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(54) Title: METHODS AND APPARATUS FOR PERFORMING A NON-CONTINUOUS CIRCUMFERENTIAL TREATMENT TO A BODY LUMEN

(57) Abstract: Methods and apparatus are provided for discontinuous circumferential treatment of a body lumen. Apparatus may be positioned within a body lumen of a patient and may deliver energy at a first lengthwise and angular position to create a less-than-full circumferential treatment zone at the first position. The apparatus also may deliver energy at one or more additional lengthwise and angular positions within the body lumen to create less-than-full circumferential treatment zone(s) at the one or more additional positions that are offset lengthwise and angularly from the first treatment zone. Superimposition of the first treatment zone and the one or more additional treatment zones defines a discontinuous circumferential treatment zone without formation of a continuous circumferential lesion. Various embodiments of methods and apparatus for achieving such discontinuous circumferential treatment are provided.

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METHODS AND APPARATUS FOR PERFORMING A NON-CONTINUOUS CIRCUMFERENTIAL TREATMENT TO A BODY LUMEN

REFERENCE TO RELATED APPLICATION

The present application claims priority to of each of the following co-pending United States patent applications:

(1) U.S. Patent Application No. 11/599,890, filed November 14, 2006.

(2) U.S. Patent Application No. 11/129,765, filed May 13, 2005, which (a) claims the benefit of U.S. Provisional Patent Application Nos. 60/616,254, filed October 5, 2004, and 60/624,793, filed November 2, 2004; and (b) is a continuation-in-part of U.S. Patent Application No. 10/408,665, filed April 8, 2003, which claims the benefit of U.S. Provisional Application Nos. 60/370,190 filed April 8, 2002; 60/415,575, filed October 3, 2002; and 60/442,970, filed January 29, 2003.

(3) U.S. Patent Application No. 11/189,563 filed July 25, 2005, which (a) is a continuation-in-part of U.S. Patent Application No. 11/129,765, filed May 13, 2005, which claims the benefit of U.S. Provisional Patent Application Nos. 60/616,254, filed October 5, 2004, and 60/624,793, filed November 2, 2004; and (b) is a continuation-in-part of U.S. Patent Application No. 10/900,199, filed July 28, 2004 (now U.S. Patent No. 6,978,174), which is a continuation-in-part of U.S. Patent Application No. 10/408,665, filed April 8, 2003, which claims the benefit of U.S. Provisional Application Nos. 60/370,190 filed April 8, 2002; 60/415,575, filed October 3, 2002; and 60/442,970, filed January 29, 2003.

All the foregoing applications and patents are incorporated herein by reference in their entireties.

INCORPORATION BY REFERENCE

All publications and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

TECHNICAL FIELD

The present invention relates to methods and apparatus for performing a non-continuous circumferential treatment within a body lumen. Several embodiments of such methods and apparatus are directed to circumferential treatments of the body lumen that apply energy in one or more discrete treatment areas to form one or more lesions that are not contiguous or continuous about any complete circumference of a cross-section normal to a longitudinal axis of the body lumen.

BACKGROUND

Applicants have described methods and apparatus for treating a variety of renal and cardio-renal diseases, such as heart failure, renal disease, renal failure, hypertension, contrast nephropathy, atrial fibrillation and myocardial infarction, by modulating neural fibers that contribute to renal function, e.g., denervating tissue containing the neural fibers that contribute to renal function. This is expected to reduce renal sympathetic nervous activity, which increases removal of water and sodium from the body, and returns renin secretion to more normal levels. Normalized renin secretion causes blood vessels supplying the kidneys to assume a steady state level of dilation/constriction, which provides adequate renal blood flow. See, for example, Applicants' co-pending United States Patent Application Nos.: (a) 10/408,665, filed April 8, 2003; (b) 11/129,765, filed on May 13, 2005; (c) 11/189,563, filed on July 25, 2005; (d) 11/363,867, filed on February 27, 2006; (e) 11/504,117, filed on August 14, 2006; as well as United States Patent No. 6,978,174. All of these applications and the patent are incorporated herein by reference in their entireties.

Applicants also have previously described methods and apparatus for intravascularly-induced neuromodulation or denervation of an innervated blood vessel in a patient or any target neural fibers in proximity to a blood vessel, for example, to treat any neurological disorder or other medical condition. Nerves in proximity to a blood vessel may innervate an effector organ or tissue. Intravascularly-induced neuromodulation or denervation may be utilized to treat a host of neurological disorders or other medical conditions, including, but not limited to, the aforementioned conditions including heart failure and hypertension, as well as pain and peripheral arterial occlusive disease (e.g., via pain mitigation). The methods and apparatus may be used to modulate efferent or afferent nerve signals, as well as combinations of efferent and afferent nerve signals. See, for example, Applicants' co-pending United States Patent Application No. 11/599,649, filed on November 14, 2006, entitled Methods and Apparatus for Intravascularly-Induced Neuromodulation or Denervation (Attorney Docket No. 57856.8018.US), which is incorporated herein by reference in its entirety.

Although the foregoing methods are useful by themselves, one challenge of intravascular neuromodulation and/or denervation is sufficiently affecting the neural tissue from within the vessel. For example, intravascular neuromodulation should avoid increasing the risk of acute and/or late stenosis. Therefore, it would be desirable to provide methods and apparatus that further address these challenges.

BRIEF DESCRIPTION OF THE DRAWINGS

Several embodiments of the present invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

Figure 1 is a schematic isometric detail view showing a common location of neural fibers proximate an artery.

Figures 2A-2J are schematic side views, partially in section, illustrating an example of methods and apparatus for a non-continuous circumferential treatment of a body lumen.

Figure 3 is a schematic side view, partially in section, illustrating an alternative embodiment of the methods and apparatus of Figures 2.

Figure 4 is a schematic side view, partially in section, illustrating further alternative methods and apparatus for non-continuous circumferential treatments.

Figures 5A and 5B are schematic side views, partially in section, illustrating still further alternative methods and apparatus for non-continuous circumferential treatments.

DETAILED DESCRIPTION

A. Overview

The applicants have discovered that it may be desirable to perform a circumferential treatment of a body lumen to positively affect a medical condition by applying energy to discrete zones that are non-continuous along the complete circumference of a radial cross-section generally normal to the lumen wall. For example, in the treatment of atrial fibrillation, a circumferential treatment may be achieved by forming a continuous circumferential lesion that is continuous completely about a radial cross-section of the pulmonary vein to disrupt aberrant electrical signals. In the treatment of heart failure, a circumferential treatment may be achieved by forming a similar continuous circumferential lesion that is continuous completely about a radial cross-section of a renal artery to reduce renal sympathetic neural activity. However, continuous circumferential lesions that extend continuously about a full 360° of the circumference of a radial cross-section normal to the body lumen or tissue in proximity to the body lumen may increase a risk of acute and/or late stenosis formation within the blood vessel. Therefore, many of the embodiments described below are directed to forming discrete, non-continuous lesions within a lumen without adversely affecting the vessel.

Such non-continuous treatments may, for example, be conducted from an intravascular or intraluminal position, which can include treatment utilizing elements passed from an intravascular location to an extravascular location, i.e., intra-to-extravascular treatment. However, it should be understood that extravascular treatment apparatus and methods in accordance with the present invention also may be provided.

The treatments can be applied relative to nerves, including nervous tissue in the brain, or other target structures within or in proximity to a blood vessel or other body lumen that travel at least generally parallel or along a lengthwise dimension of the blood vessel (body lumen). The target structures can additionally or alternatively comprise a rotational orientation relative to the blood vessel (body lumen). Several disclosed embodiments of non-continuous circumferential treatments may reduce the risk of acute and/or late stenosis formation by treating neural matter along portions of multiple radial planes or cross-sections that are spaced apart along the lengthwise dimension of the blood vessel (body lumen).

The treatment area at each radial plane or cross-section defines a treatment zone that is not completely continuous along a circumference, i.e., defines a treatment zone without a continuous circumferential lesion. However, superimposition of the multiple treatment zones along the multiple radial planes or cross-sections defines a non-continuous, overlapping circumferential treatment zone along a lengthwise segment of the blood vessel (body lumen). In some embodiments, this overlapping treatment zone may provide a non-continuous, but substantially fully circumferential treatment without formation of a continuous circumferential lesion. In other embodiments, the overlapping treatment zone may provide a non-continuous, partial circumferential treatment.

In this manner, a discontinuous circumferential treatment is performed over a lengthwise segment of the blood vessel (body lumen), as compared to a continuous circumferential treatment at a single lengthwise cross-section or radial plane. Target structures substantially traveling along the lengthwise dimension of the blood vessel (body lumen) are thus circumferentially affected in a discontinuous fashion without formation of the continuous circumferential lesion along any cross-section or radial plane of the blood vessel (body lumen). This may reduce a risk of acute or late stenosis formation within the blood vessel (body lumen). A discontinuous circumferential treatment can thus comprise a treatment conducted at multiple positions about the lengthwise dimension of a body lumen, wherein the treatment zone at any one lengthwise position does not comprise a continuous circumferential lesion completely about a radial plane, but wherein a superimposition of the treatment zones at all or some of the lengthwise positions may define an overlapping circumferential treatment zone.

