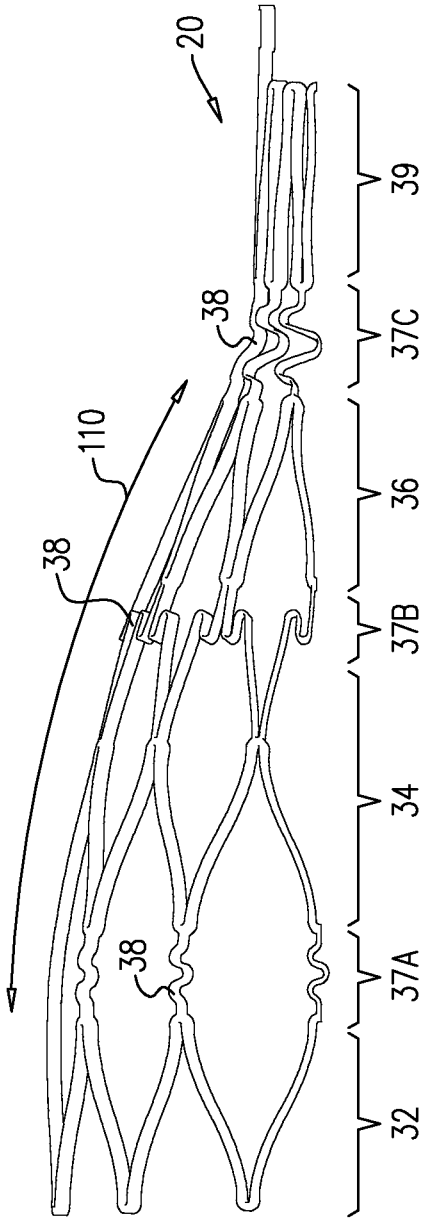



FIG. 10E

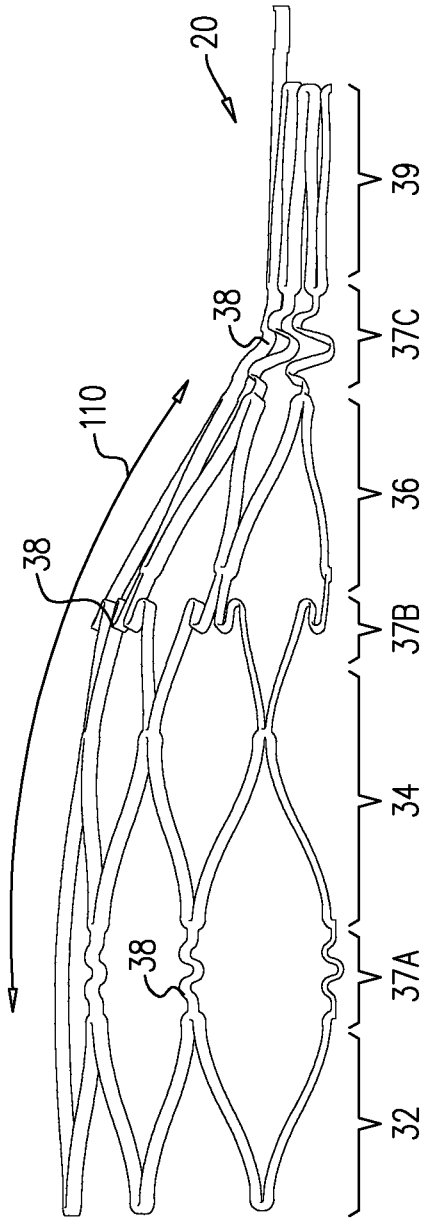


FIG. 11

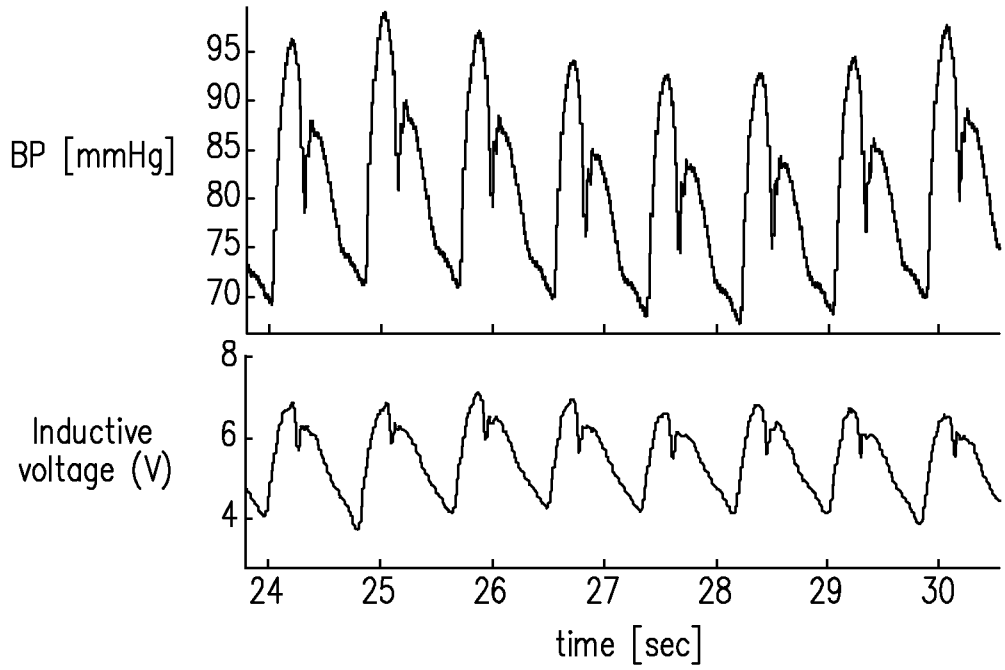

BP [mmHg]
95
90
85
80
75
70
Inductive voltage (V)
8
6
4
24
25
26
27
28
29
30
time [sec]

