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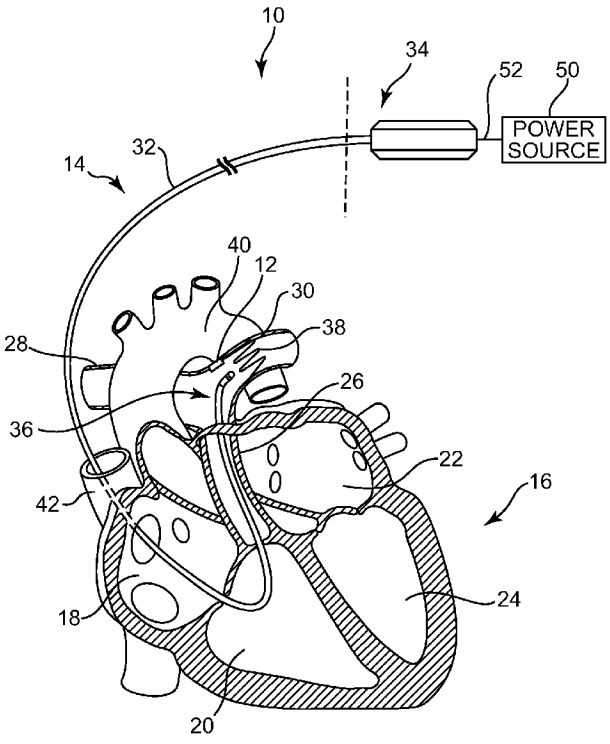

Fig. 1

(57) Abstract: Methods, systems, and apparatus for recharging medical devices implanted within the body are disclosed. An illustrative method of recharging an implanted medical device includes delivering a charging device to a location adjacent to the implanted medical device, activating a charging element coupled to the charging device and transmitting charging energy to a receiver of the implanted medical device, and charging the implanted medical device using the transmitted charging energy from the charging device.

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METHODS AND SYSTEMS FOR RECHARGING IMPLANTABLE DEVICES

TECHNICAL FIELD

[0001] The present invention relates generally to implantable medical devices including rechargeable power sources. More specifically, the present invention pertains to methods, systems, and apparatus for recharging medical devices implanted within the body.

BACKGROUND

[0002] Actively powered implantable medical devices sometimes require a power supply such as a battery or power capacitor to provide electrical power to the device, in some cases over an extended period of time. In cardiac rhythm management applications, for example, an implantable medical device such as a pressure sensor may require a power supply capable of operating the device over a period of several years. In some cases, the time required to power the device is beyond the capability of the power supply, requiring replacement of the power supply or the implantation of a new device within the body.

[0003] With advances in power management and battery technology, more recent trends have focused on the use of small rechargeable power sources for providing power to implantable devices. Current charging techniques often rely on the patient and/or a health-care provider to ensure that the battery is charged periodically. In some cases, the patient may be required to undergo recharging within a clinical environment, which can be burdensome to the patient and often adds to the overall costs associated with recharging. If recharging is to be performed in a clinic, for example, a special area may be required for the patient while the recharging is being performed, adding to the overall cost and time associated with the maintenance.

SUMMARY

[0004] The present invention pertains to methods, systems, and apparatus for recharging medical devices implanted within the body. An illustrative recharging system includes a device implanted within a body lumen having a rechargeable power source and a receiver, and a charging device adapted to provide charging energy to the implanted device from a location within the body adjacent to the device. A charging element coupled to the charging device is configured to transmit energy at a location within the body proximate to the receiver. In some embodiments, for example, the charging element includes a source transducer adapted to transmit an acoustic signal to a target transducer coupled to the implanted device for acoustically recharging the device. Alternatively, and in other embodiments, the charging element includes an electromagnetic transmitter adapted to transmit an electromagnetic signal to an antenna or coil coupled to the implanted device for recharging the device using RF or other forms of electromagnetic energy. Other energy transfer modes can also be employed for recharging the implanted device.