The discontinuous circumferential treatment optionally may be achieved via apparatus positioned within a body lumen in proximity to target neural fibers for application of energy to the target neural fibers. The treatment may be induced, for example, via electrical and/or magnetic energy application, via thermal energy application (either heating or cooling), via mechanical energy application, via chemical energy application, via nuclear or radiation energy application, via fluid energy application, etc. Such treatment may be achieved, for example, via a thermal or non-thermal electric field, via a continuous or pulsed electric field, via a stimulation electric field, via localized drug delivery, via high intensity focused ultrasound, via thermal techniques, via athermal techniques, combinations thereof, etc. Such treatment may, for example, effectuate irreversible electroporation or electrofusion, necrosis and/or inducement of apoptosis, alteration of gene expression, action potential blockade or attenuation, changes in cytokine up-regulation, ablation and other conditions in target neural fibers. All or a part of the apparatus optionally may be passed through a wall of the body lumen to an extraluminal location in order to facilitate the treatment. The body lumen may, for example, comprise a blood vessel, and the apparatus may be positioned within the blood vessel via well-known percutaneous techniques.

Treatment may be achieved via either direct alteration of the target structures (e.g., target neural structures) or at least in part via alteration of the vascular or other structures that support the target structures or surrounding tissue, such as arteries, arterioles, capillaries, veins or venules. In some embodiments, the treatment may be achieved via direct application of energy to the target or support structures. In other embodiments, the treatment may be achieved via indirect generation and/or application of the energy, such as through application of an electric field or of high-intensity focused ultrasound that causes resistive heating in the target or supporting structures. Alternative thermal techniques also may be utilized.

In some embodiments, methods and apparatus for real-time monitoring of the treatment and its effects on the target or support structures, and/or in non-target tissue, may be provided. Likewise, real-time monitoring of the energy delivery apparatus may be provided. Power or total energy delivered, impedance and/or the temperature, of the target or non-target tissue or of the apparatus, additionally or alternatively may be monitored.

When utilizing an electric field to achieve desired circumferential treatment, the electric field parameters may be altered and combined in any combination, as desired. Such parameters can include, but are not limited to, voltage, power, field strength, pulse width, pulse duration, the shape of the pulse, the number of pulses and/or the interval between pulses (e.g., duty cycle), etc. For example, suitable field strengths can be up to about 10,000 V/cm, and may be either continuous or pulsed. Suitable shapes of the electrical waveform include, for example, AC waveforms, sinusoidal waves, cosine waves, combinations of sine and cosine waves, DC waveforms, DC-shifted AC waveforms, RF waveforms, square waves, trapezoidal waves, exponentially-decaying waves, or combinations thereof.

When utilizing a pulsed electric field, suitable pulse widths can be of any desired interval, for example, up to about 1 second. The field includes at least one pulse, and in many applications the field includes a plurality of pulses or is continuously applied, e.g., for up to several minutes. Suitable pulse intervals include, for example, intervals less than about 10 seconds. These parameters are provided as suitable examples and in no way should be considered limiting.

When utilizing thermal mechanisms to achieve the desired treatment, protective elements optionally may be provided to protect the non-target tissue, such as the smooth muscle cells, from thermal damage during the thermally-induced discontinuous circumferential treatment. For example, when heating target nerves or support structures, protective cooling elements, such as convective cooling elements, may be provided to protect the non-target tissue. Likewise, when cooling target nerves or support structures, protective heating elements, such as convective heating elements, may be utilized to protect the non-target tissue. Thermal energy may be applied either directly or indirectly for a brief or a sustained period of time in order to achieve, for example, desired neuromodulation or denervation. Feedback, such as sensed temperature along target or non-target tissue or along the apparatus, optionally may be used to control and monitor delivery of the thermal energy.

The non-target tissue optionally may be protected during, e.g., the neuromodulation or denervation, by utilizing blood flow as a conductive and/or convective thermal sink that absorbs excess thermal energy (hot or cold). For example, when blood flow is not blocked, the circulating blood may provide a relatively constant temperature medium for removing the excess thermal energy from the non-target tissue during the procedure. The non-target tissue additionally or alternatively may be protected by focusing the thermal (or other) energy on the target or support structures, such that an intensity of the energy is insufficient to induce thermal damage in the non-target tissue distant from the target or support structures.

Additional and alternative methods and apparatus may be utilized to achieve a discontinuous circumferential treatment without formation of a continuous circumferential lesion, as described hereinafter. To better understand the structures of devices of the present invention and the methods of using such devices for discontinuous circumferential treatment, it is instructive to examine a common neurovascular anatomy in humans.

B. Neurovascular Anatomy Summary

Figure 1 illustrates a common anatomical arrangement of neural structures relative to body lumens or vascular structures, typically arteries. Neural fibers **N** generally may extend longitudinally along the lengthwise dimension **L** of an artery **A** about a relatively small range of positions along the radial dimension **r**, often within the adventitia of the artery. The artery **A** has smooth muscle cells **SMC** that surround the arterial circumference and generally spiral around the angular dimension θ of the artery, also within a relatively small range of positions along the radial dimension **r**. The smooth muscle cells of the artery accordingly have a lengthwise or longer dimension generally extending transverse (i.e., non-parallel) to the lengthwise dimension of the blood vessel. The misalignment of the lengthwise dimensions of the neural fibers and the smooth muscle cells is defined as "cellular misalignment."

The cellular misalignment of the nerves **N** and the smooth muscle cells **SMC** may be exploited to selectively affect the nerve cells with reduced effect on the smooth muscle cells. More specifically, a discontinuous circumferential treatment may be achieved by superimposing treatments undertaken along multiple radial or cross-sectional planes of the artery **A** that are separated along the lengthwise dimension **L** of the artery, rather than performing a continuous circumferential treatment along a single radial plane or cross-section of the artery. In this manner, due to the cellular misalignment, the lengthwise-oriented neural fibers may experience a full, discontinuous circumferential treatment, while the angularly-oriented smooth muscle cells may experience only a partial circumferential treatment. Monitoring elements optionally may be utilized to assess an extent of treatment induced in the nerves and/or in the smooth muscle cells, as well as to adjust treatment parameters to achieve a desired effect.

C. Embodiments of Apparatus and Methods for Non-continuous Circumferential Treatment of a Body Lumen

Figures 2-5 illustrate examples of intravascular systems and methods for performing non-continuous circumferential treatments. The applicants have described intravascular and intra-to-extravascular systems for neuromodulation or denervation, for example, in co-pending U.S. Patent Application Nos. 11/129,765, filed May 13, 2005; and 11/363,867, filed on February 27, 2006, both of which have been incorporated herein by reference. The applicants also have described extravascular systems for neuromodulation or denervation (see, for example, U.S. Patent Application No. 11/189,563, filed July 25, 2005, incorporated herein by reference), and it should be understood that discontinuous circumferential treatments may be performed using extravascular (or extraluminal) systems, in addition to intravascular (intraluminal) or intra-to-extravascular (intra-to-extraluminal) systems. Applicants also have previously described thermal systems for neuromodulation or denervation, for example, in co-pending U.S. Patent Application No. 11/504,117, filed on August 14, 2006.

Referring now to Figures 2A-2J, the embodiment of an apparatus 300 comprises a catheter 302 having an optional positioning element 304 (e.g., a balloon, an expandable wire basket, other mechanical expanders, etc.) and expandable electrode element 306 positioned along the shaft of the catheter and illustratively located over the positioning element. The electrode element 306 can have one or more electrodes 307 electrically coupled to a field generator 50 for delivery of an electric field to the target neural fibers. In an alternative embodiment, one or more of the electrode(s) 307 of the electrode element 306 may comprise Peltier electrodes for heating or cooling the target neural fibers to modulate the fibers. The electrode(s) 307 optionally may be individually assignable and may be utilized in a bipolar fashion, and/or may be utilized in a monopolar fashion with an external ground pad attached to the exterior of the patient.

The field generator 50, as well as any of the electrode embodiments described herein, may be utilized with any embodiment of the present invention for delivery of an electric field with desired field parameters. The field generator 50 can be external to the patient. It should be understood that electrodes of embodiments described hereinafter may be electrically connected to the generator even though the generator is not explicitly shown or described with each embodiment. Furthermore, the field generator optionally may be positioned internal to the patient, and the electrodes and/or the field generator optionally may be temporarily or permanently implanted within the patient.

The positioning element 304 optionally may position or otherwise drive the electrode(s) 307 into contact with the vessel wall. The positioning element 304 may also comprise an impedance-altering element that alters the impedance within the vessel during the therapy to direct the electric field across the vessel wall. This may reduce an energy required to achieve desired neuromodulation or denervation and may reduce a risk of injury to non-target tissue. Applicants have previously described use of an impedance-altering element, for example, in co-pending U.S. Patent Application Serial No. 11/266,993, filed November 4, 2005, which is incorporated herein by reference in its entirety. When the positioning element 304 comprises an inflatable balloon, as in Figures 2A-J, the balloon may serve as both a centering and/or expansion element for the expandable electrode element 306, and as an impedance-altering electrical insulator for directing an electric field delivered via the electrode(s) 307 into or across the vessel wall for modulation of target neural fibers. Electrical insulation provided by the element 304 may reduce the magnitude of applied energy or other parameters of the electric field necessary to achieve desired modulation of the target fibers, up to and including full denervation of tissue containing the target fibers.