FIG. 12

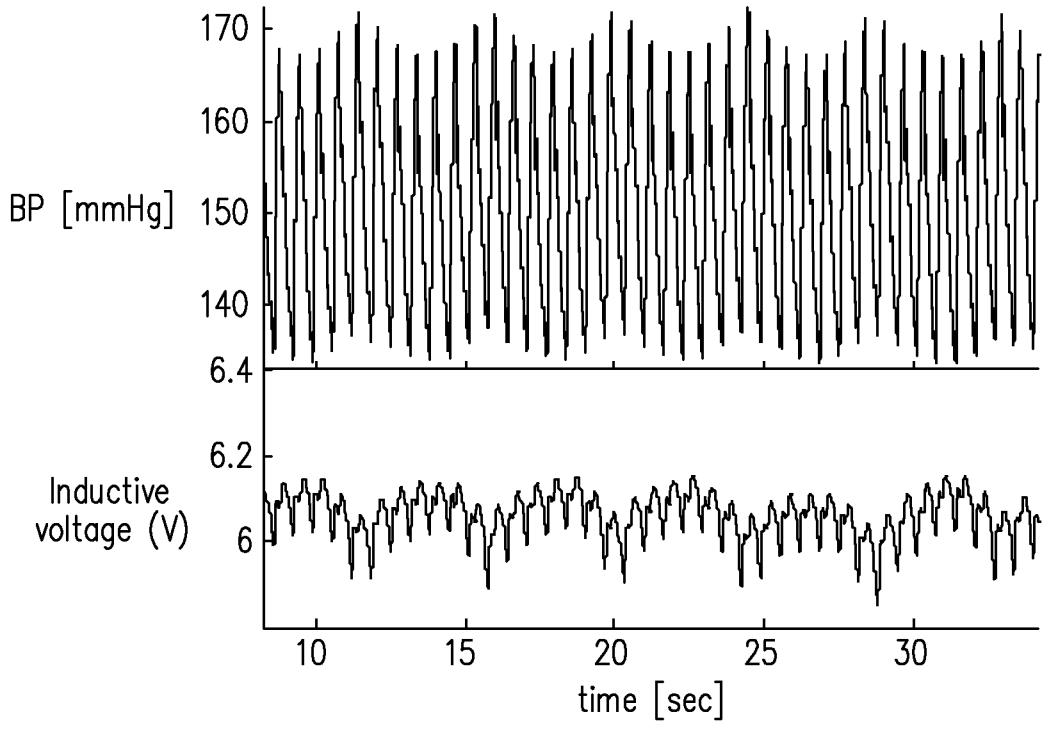
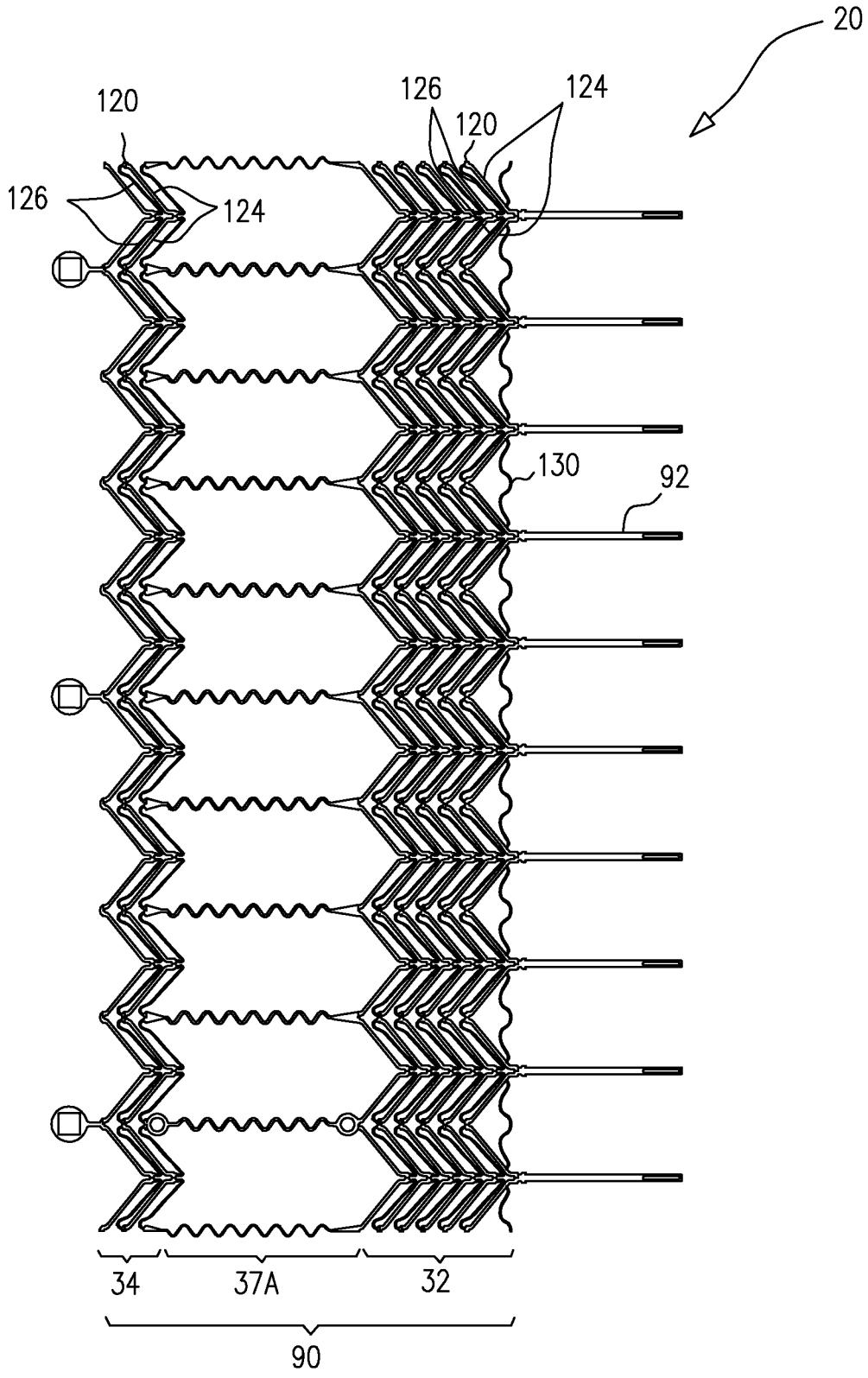

BP [mmHg]
170
160
150
140
Inductive voltage (V)
6.4
6.2
6
10
15
20
25
30
time [sec]