[0005] An illustrative method of recharging a medical device implanted within a body lumen of a patient's body includes delivering a distal section of the charging device to a location adjacent to the implanted device, activating a charging element operatively coupled to a power source and wirelessly transmitting energy to a receiver coupled to the implanted device, and converting the energy received by the receiver into electrical energy for charging the implanted device. The charging device can be positioned at a target location within the same body lumen as the implanted device, or alternatively, within a different body lumen. For recharging a pressure sensor implanted within a pulmonary artery, for example, the charging device can be delivered to a location within the pulmonary artery, an adjacent artery, or an adjacent lumen or cavity such

as the aorta or esophagus. Once positioned adjacent to the implanted device, the charging element can be activated to transmit charging energy to the device from a position within the body. In some embodiments, the charging device can be used to perform other functions within the body such as calibrating the implanted device, confirming the proper operation of the charging device, and/or performing therapy within the body.

[0006] While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 1 is a schematic view of an illustrative system for recharging a medical device implanted within a body lumen;

[0008] Figure 2 is a partial cross-sectional view showing the distal section of the charging device of Figure 1 inserted at a target location within the body adjacent to the implanted device;

[0009] Figure 3 is a partial cross-sectional view showing the distal section of a charging device in accordance with another illustrative embodiment including a sensor;

[0010] Figure 4 is a partial cross-sectional view showing the distal section of a charging device in accordance with another illustrative embodiment including a thermocouple wire;

[0011] Figure 5 is a partial cross-sectional view showing the distal section of a charging device in accordance with another illustrative embodiment including a cooling lumen;

[0012] Figure 6 is a partial cross-sectional view showing the distal section of a charging device in accordance with another illustrative embodiment including a cooling lumen;

[0013] Figure 7 is a schematic view showing another illustrative system for recharging a medical device implanted within a body lumen;

[0014] Figure 8 is a schematic view showing another illustrative system for recharging a medical device implanted within a body lumen;

[0015] Figure 9 is a partial cross-sectional view showing the distal section of the charging device of Figure 8 inserted at a target location within the body adjacent to the implanted device;

[0016] Figure 10 is a schematic view showing another illustrative system for recharging a medical device implanted within a body lumen;

[0017] Figure 11 is another view of the charging device of Figure 10; and

[0018] Figure 12 is a transverse view of a patient's thorax, showing the insertion of the charging device of Figure 10 in the esophagus adjacent to a medical device implanted within the right pulmonary artery.

[0019] While the invention is amenable to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and are described in detail below. The intention, however, is not to limit the invention to the particular embodiments described. On the contrary, the invention is intended to cover all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

[0020] Figure 1 is a schematic view of an illustrative system 10 for recharging a medical device implanted within a body lumen. The system 10, illustratively a system for recharging a device 12 implanted within a pulmonary artery, includes a charging catheter 14 adapted for insertion at

a target location within a patient's body such as in or near the heart 16. The heart 16 includes a right atrium 18, a right ventricle 20, a left atrium 22, and a left ventricle 24. The right ventricle 20 leads to the main pulmonary artery 26, which further branches to the right pulmonary artery 28 and the left pulmonary artery 30, as shown.

[0021] The charging catheter 14 includes an elongate shaft 32 having a proximal section 34 located outside of the patient's body, and a distal section 36 insertable into the patient's body at a location adjacent to the implanted device 12. In the illustrative embodiment of Figure 1, the distal section 36 of the elongate shaft 32 is shown inserted into the main pulmonary artery 26 of the heart 16 at a location adjacent to the device 12, which is shown secured within a portion of the left pulmonary artery 30 via a fixation element 38. The distal section 36 of the charging catheter 14 can be positioned at other locations within the body, including the right pulmonary artery 28, the left pulmonary artery 30, or an adjacent vessel or body lumen such as the aorta 40, as discussed further herein. The positioning of the charging catheter 14 within the body will typically depend on the implantation location and configuration of the implanted device 12 to be recharged, the anatomy surrounding the implanted device 12, as well as other factors.