Furthermore, element 304 optionally may be utilized as a thermal element. For example, it may be inflated with a chilled fluid that serves as a heat sink for removing heat from tissue that contacts the element. Conversely, element 304 may be inflated with a warmed fluid that heats tissue in contact with the element. The thermal fluid within the element optionally may be circulated and/or exchanged within the positioning element 304 to facilitate more efficient conductive and/or convective heat transfer. Thermal fluids also may be used to achieve thermal neuromodulation via thermal cooling or heating mechanisms, as described in greater detail herein below.

The electrode(s) 307 can be individual electrodes (i.e., independent contacts), a segmented electrode with commonly connected contacts, or a single continuous electrode. Furthermore, the electrode(s) 307 may be configured to provide a bipolar signal, or the electrode(s) 307 may be used together or individually in conjunction with a separate patient ground pad for monopolar use. As an alternative or in addition to placement of the electrode(s) 307 along the expandable electrode element 306, as in Figures 2, the electrode(s) 307 may be attached to the positioning element 304 such that they contact the wall of the artery upon expansion of the positioning element. In such a variation, the electrode(s) may, for example, be affixed to the inside surface, outside surface or at least partially embedded within the wall of the positioning element (see Figures 5A and 5B). In another embodiment, the electrode(s) do not contact the vessel wall, and may be positioned at any desired location within the vessel.

The electrode(s) 307 or any other portion of the apparatus 300, such as catheter 302 or element 304, additionally or alternatively may comprise one or more sensors, such as thermocouples 310, for monitoring the temperature or other parameters of the target tissue, the non-target tissue, the electrodes, the positioning element and/or any other portion of the apparatus 300 or of the patient's anatomy. The treatment regime may be controlled using the measured parameter(s) as feedback. This feedback may be used, for example, to maintain the parameter(s) below a desired threshold, for example, a threshold that may cause injury to the non-target tissues. Conversely, the feedback may be used to maintain the parameter(s) at or above a desired threshold, for example, a threshold that may induce a desired effect in the target tissues, such as neuromodulation of target neural fibers or denervation of tissues innervated by the target neural fibers. Furthermore, the feedback may be used to keep the parameter(s) within a range that will induce the desired effect in the target tissues without injuring the non-target tissues. Multiple parameters (or the same or multiple parameters at multiple locations) optionally may be used as control feedback for ensuring the desired effects while mitigating the undesired effects.

As seen in Figure 2A, the catheter 302 may be delivered to a treatment site within the artery **A** (or within a vein or any other vessel in proximity to target neural fibers) in a low profile delivery configuration, for example, through the guide catheter or sheath 303. Alternatively, catheters may be positioned in multiple vessels for neuromodulation, e.g., within both an artery and a vein. Multi-vessel techniques for electric field neuromodulation have been described previously, for example, in Applicant's co-pending U.S. Patent Application No. 11/451,728, filed July 12, 2006, which is incorporated herein by reference in its entirety.

Once positioned within the vasculature as desired, the optional positioning element 304 may be expanded to expand the electrode element 306 and bring the electrodes 307 into contact with an interior wall of the vessel, as seen in Figure 2B. An electric field then may be generated by the field generator 50, transferred through the catheter 302 to the electrode element 306 and the electrodes 307, and delivered via the electrodes 307 across the wall of the artery. The electric field modulates the activity along neural fibers within the wall of the artery or in proximity to the artery, e.g., at least partially denervates tissue or organ(s) innervated by the neural fibers. This may be achieved, for example, via ablation or necrosis or via non-ablative injury or other changes to the target neural fibers or supporting structures. The electric field also may induce electroporation in the neural fibers.

As seen in the cross-sectional view of Figure 2C taken along the radial plane I--I of Figure 2B, the apparatus 300 illustratively comprises four electrodes 307 equally spaced about the circumference of the electrode element 306 and the positioning element 304. As seen in Figure 2D, when utilized in a monopolar fashion in combination with an external ground (not shown; *per se* known), the circumferential segments treated by each electrode overlap to form discrete treatment zones $\mathbf{TZ}_I$ that are not continuous completely around the circumference of the artery in a radial plane normal to the vessel wall. As a result, there are discrete untreated zones $\mathbf{UZ}_I$ about the circumference of the artery.

As seen in Figure 2E, the electrode element 306 may be collapsed about the radial dimension **r** of the artery such that the electrodes 307 do not contact the vessel wall, e.g., by collapsing the positioning element 304. The electrode element 306 may be rotated about the angular dimension θ of the artery to angularly reposition the electrodes 307 (best shown in Figure 2G). This rotation may be achieved, for example, by angularly rotating the catheter 302. In Figure 2E, the electrode element illustratively has been rotated approximately 45° about the angular dimension of the artery. In the embodiment of apparatus 300 shown in Figures 2A-D, the electrodes are equally spaced about the circumference of the apparatus such that a 45° angular rotation repositions the electrodes approximately halfway between the initial positions of the electrodes shown in Figure 2D.

In addition to angular repositioning of the electrodes, the electrodes may be repositioned along the lengthwise dimension **L** of the artery, which is also shown in Figure 2E as the longitudinal offset between the electrodes 307 and the radial plane I-I. Such lengthwise repositioning may occur before, after or concurrent with angular repositioning of the electrodes. As seen in Figure 2F, once repositioned in both the lengthwise and angular dimensions, the electrode element 306 may be re-expanded about the radial dimension to contact the electrodes 307 with the vessel wall. An electric field then may be delivered via the angularly and lengthwise repositioned electrodes 307.

In Figure 2G, the treatment along radial plane II---II of Figure 2F creates treatment zone $\mathbf{TZ}_{II}$ and untreated zone $\mathbf{UZ}_{II}$. As with the treatment zone $\mathbf{TZ}_{I}$ of Figure 2D, the treatment zone $\mathbf{TZ}_{II}$ of Figure 2G is not continuous about the complete circumference of the artery. Figures 2H and 2I allow comparison of the treatment zone $\mathbf{TZ}_{I}$ and the treatment zone $\mathbf{TZ}_{II}$. The apparatus 300 is not shown in Figures 2H and 2I, e.g., the apparatus may have been removed from the patient to complete the procedure.

As shown, the untreated zones $\mathbf{UZ}_{I}$ and $\mathbf{UZ}_{II}$ along the radial planes I--I and II—II, respectively, are angularly offset from one another. As seen in Figure 2J, by superimposing the treatment zones $\mathbf{TZ}_{I}$ and $\mathbf{TZ}_{II}$, which are positioned along different cross-sections or radial planes of the artery **A**, a composite treatment zone $\mathbf{TZ}_{I\text{-}II}$ is formed that provides a non-continuous, yet substantially circumferential treatment over a lengthwise segment of the artery. This superimposed treatment zone beneficially does not create a continuous circumferential lesion along any individual radial plane or cross-section normal to the artery, which may reduce a risk of acute or late stenosis formation, as compared to previous circumferential treatments that create a continuous circumferential lesion.

As discussed previously, non-continuous circumferential treatment by positioning electrodes at different angular orientations along multiple lengthwise locations may preferentially affect anatomical structures that substantially propagate along the lengthwise dimension of the artery. Such anatomical structures can be neural fibers and/or structures that support the neural fibers. Furthermore, such a discontinuous circumferential treatment may mitigate or reduce potentially undesirable effects induced in structures that propagate about the angular dimension of the artery, such as smooth muscle cells. The angular or circumferential orientation of the smooth muscle cells relative to the artery may at least partially explain why continuous circumferential lesions may increase a risk of acute or late stenosis.

Although in Figures 2A-J the electrode element 306 is expanded via the positioning element 304, it should be understood that expandable electrode elements or electrodes in accordance with the present invention additionally or alternatively may be configured to self-expand into contact with the vessel wall. For example, the electrodes may self-expand after removal of a sheath or a guide catheter 303 constraining the electrodes in a reduced delivery configuration. The electrodes or electrode elements may, for example, be fabricated from (or coupled to) shape-memory elements that are configured to self-expand. Self-expanding embodiments optionally may be collapsed for retrieval from the patient by re-positioning of a constraining sheath or catheter over the self-expanding elements.

Figure 3 illustrates an alternative embodiment of the apparatus 300 having a self-expanding electrode element 306'. Positioning element 304 has been removed from the apparatus. In use, the apparatus 300 is advanced to a treatment site within sheath or guide catheter 303. The sheath is removed, and the element 306' self-expands to bring the electrodes 307 into contact with the vessel wall. Advantageously, blood continues to flow through the artery **A** during formation of treatment zone $\mathbf{TZ_{I}}$. The element 306' then may be partially or completely collapsed (e.g., within sheath 303), angularly rotated relative to the vessel, laterally repositioned relative to the vessel, and re-expanded into contact with the vessel wall along a different radial plane or cross-section. Treatment may proceed at the new location and in the new angularly orientation in the presence of blood flow, e.g., to form overlapping treatment zone $\mathbf{TZ_{II}}$ that completes a discontinuous circumferential treatment zone $\mathbf{TZ_{I-II}}$ when superimposed with the treatment zone $\mathbf{TZ_{I}}$. The element 306' then may be re-collapsed, and the apparatus 300 may be removed from the patient to complete the procedure.

Referring now to Figure 4, it may be desirable to achieve a discontinuous circumferential treatment without angular and/or lengthwise repositioning of electrodes or other energy delivery elements. To this end, in another embodiment an apparatus

400 comprises catheter 402 having actively-expandable or self-expanding wire basket 404 having proximal electrodes 406 and distal electrodes 408 spaced longitudinally apart from the proximal electrodes. The proximal electrodes 406 and distal electrodes 408 are also spaced apart radially about the wire basket and electrically coupled to the field generator 50 (see Figure 2A). The proximal electrodes 406 can be positioned along different wires of the wire basket than the distal electrodes. The proximal and distal electrodes are accordingly angularly and laterally offset from one another.