FIG. 13A



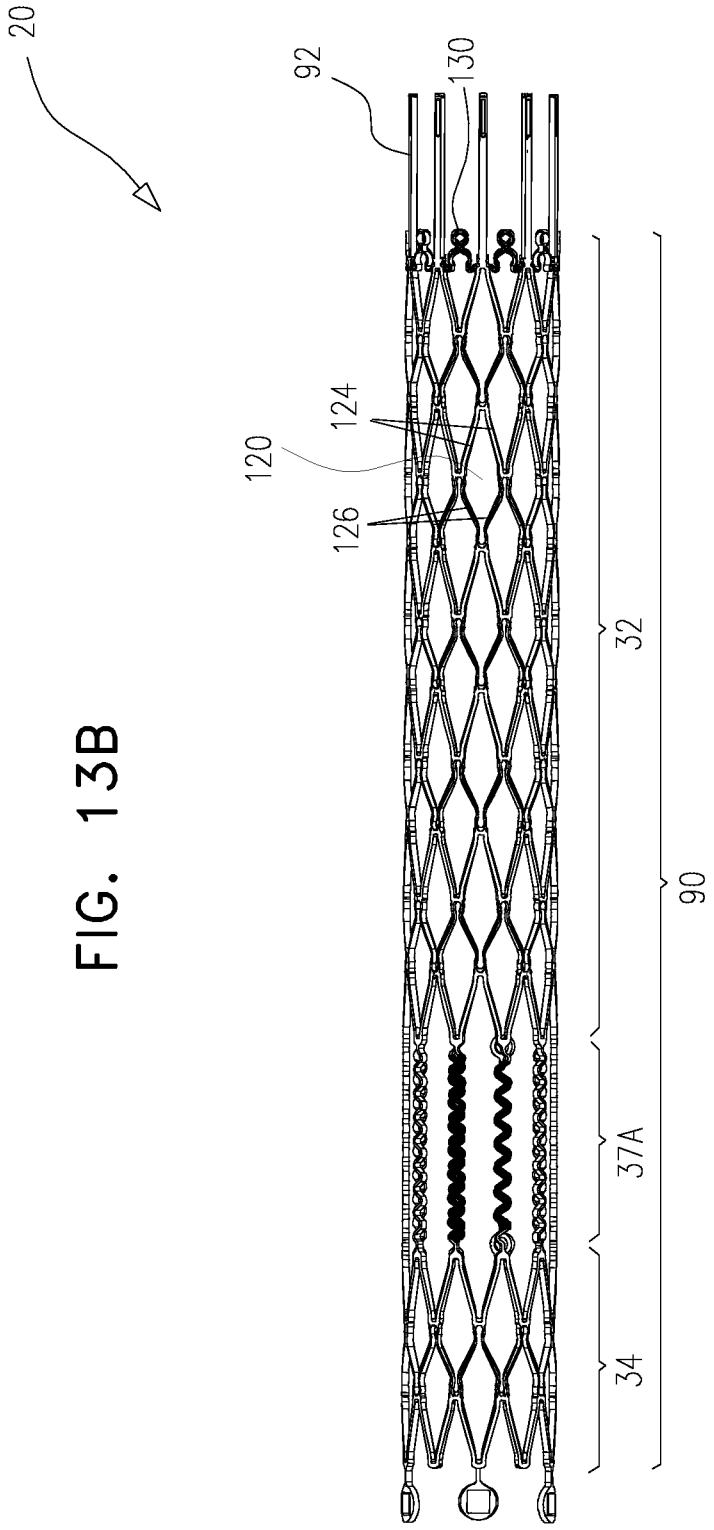



FIG. 13B

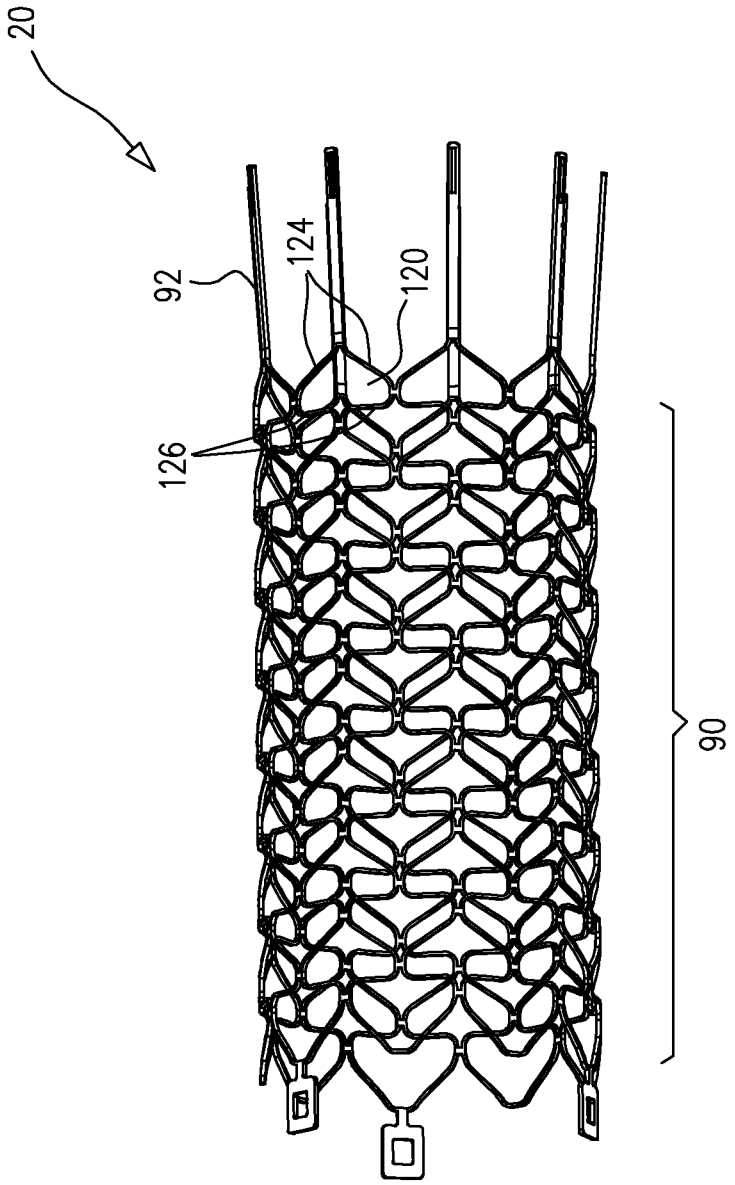



FIG. 13C

FIG. 13D

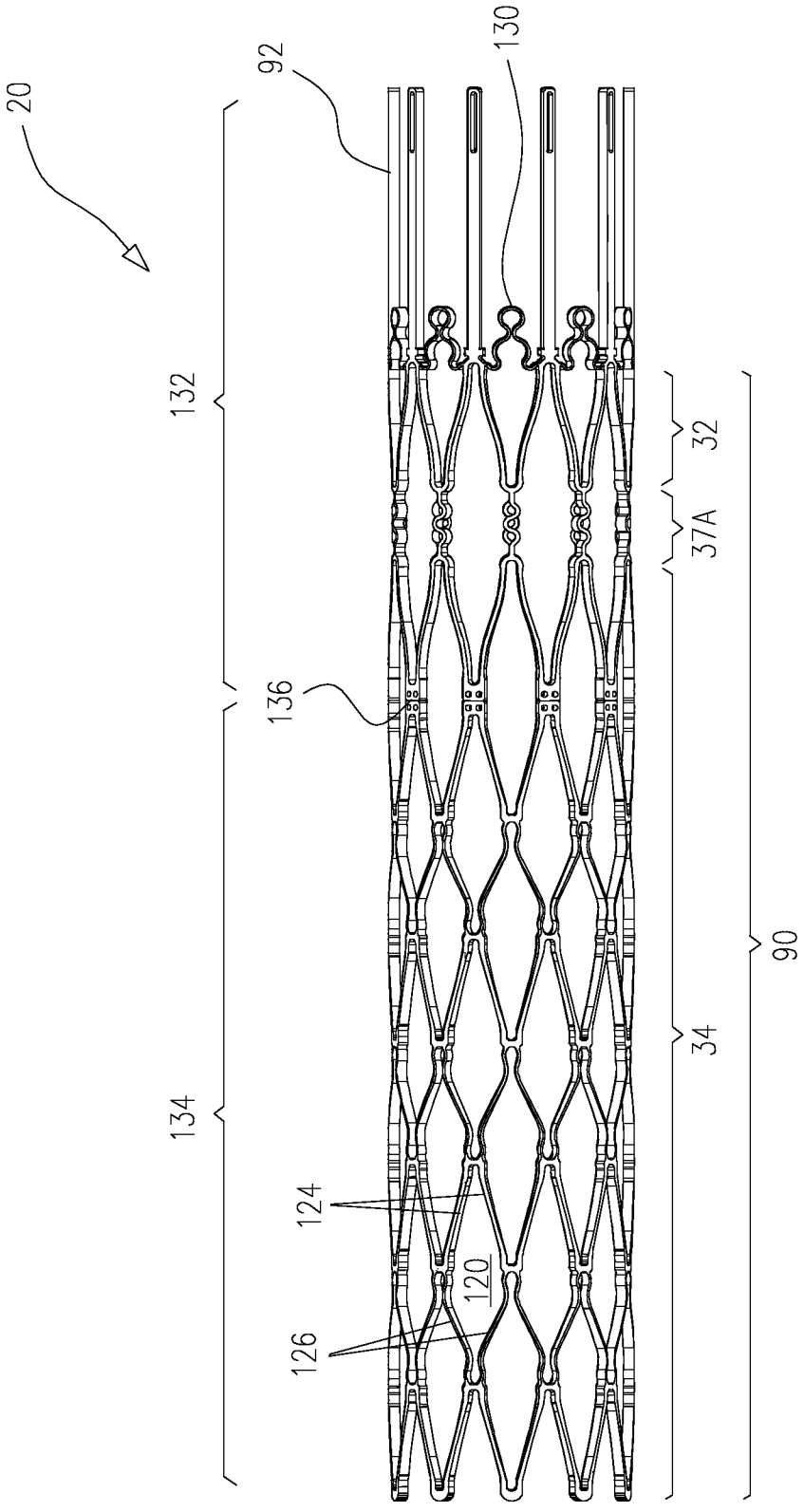


FIG. 14

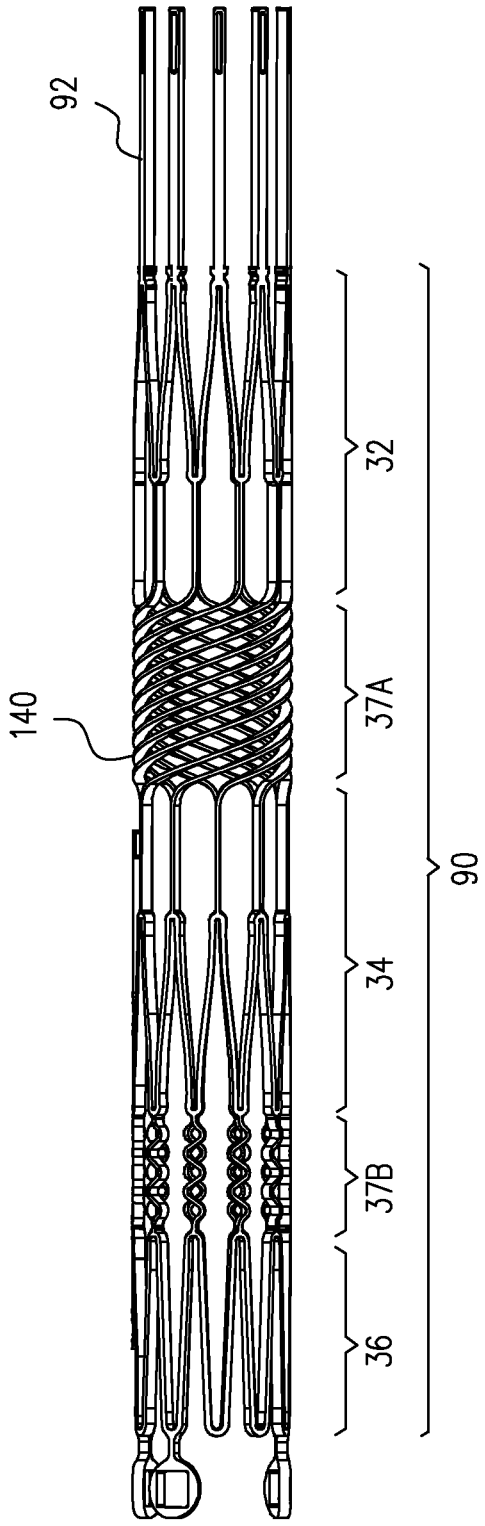


FIG. 15B

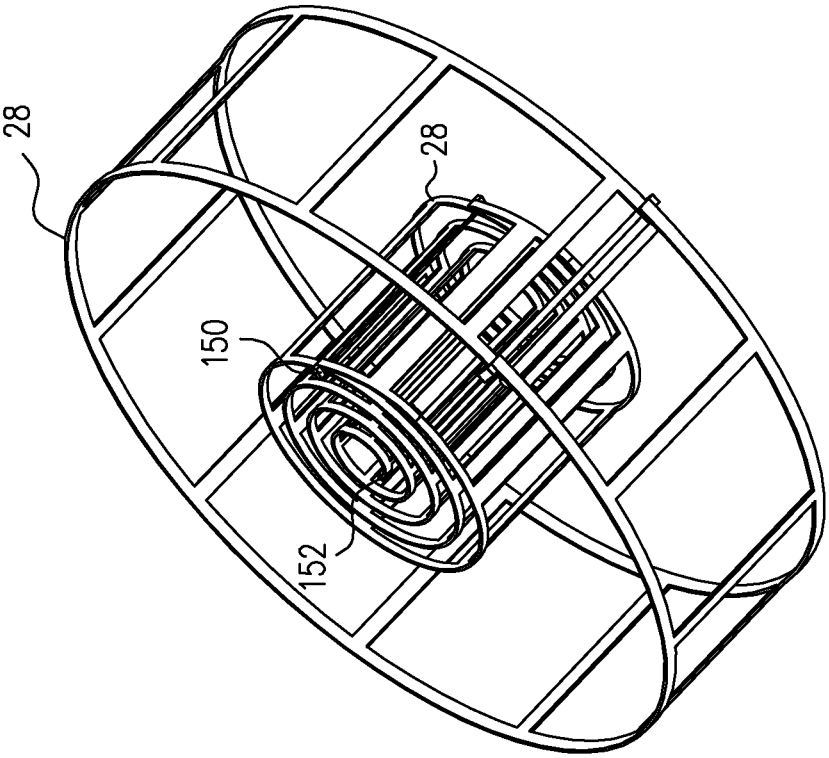



FIG. 15A

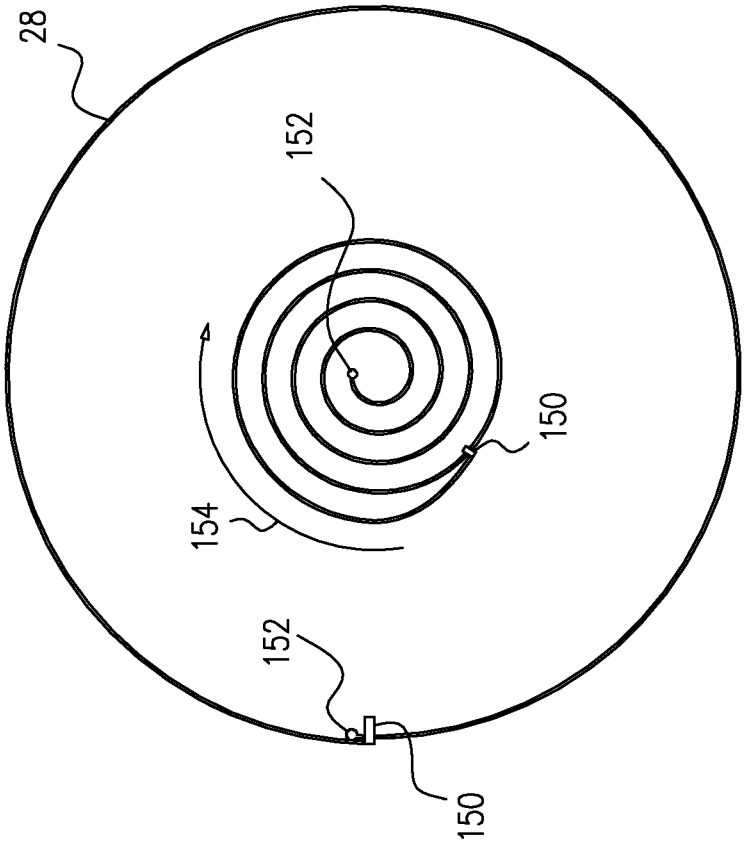


FIG. 15C

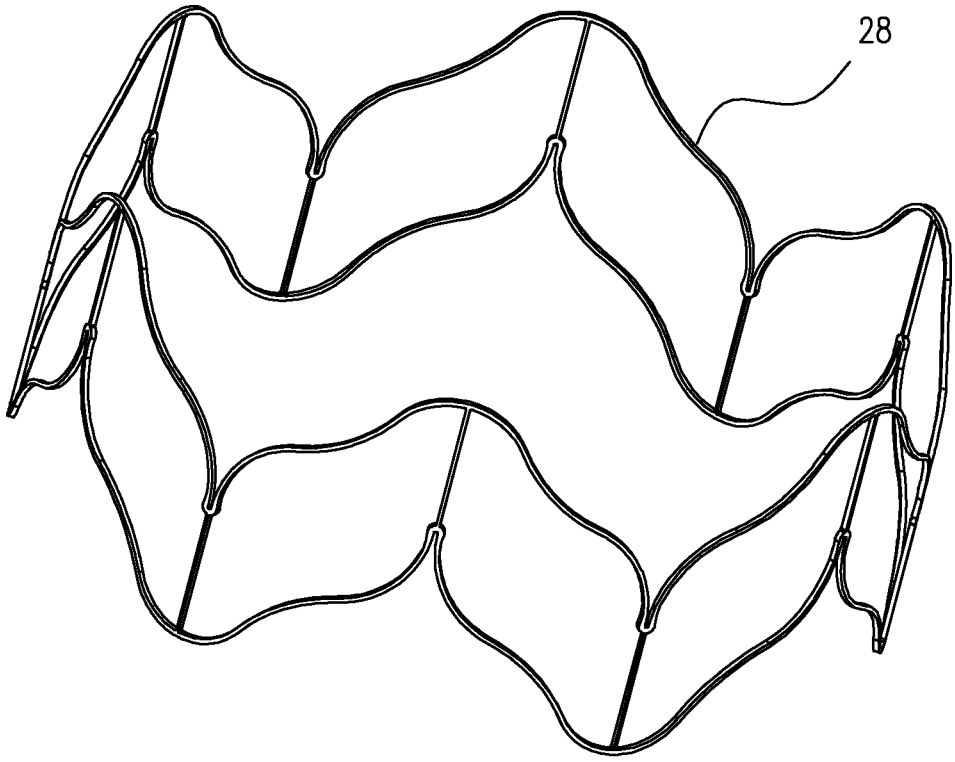


FIG. 16

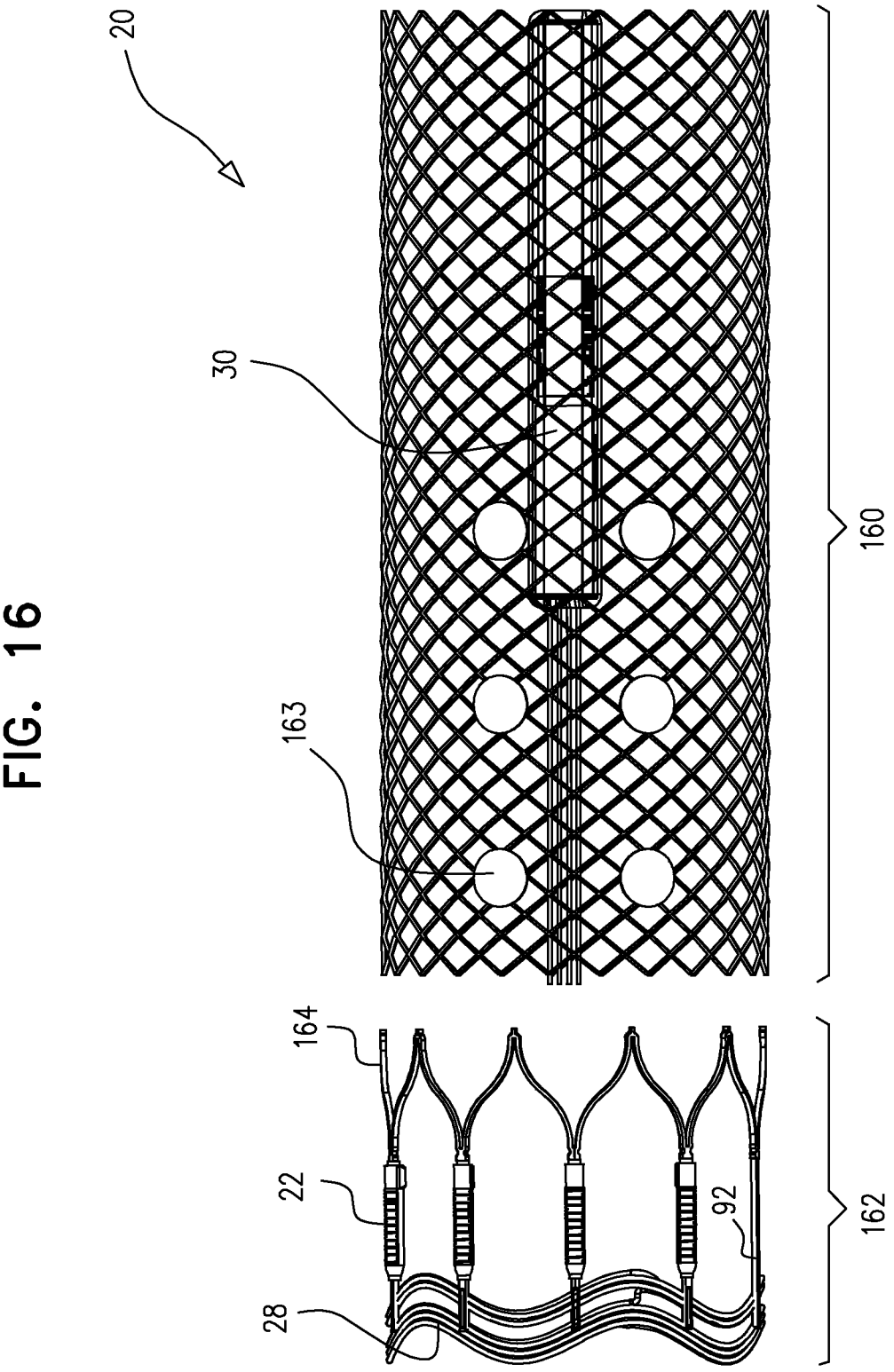


FIG. 17

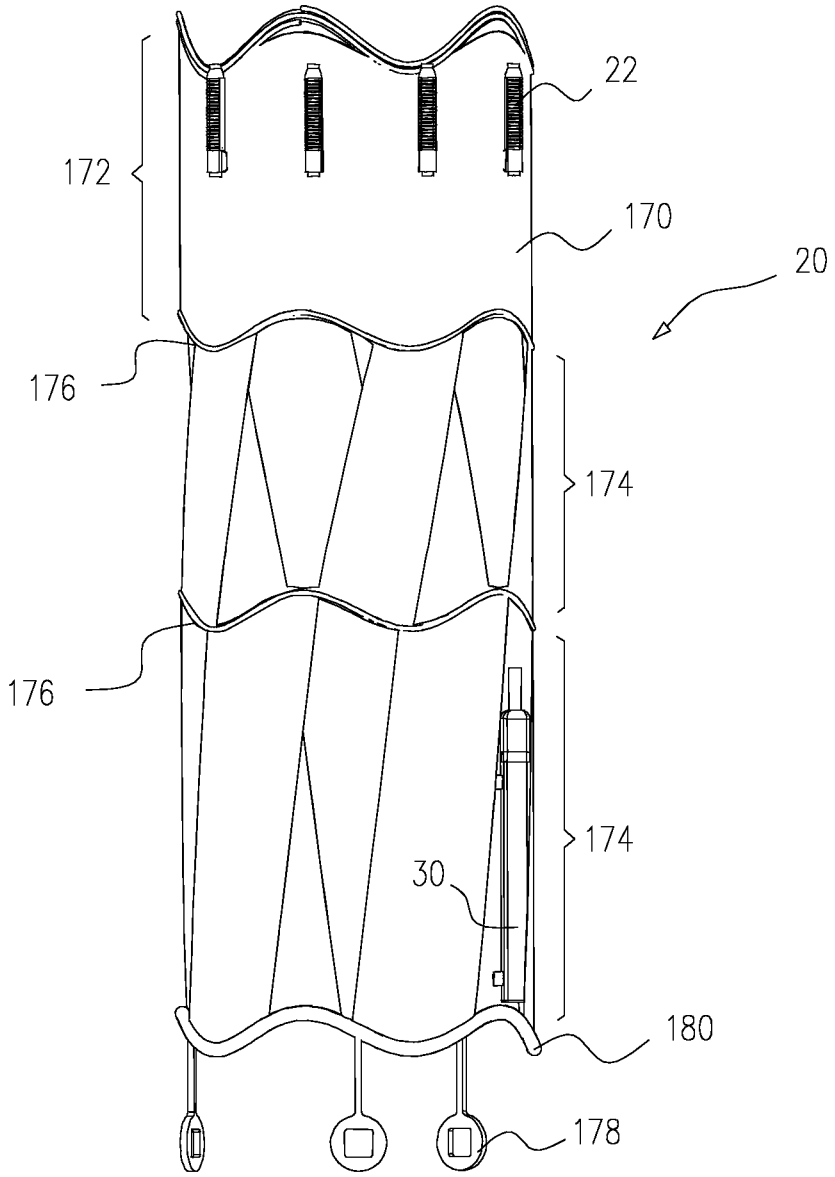


FIG. 18B

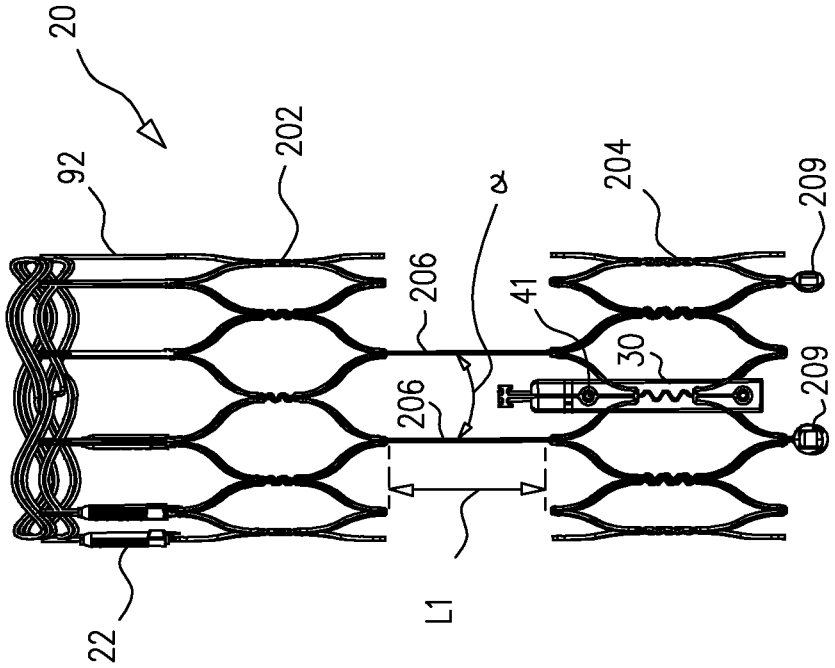



FIG. 18A

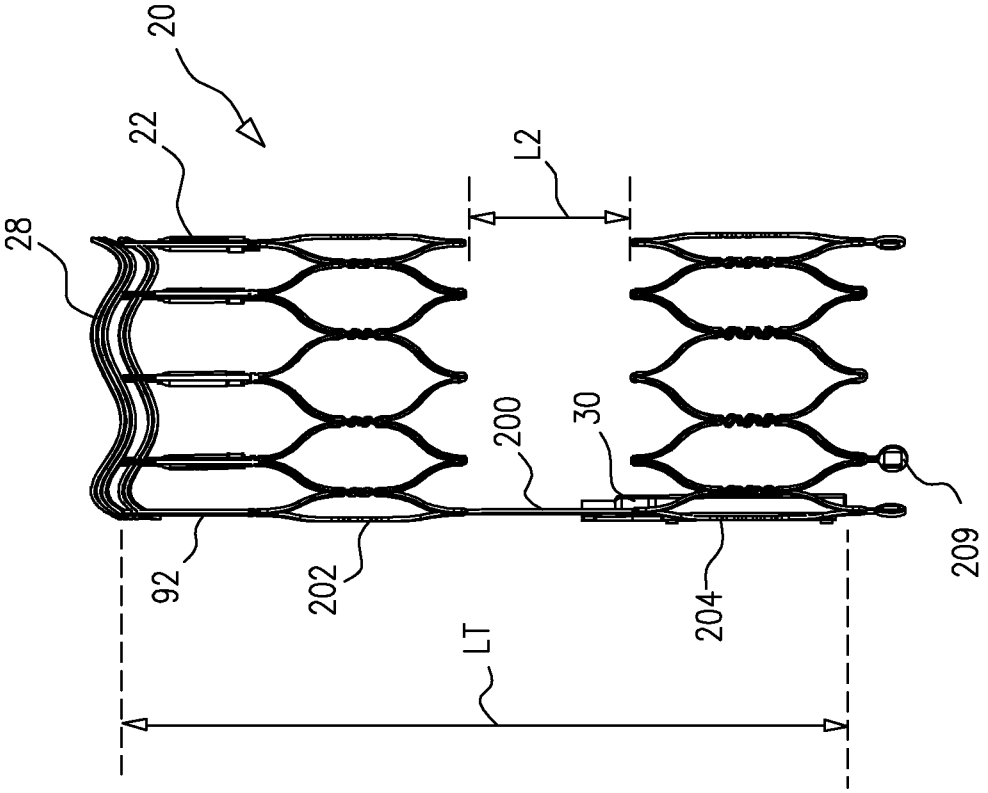


FIG. 19A

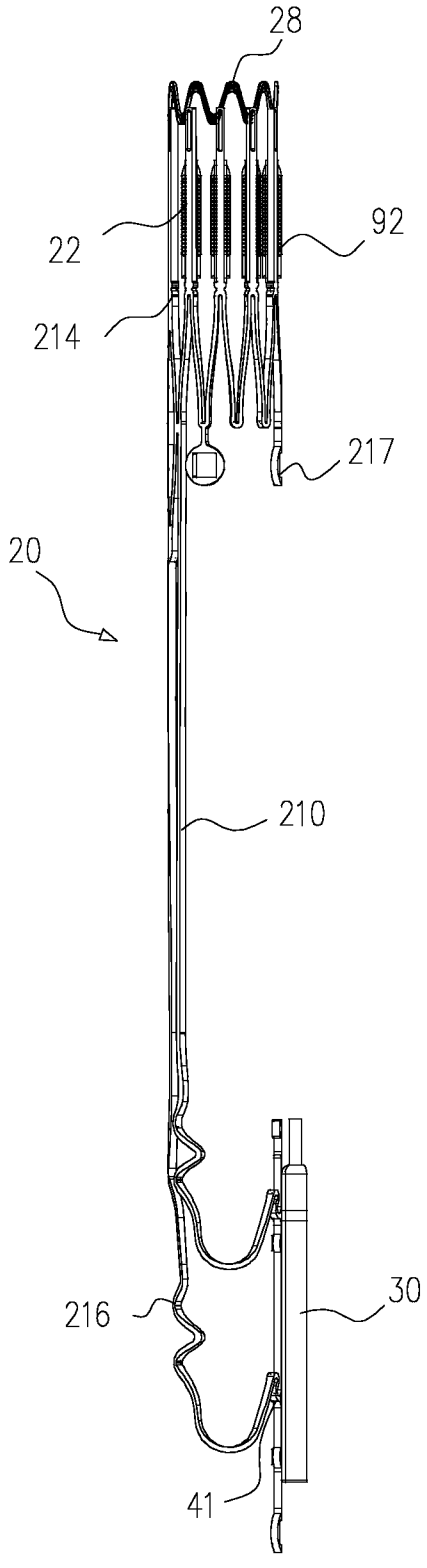



FIG. 19B

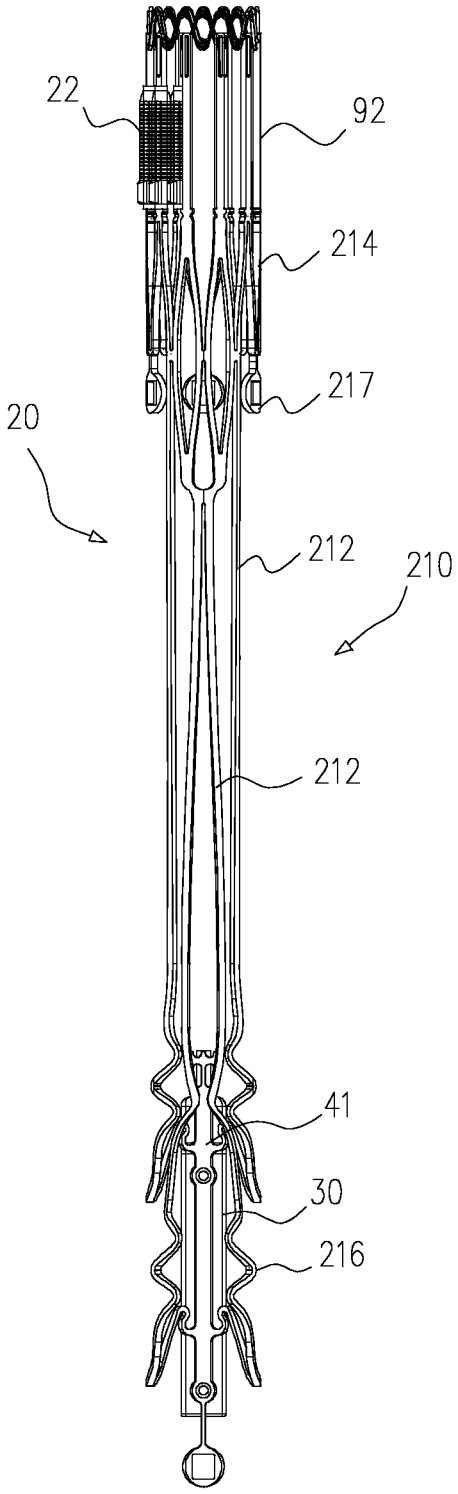


FIG. 20B

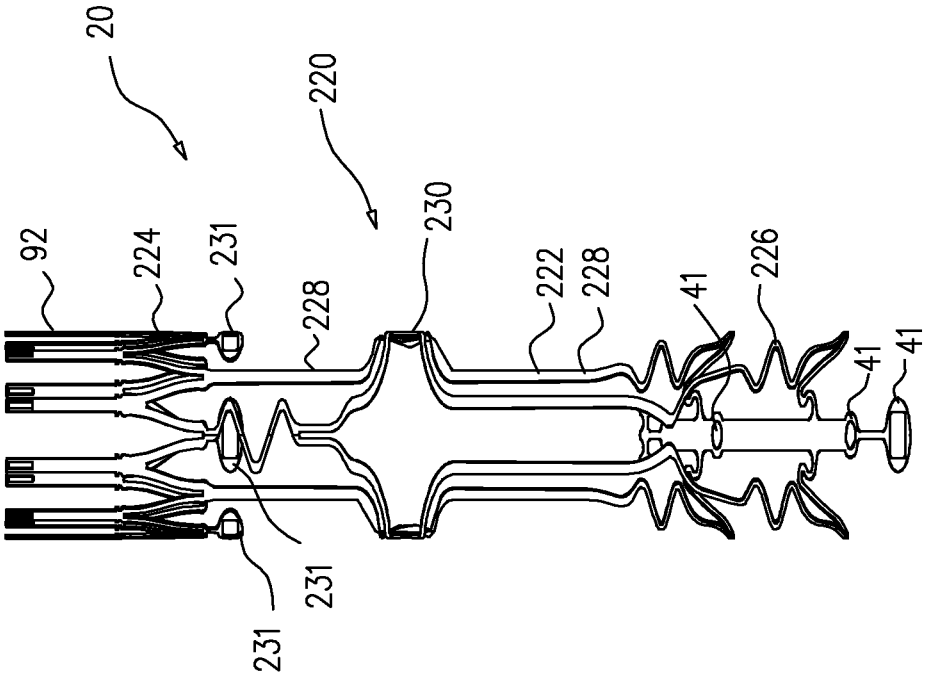



FIG. 20A

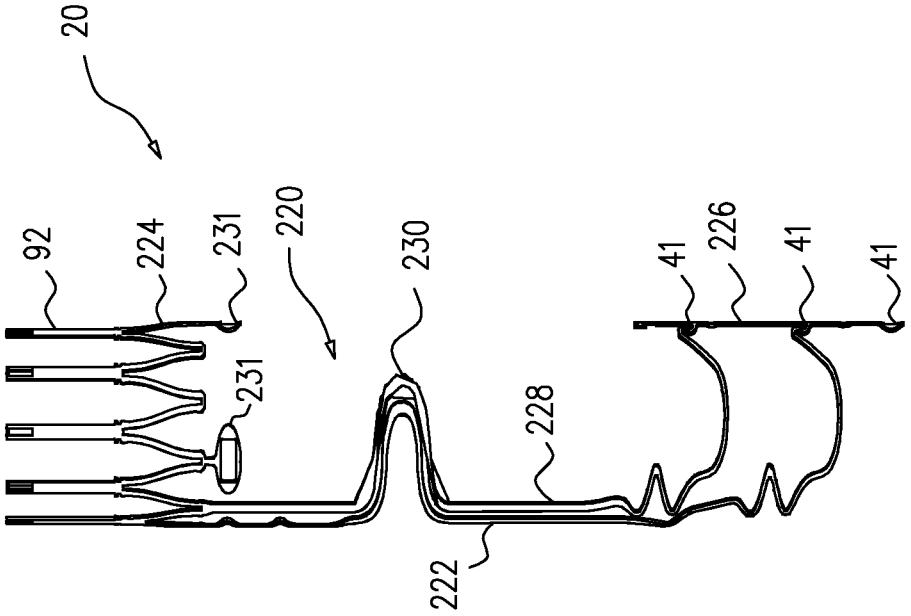


FIG. 21

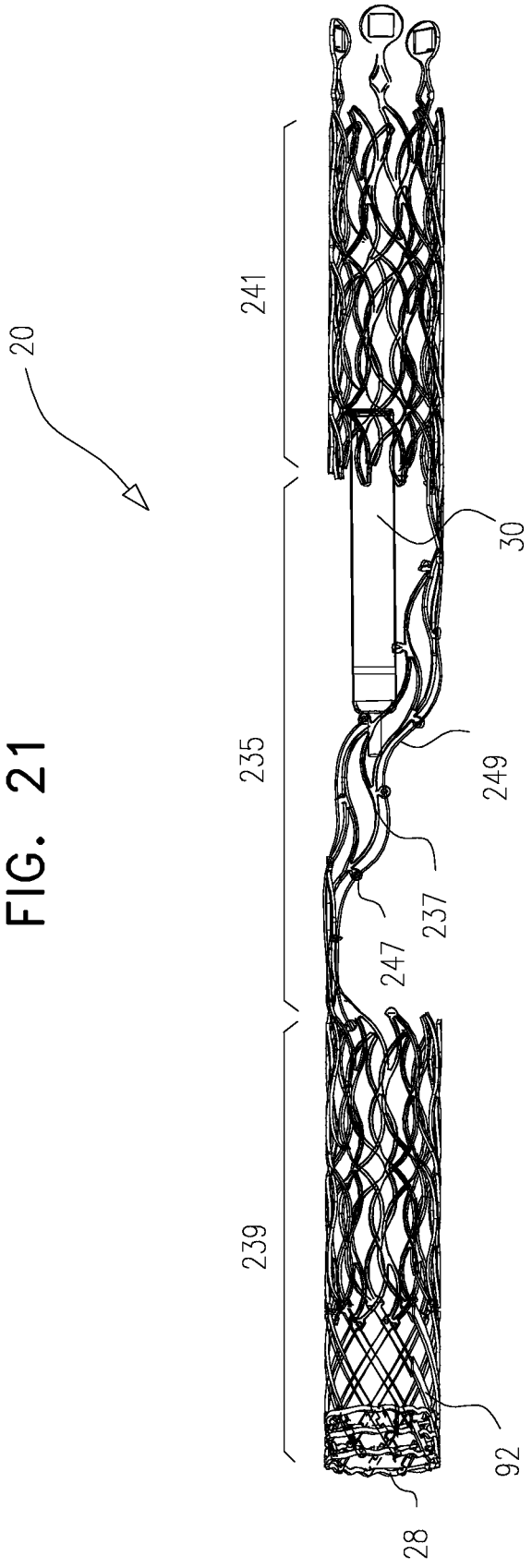


FIG. 22B

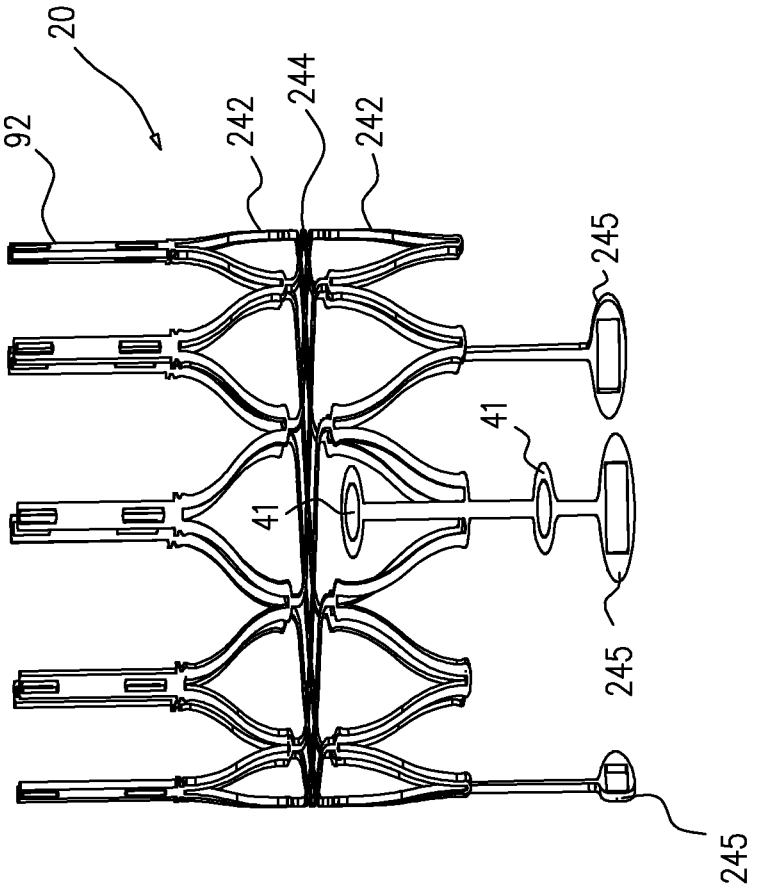