The proximal electrodes may be operated independently of the distal electrodes, and/or the proximal and distal electrodes all may be operated at the same polarity, e.g., in a monopolar fashion as active electrodes in combination with an external ground. Alternatively or additionally, the proximal electrodes may be utilized in a bipolar fashion with one another and/or the distal electrodes may be utilized in a bipolar fashion with one another. The proximal and distal electrodes preferably are not utilized together in a bipolar fashion. By treating with the distal electrodes 408, the treatment zone $\mathbf{TZ_{I}}$ of Figure 2H may be formed about the artery. Treating with the proximal electrodes 406 may create the treatment zone $\mathbf{TZ_{II}}$ of Figure 2I, which is angularly offset relative to the treatment zone $\mathbf{TZ_{I}}$. Superimposition of the treatment zones $\mathbf{TZ_{I}}$ and $\mathbf{TZ_{II}}$ creates the discontinuous circumferential treatment zone $\mathbf{TZ_{I-II}}$ over a lengthwise segment of the artery.

The proximal and distal electrodes optionally may be utilized concurrently to concurrently form the treatment zones $\mathbf{TZ_{I}}$ and $\mathbf{TZ_{II}}$. Alternatively, the electrodes may be operated sequentially in any desired order to sequentially form the treatment zones. As yet another alternative, the treatment zones may be formed partially via concurrent treatment and partially via sequential treatment.

Figures 5A and 5B describe additional apparatus and methods for discontinuous circumferential treatment without having to reposition electrodes or other energy delivery elements. As seen in Figures 5A and 5B, the apparatus 300 has an electrode element 306" that comprises a flex circuit coupled to or positioned about the positioning element 304. The flex circuit is electrically coupled to the field generator 50 by wires that extend through or along the catheter 302 or by wireless. In Figure 5A, the flex circuit comprises a collapsible cylinder positioned about the positioning element 304. In Figure 5B, the flex circuit comprises individual electrical connections for each electrode 307, which may facilitate collapse of the flex circuit for delivery and retrieval. As with the electrodes of apparatus 400 of Figure 4, the electrodes 307 of Figure 7 are spaced at multiple lengthwise positions relative to the positioning element and the blood vessel. The electrodes may be operated as described previously to achieve a discontinuous circumferential treatment. As the electrodes 307 illustratively are positioned at three different lengthwise positions, the discontinuous circumferential treatment may, for example, be formed via superimposition of three treatment zones (one at each lengthwise position within the blood vessel).

Figures 2-5 illustratively describe electrical methods and apparatus for circumferential treatment without formation of a circumferential lesion. However, it should be understood that alternative energy modalities, including magnetic, thermal, chemical, nuclear/radiation, fluid, etc., may be utilized to achieve the desired circumferential treatment without circumferential lesion. Furthermore, although Figures 2-5 illustratively comprise fully intravascular positioning of the apparatus, it should be understood that all or a portion of the apparatus may be positioned extravascularly, optionally via an intra-to-extravascular approach.

During delivery of the electric field (or of other energy), blood within the vessel may act as a thermal sink (either hot or cold) for conductive and/or convective heat transfer for removing excess thermal energy from the non-target tissue (such as the interior wall of the vessel), thereby protecting the non-target tissue. This effect may be enhanced when blood flow is not blocked during energy delivery, as in the embodiments of Figures 3 and 4. Use of the patient's blood as a thermal sink is expected to facilitate delivery of longer or higher energy treatments with reduced risk of damage to the non-target tissue, which may enhance the efficacy of the treatment at the target tissue, for example, at target neural fibers.

In addition or as an alternative to utilizing the patient's blood as a thermal sink, a thermal fluid (hot or cold) may be injected into the vessel, e.g., upstream of the electrode(s) or other energy delivery element, to remove excess thermal energy and protect the non-target tissues. The thermal fluid may, for example, be injected through the device catheter or through a guide catheter. Furthermore, this method of using an injected thermal fluid to remove excess thermal energy from non-target tissues to protect the non-target tissues from thermal injury during therapeutic treatment of target tissues may be utilized in body lumens other than blood vessels.

Although preferred illustrative variations of the present invention are described above, it will be apparent to those skilled in the art that various changes and modifications may be made thereto without departing from the invention. For example, although in the described embodiments of Figures 2-4 discontinuous circumferential treatment is achieved via superimposition of treatment at two locations, it should be understood that treatment at more than two locations may be superimposed to achieve the circumferential treatment, as described with respect to Figures 5A and 5B. Furthermore, although in the described embodiments the methods are conducted in a blood vessel, it should be understood that treatment alternatively may be conducted in other body lumens. It is intended in the appended claims to cover all such changes and modifications that fall within the true spirit and scope of the invention.

CLAIMS

I/We claim:

1. A method for discontinuous circumferential treatment of a body lumen of a patient, the method comprising:

positioning an energy delivery element at least proximate to a wall of the body lumen;

delivering energy from the energy delivery element to less than a full circumference of the body lumen at a first lengthwise position relative to the body lumen to form a first treatment zone; and

delivering energy from the energy delivery element to less than a full circumference of the body lumen at a second lengthwise position relative to the body lumen to form at least a second treatment zone, wherein the first lengthwise position and the second lengthwise position are spaced apart from one another along a lengthwise dimension of the lumen.

2. The method of claim 1, wherein delivering energy at the second lengthwise position further comprises re-positioning the energy delivery element relative to the body lumen of the patient.

3. The method of claim 1, wherein positioning the energy delivery element in proximity to the body lumen of the patient further comprises positioning the energy delivery element in proximity to a blood vessel of the patient.

4. The method of claim 1, wherein positioning the energy delivery element in proximity to the body lumen of the patient further comprises positioning the energy delivery element within the body lumen of the patient.

5. The method of claim 4, wherein positioning the energy delivery element within the body lumen of the patient further comprises positioning the energy delivery element within a blood vessel of the patient.

6. The method of claim 5 further comprising blocking blood flow within the blood vessel during the energy delivery.

7. The method of claim 4, wherein positioning the energy delivery element within the body lumen of the patient further comprises contacting the wall of the body lumen with the energy delivery element.

8. The method of claim 4, wherein positioning the energy delivery element within the body lumen of the patient further comprises passing the energy delivery element across the wall of the body lumen prior to the energy delivery.

9. The method of claim 1, wherein positioning the energy delivery element in proximity to the body lumen further comprises positioning an energy delivery element comprising energy delivery sub-elements that are spaced lengthwise and angularly relative to one another.

10. The method of claim 9, wherein delivering energy at the first and at least second lengthwise positions further comprises delivering energy with the lengthwise- and angularly-spaced energy delivery sub-elements.

11. The method of claim 10, wherein delivering energy with the energy delivery sub-elements further comprises concurrently delivering energy at the first and the at least second lengthwise positions.

12. The method of claim 11, wherein delivering energy with the energy delivery sub-elements further comprises sequentially delivering energy at the first and the at least second lengthwise positions in any desired order.

13. The method of claim 1, wherein positioning the energy delivery in proximity to the body lumen of the patient further comprises positioning the energy delivery element in proximity to multiple body lumens of the patient.

14. The method of claim 5, wherein positioning the energy delivery element within the blood vessel of the patient further comprises positioning the energy delivery element within a renal vasculature of the patient.

15. The method of claim 1, wherein positioning the energy delivery element in proximity to the body lumen further comprises positioning at least one electrode in proximity to the body lumen, and

wherein delivering energy with the energy delivery element further comprises delivering an electric field from the at least one electrode.

16. The method of claim 15 further comprising attaching an external ground to an exterior of the patient,

wherein delivering the electric field further comprises delivering the electric field in a monopolar fashion between the at least one electrode and the external ground.

17. Apparatus for discontinuous circumferential treatment of a body lumen of a patient, the apparatus comprising:

a device configured for positioning in proximity to the body lumen;

a first energy delivery element coupled to the device; and

a second energy delivery element coupled to the device,

wherein the first energy delivery element and the second energy delivery element are spaced apart lengthwise and angularly offset from one another about a length of the device,

wherein each of the first energy delivery element and the second energy delivery element are configured to deliver energy to a less than a full circumference of the body lumen of the patient.

18. The apparatus of claim 17, wherein the device comprises a catheter configured for positioning within the body lumen, and

wherein the first energy delivery element and the second energy delivery element are coupled to an expandable element that is configured to bring the first energy delivery element and the second energy delivery element into contact with a wall of the body lumen.

19. The apparatus of claim 18, wherein the expandable element is configured to block fluid flow within the body lumen during energy delivery.

20. The apparatus of claim 17, wherein the device comprises a catheter configured for positioning within the body lumen, and

wherein the first energy delivery element and the at least second energy delivery element are configured for passage across a wall of the body lumen.

21. The apparatus of claim 17 further comprising at least one sensor configured to monitor a parameter of the apparatus or of tissue within the patient.

22. The apparatus of claim 21 further comprising a feedback control system configured to alter treatment in response to the monitored parameter.

23. A method for treatment, the method comprising:

positioning an energy delivery element at a first lengthwise and angular position relative to a body lumen of a patient;

delivering energy from the energy delivery element to less than a full circumference of the body lumen at the first lengthwise and angular position to form a first treatment zone;

repositioning the energy delivery element to a second lengthwise and angular position relative to the body lumen that is different than the first lengthwise and angular position; and

delivering energy from the energy delivery element to less than a full circumference of the body lumen at the second lengthwise and angular position to form a second treatment zone.

24. The method of claim 23, wherein a composite treatment zone formed via superimposition of the first treatment zone and the second treatment zone comprises a discontinuous, fully circumferential treatment zone.

25. A method for treating a patient, comprising:

delivering energy to a first treatment zone at an inner wall of a body lumen and to a second treatment zone at the wall of the lumen, wherein the first treatment zone has a discrete, non-continuous first lesion at a radial plane and the second treatment zone has a discrete, non-continuous second lesion at a second radial plane spaced apart from the first radial plane; and

affecting neural tissue outside of the inner wall body lumen.

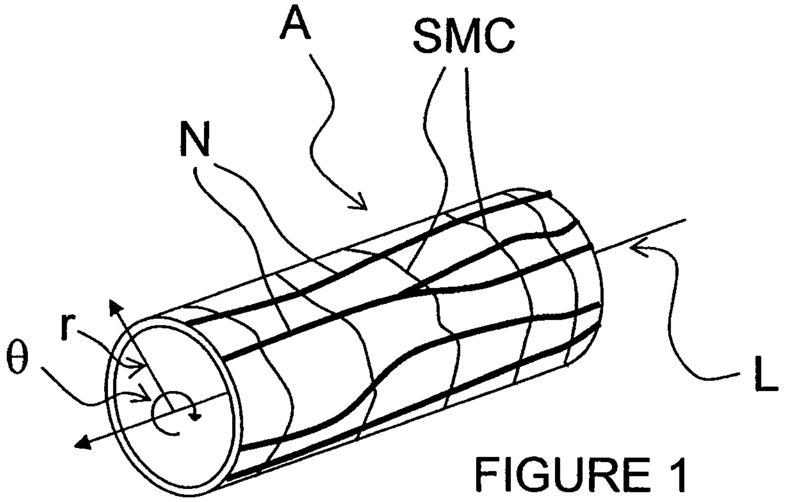

FIGURE 1

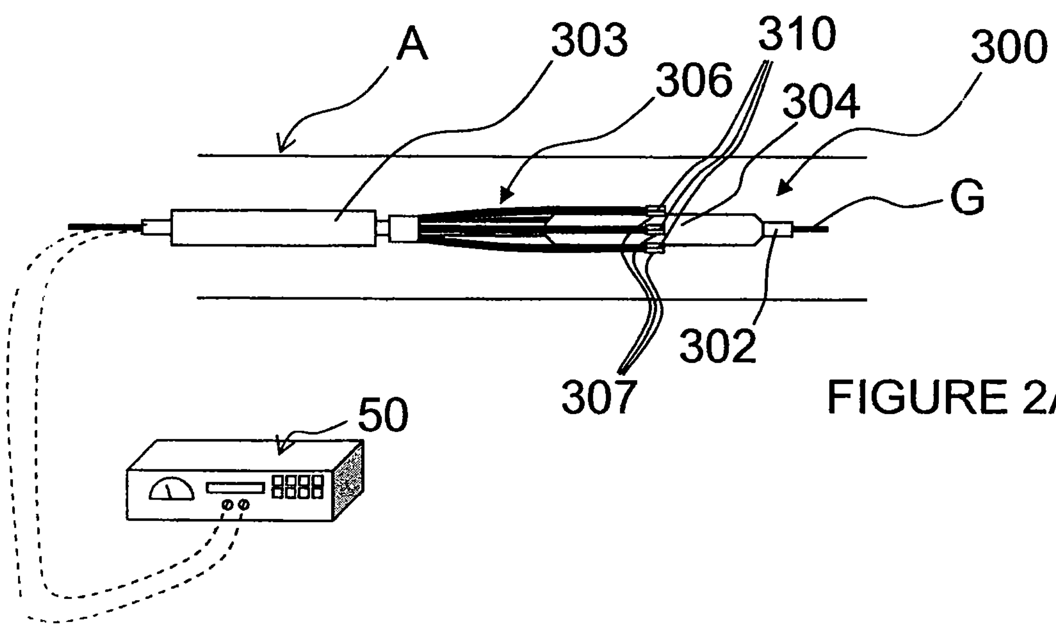

FIGURE 2A

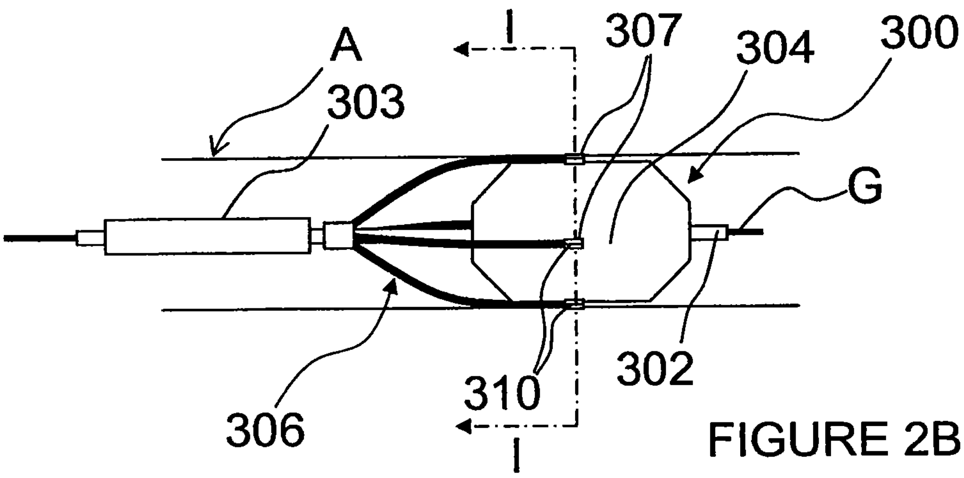

FIGURE 2B

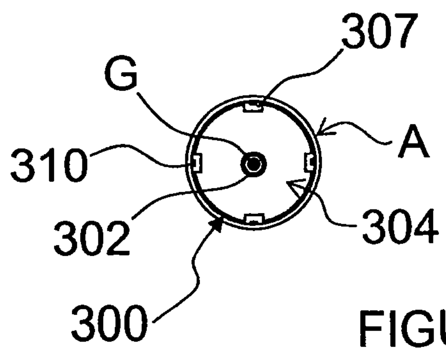

FIGURE 2C

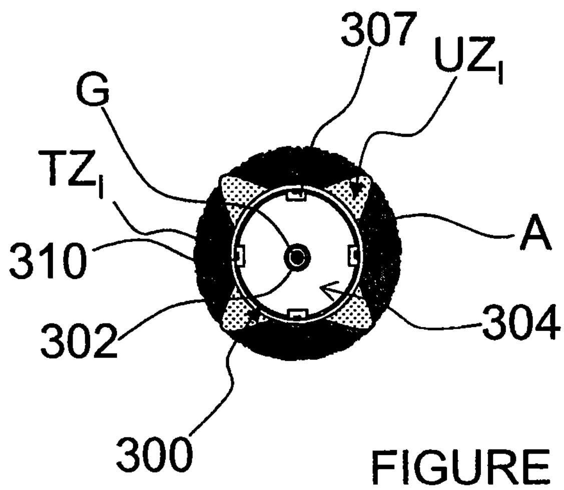

FIGURE 2D

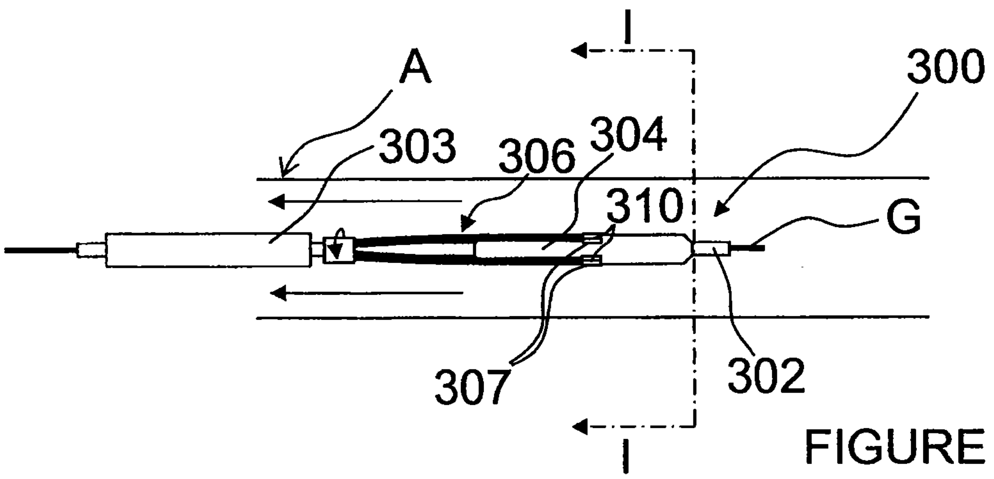

FIGURE 2E

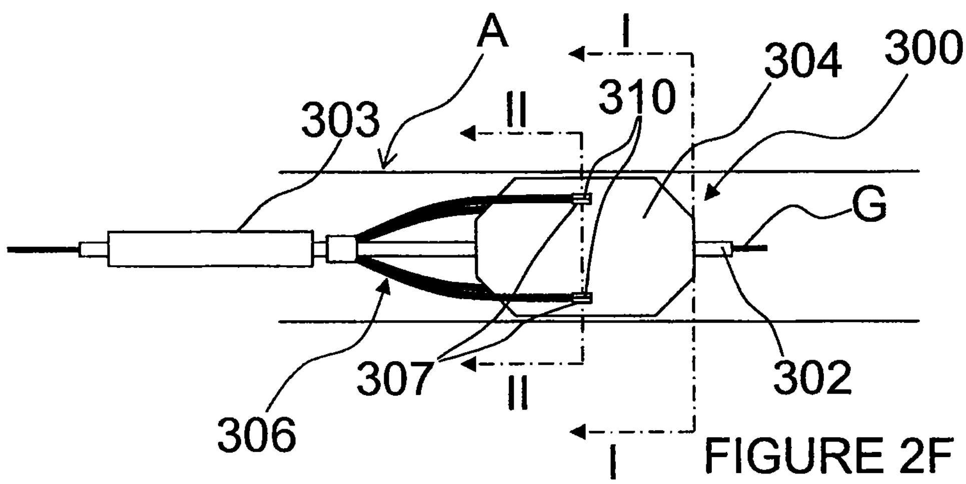

FIGURE 2F

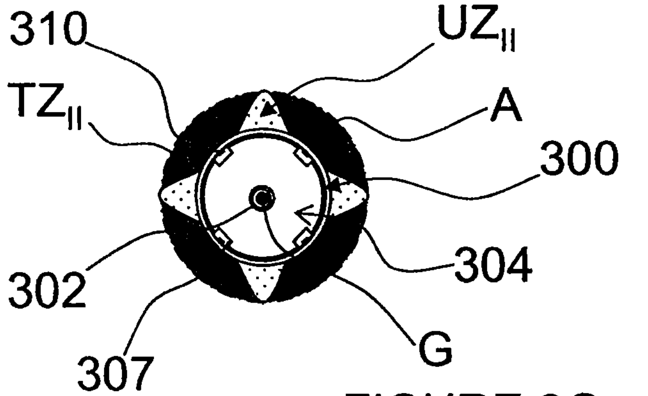

FIGURE 2G

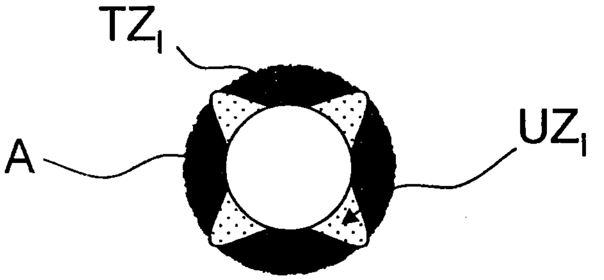

FIGURE 2H

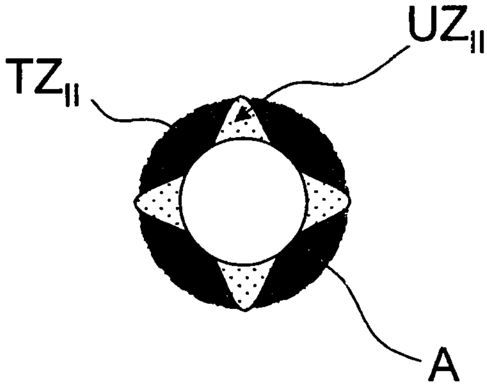

FIGURE 2I

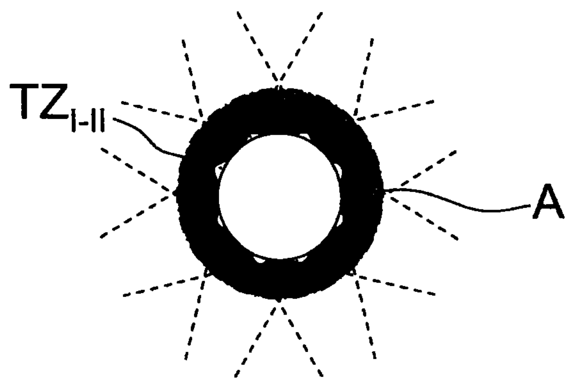

FIGURE 2J