FIG. 22A

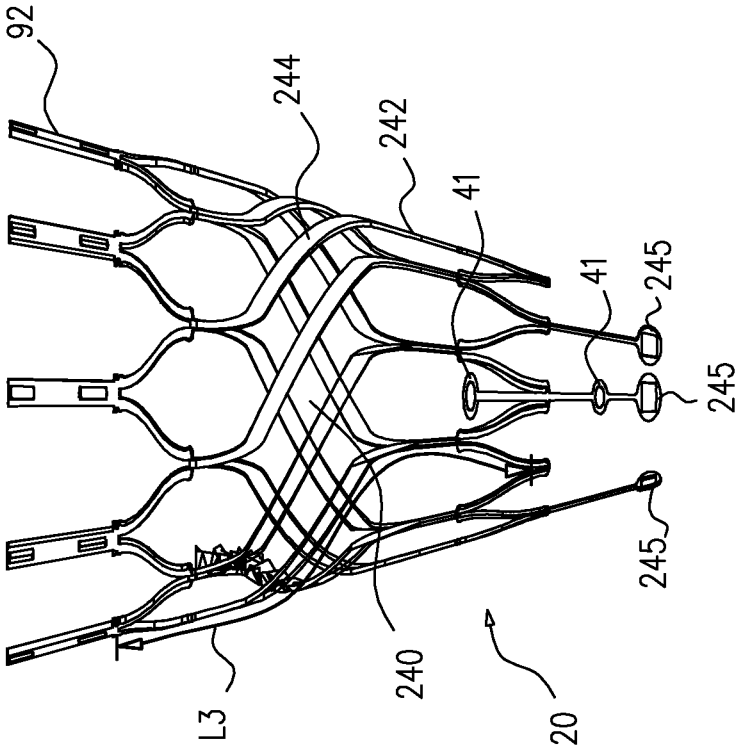


FIG. 23B

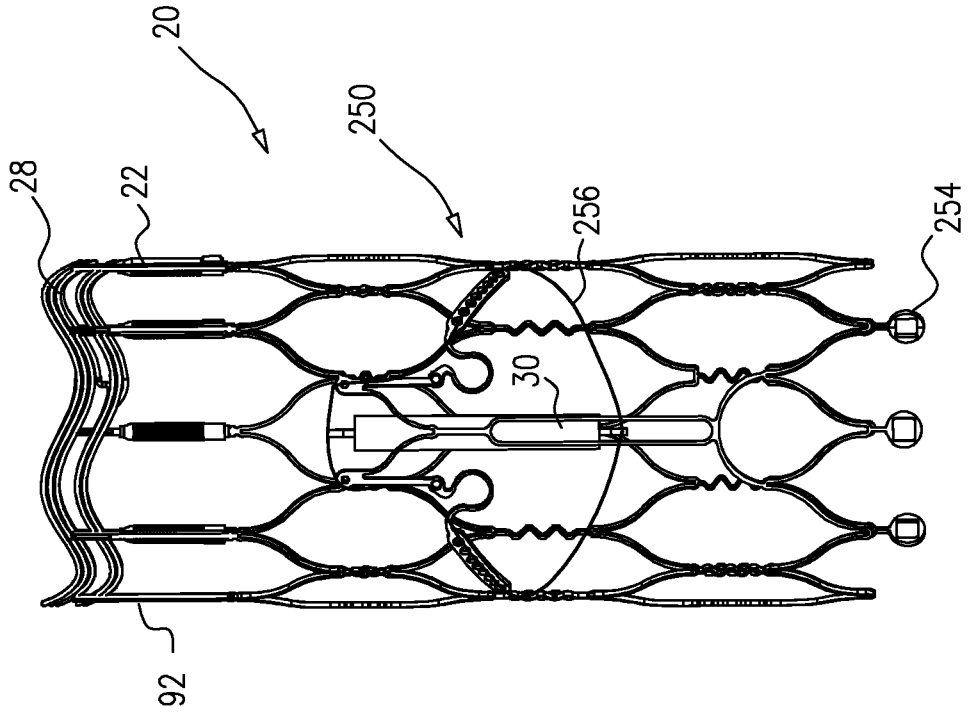
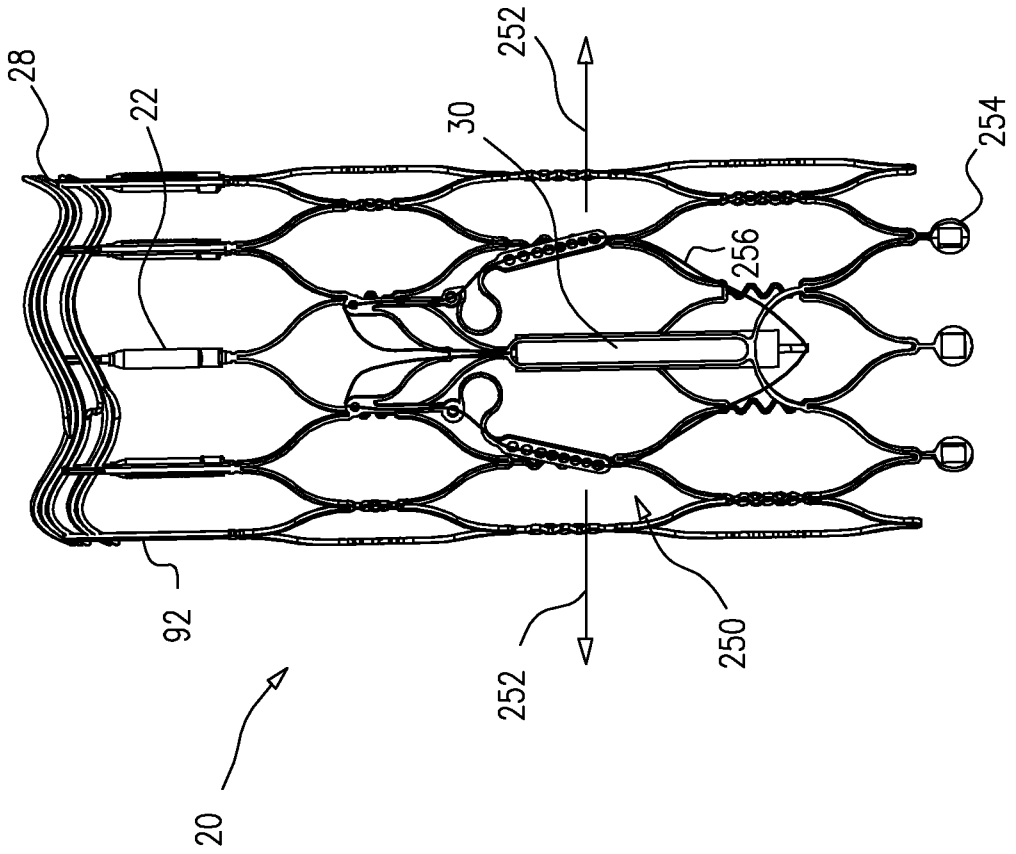



FIG. 23A



# INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2013/050375

A. CLASSIFICATION OF SUBJECT MATTER
**IPC(8) - A61F 2/82 (2013.01)**
**USPC - 623/1.15**
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)
IPC(8) - A61F 2/06, 2/82; A61N 1/00, 1/05, 1/36 (2013.01)
USPC - 600/381; 606/108; 607/116; 623/1.15