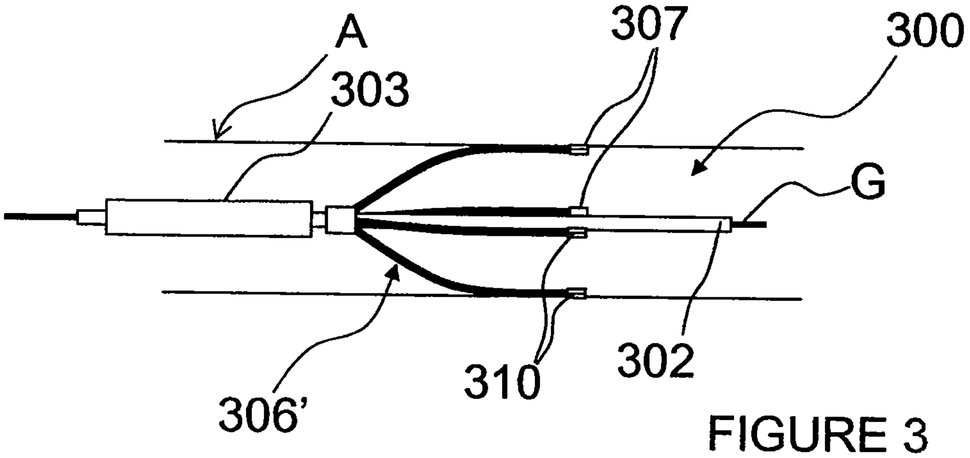

FIGURE 3

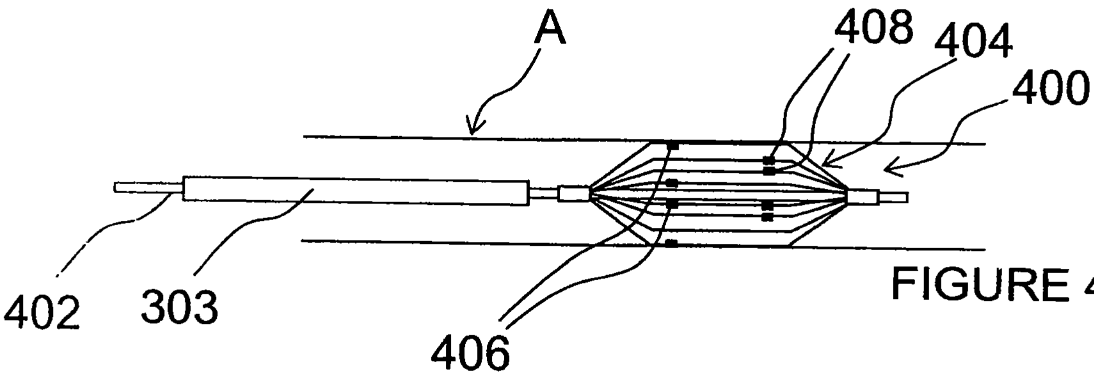

FIGURE 4

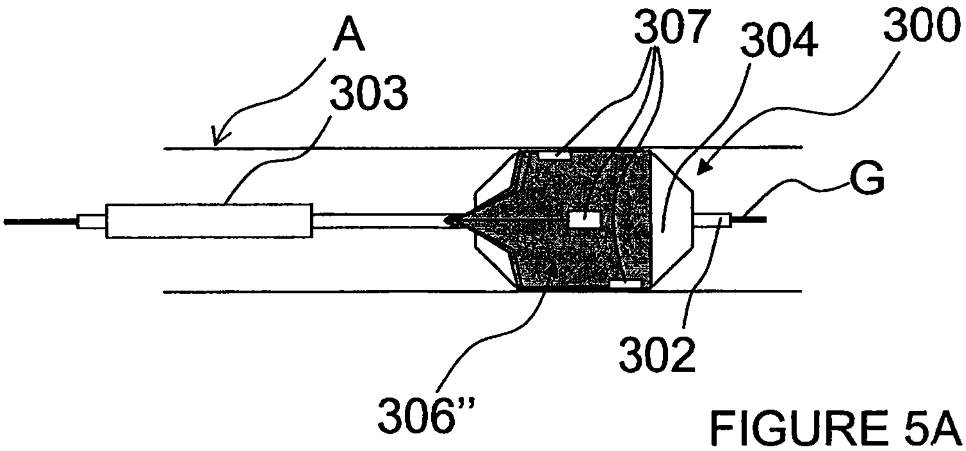

FIGURE 5A

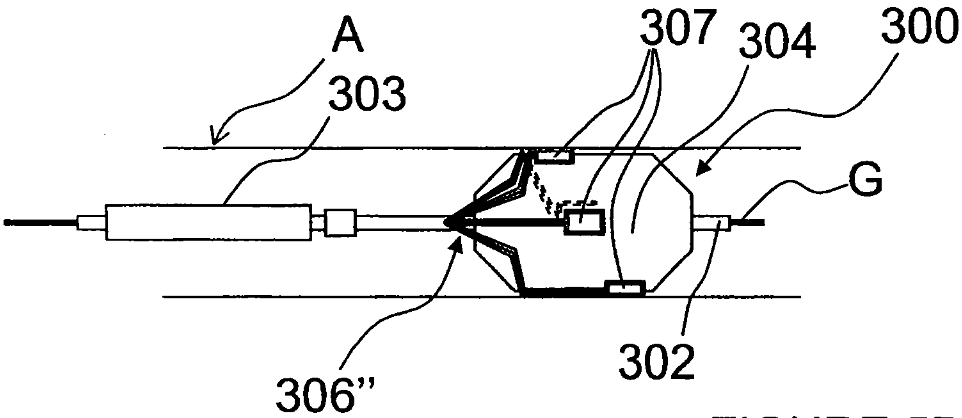

FIGURE 5B

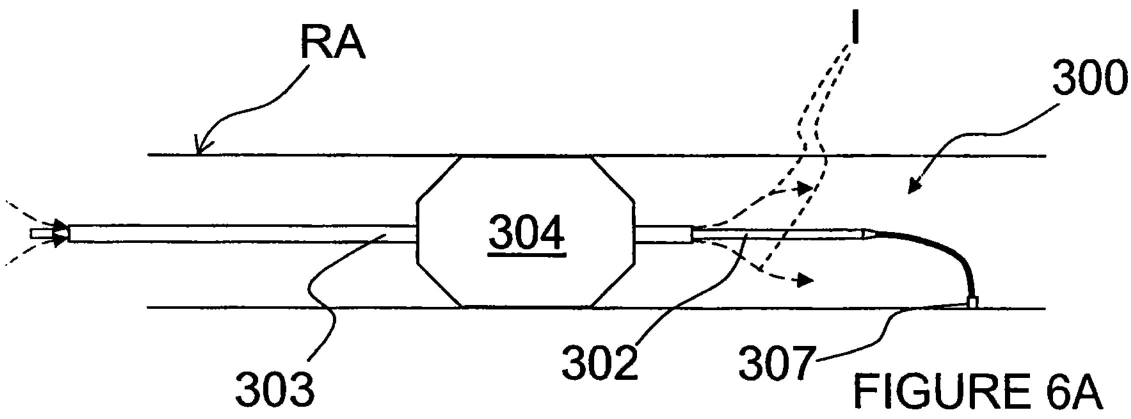

FIGURE 6A

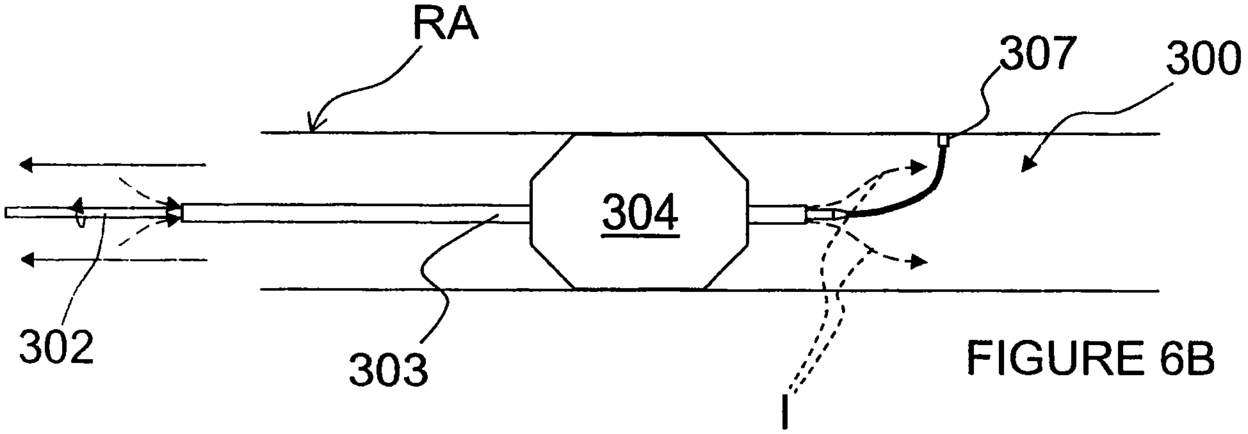

FIGURE 6B

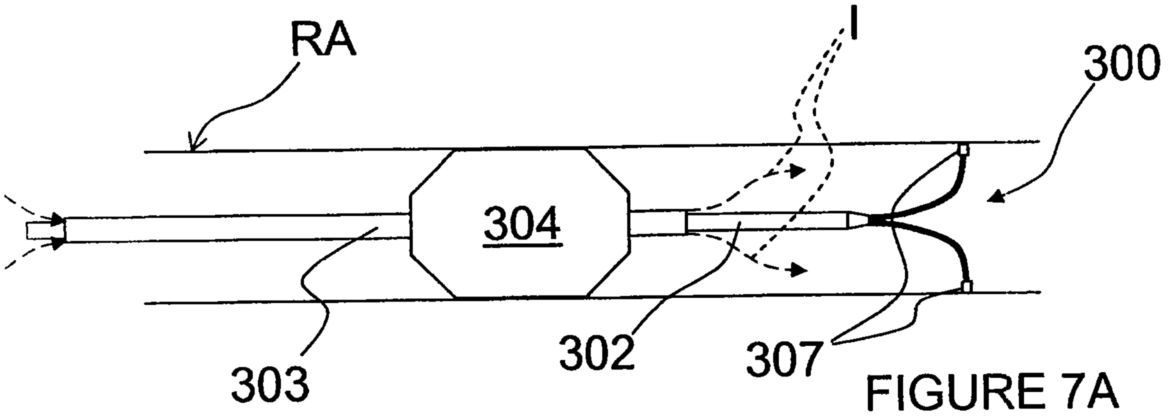

FIGURE 7A

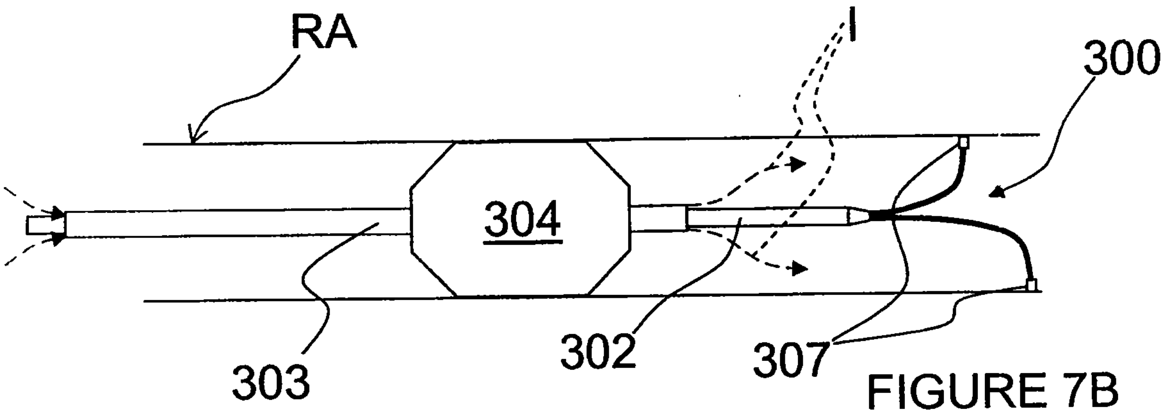

FIGURE 7B

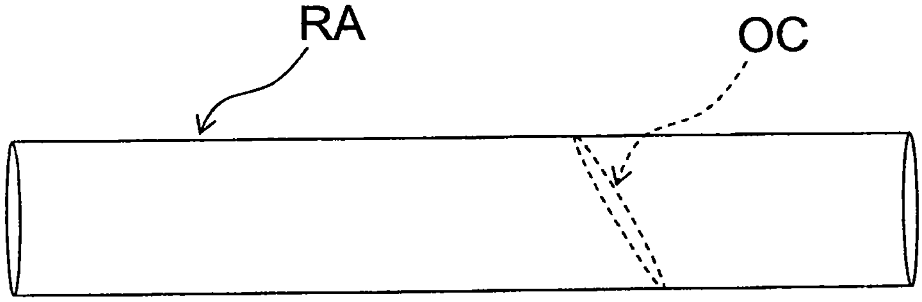

FIGURE 8

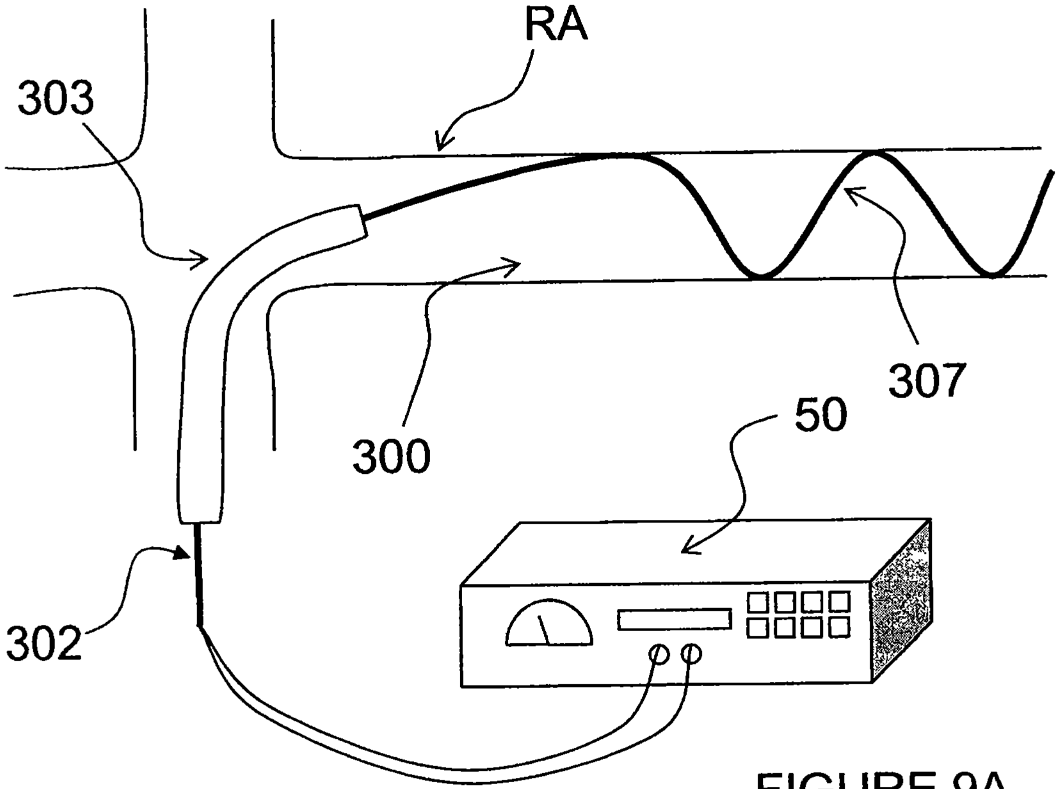

FIGURE 9A

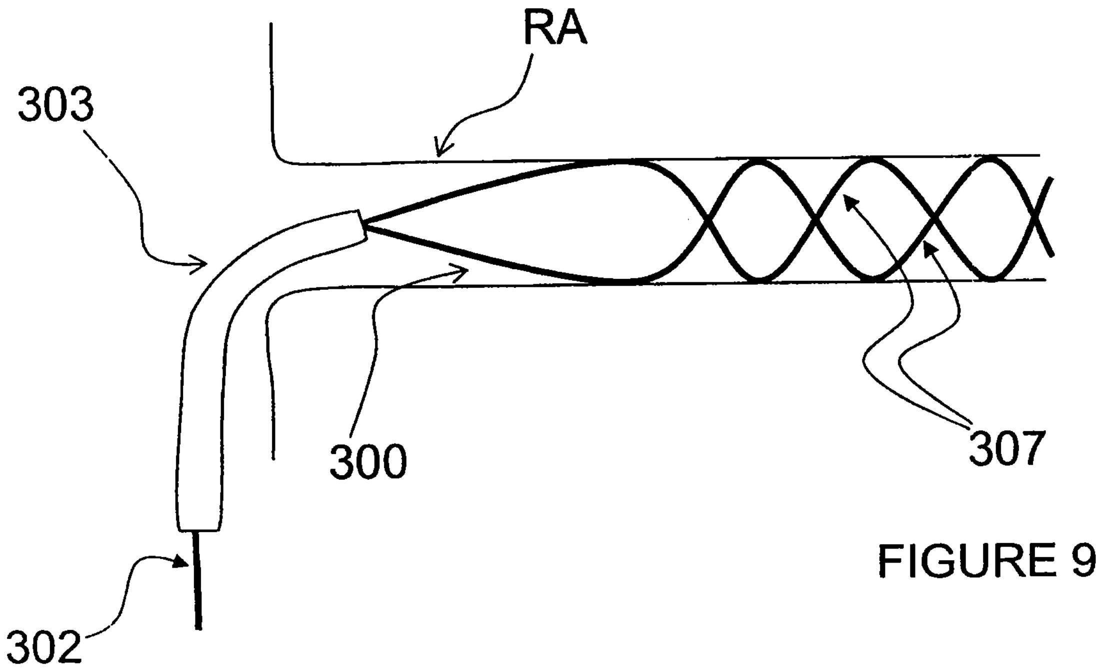

FIGURE 9B

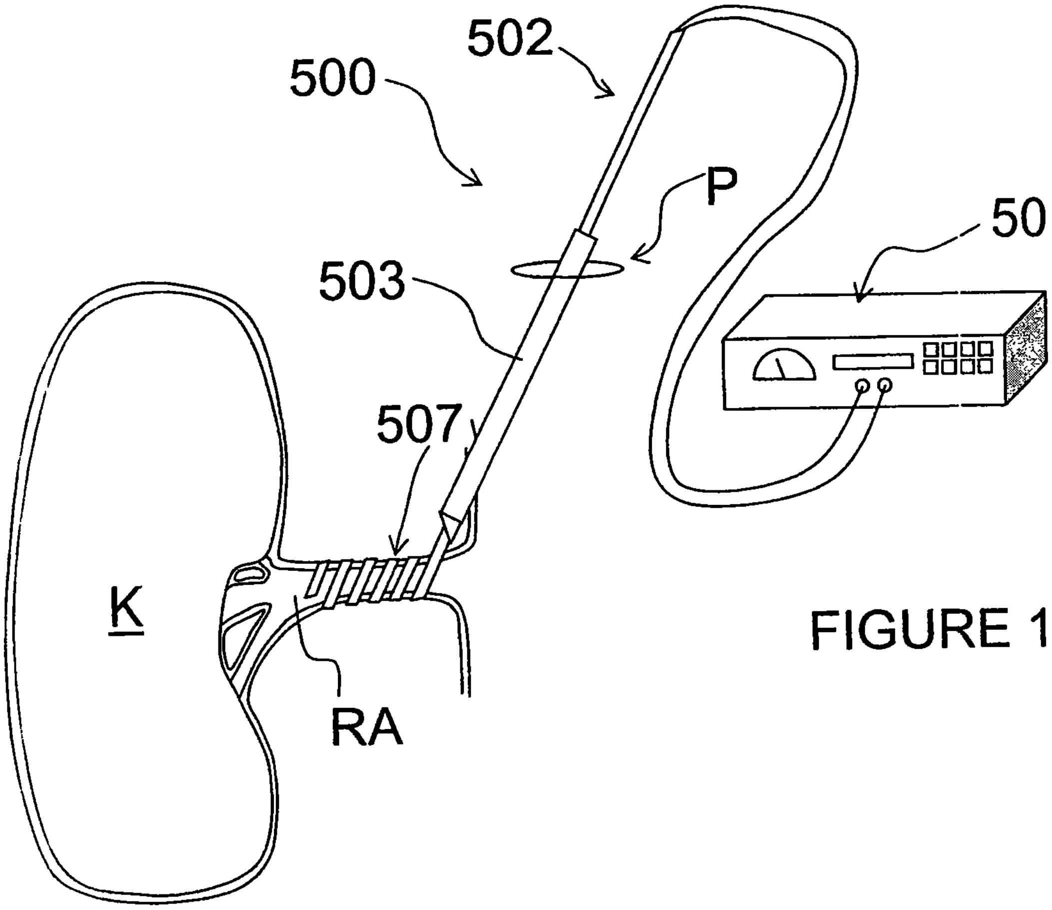

FIGURE 10A

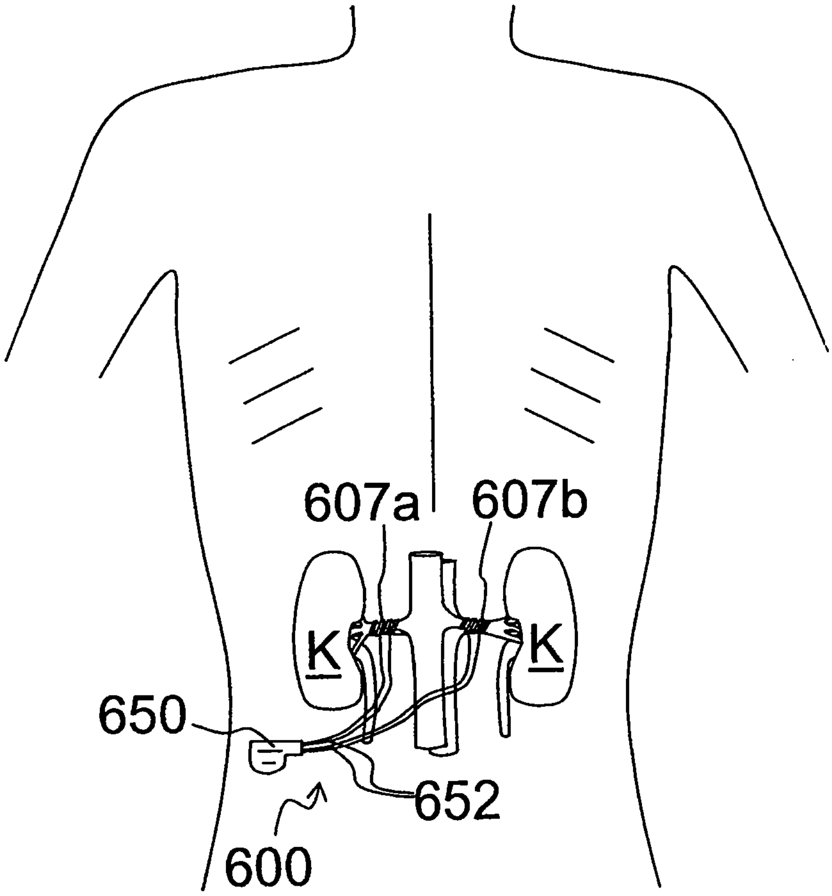

FIGURE 10B