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - A61F 2/82, 2/88; A61N 1/05, 1/056, 1/36114 (2013.01)

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 2005/0049680 A1 (FISCHELL et al) 03 March 2005 (03.03.2005) entire document | 57 |
| Y | US 2007/0100433 A1 (LIMON) 03 May 2007 (03.05.2007) entire document | 1-14,16,18-20,22-32,52,58 |
| Y | US 2007/0150009 A1 (KVEEN et al) 28 June 2007 (28.06.2007) entire document | 1-14,16,18-20,22-32,52 |
| Y | US 5,967,986 A (CIMOCHOWSKI et al) 19 October 1999 (19.10.1999) entire document | 1-14,16,18-20,22-32 |
| Y | US 5,925,061 (OGI et al) 20 July 1999 (20.07.1999) entire document | 52,58 |
| A | US 2009/0005859 A1 (KEILMAN) 01 January 2009 (01.01.2009) entire document | 1-63 |
| A | US 2010/0042186 A1 (BEN-DAVID et al) 18 February 2010 (18.02.2010) entire document | 1-63 |
| A | US 2002/0026228 A1 (SCHAUERTE) 28 February 2002 (28.02.2002) entire document | 1-63 |

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 29 July 2013 | 08 AUG 2013 |
| Name and mailing address of the ISA/US<br>Mail Stop PCT, Attn: ISA/US, Commissioner for Patents<br>P.O. Box 1450, Alexandria, Virginia 22313-1450<br>Facsimile No. 571-273-3201 | Authorized officer:<br>Blaine R. Copenheaver<br>PCT Helpdesk: 571-272-4300<br>PCTOSP: 571-272-7774 |

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