[0022] In some embodiments, the charging catheter 14 can be inserted into the main pulmonary artery 26 via an intravenous approach from a percutaneous access site such as a femoral artery or jugular vein. As shown in Figure 1, for example, delivery of the charging catheter 14 to a target location within the body can occur intravenously through the superior vena cava 42, the right atrium 18, the right ventricle 20, and the main pulmonary artery 26. Other techniques for inserting the charging catheter 14 into the right pulmonary artery 26 are also possible. In some alternative embodiments, for example, the charging catheter 14 can be inserted into the main pulmonary artery 26 via an intra-arterial approach,

percutaneously without the aid of vascular conduits, or via the esophagus, airway, or other conduit.

[0023] The implanted device 12 can be configured to perform one or more designated functions, including the sensing of physiological parameters within the body and/or providing therapy to the patient. Example physiological parameters that can be sensed using the implanted device 12 include, but are not limited to, blood pressure, blood or fluid flow, temperature, and strain. Various electrical, chemical, and/or magnetic properties may also be sensed within the body using the implanted device 12. The specific configuration and function to be performed by the implanted device 12 will typically vary depending on the particular therapeutic needs of the patient.

[0024] In some embodiments, the implanted device 12 comprises a pressure sensor adapted to sense arterial blood pressure within a pulmonary artery. As shown in the illustrative system 10 of Figure 1, for example, the implanted device 12 may comprise a pressure sensor implanted in the left pulmonary artery 30 for sensing arterial blood pressure. Alternatively, and in other embodiments, the device 12 may be implanted in the right pulmonary artery 28, the main pulmonary artery 26, or in another vessel leading into or from the heart 16. The implanted device 12 can also be implanted at other locations within the heart 16 such as in the right atrium 18, the right ventricle 20, the left atrium 22, or the left ventricle 24. In some embodiments, the implanted device 12 can be placed at other locations in the body such as within an organ such as the liver or kidney, the vasculature, muscle tissue, or an airway within the body.

[0025] The implanted device 12 can be used as part of a cardiac rhythm management (CRM) system to predict decompensation of a heart failure patient, to optimize pacing and/or defibrillation therapy, as well as perform other designated functions within the body. In certain

embodiments, for example, the implanted device 12 can be configured to transmit sensed physiological parameters to other CRM system components located within the body such as a pacemaker or defibrillator. In some embodiments, the implanted device 12 can be configured to transmit sensed physiological parameters to an external device such as a monitor or programmer for further monitoring and/or processing. Based on this information, an indication of any abnormalities within the heart 16 can be determined and an appropriate therapy provided to the patient, as necessary.

[0026] Figure 2 is a partial cross-sectional view showing the distal section 36 of the charging catheter 14 of Figure 1 inserted at a target location within the body adjacent to the implanted device 12. As can be further seen in Figure 2, and in some embodiments, the distal section 36 of the charging catheter 14 includes a charging element 44 adapted to transmit energy to the implanted device 12 that can be used to charge a rechargeable battery 46 within the device 12. In certain embodiments, for example, the charging element 44 includes an ultrasonic transducer 48 electrically coupled to an external power source 50 via a number of wires 52 extending through an interior lumen 54 of the charging catheter 14. An example piezoelectric transducer that can be used for acoustically transmitting charging energy to the implanted device 12 is described, for example, in United States Patent Number 6,140,740, entitled "Piezoelectric Transducer," which is incorporated herein by reference in its entirety. Other types of acoustic transducers can also be utilized for providing charging energy to the implanted device 12. In some embodiments, the ultrasonic transducer 48 includes an array of ultrasonic elements.

[0027] During recharging, the power source 50 can be configured to deliver a time-varying excitation current to the ultrasonic transducer 48, causing the transducer 48 to generate an acoustic signal 56 within the

body that is received by a receiver 58 coupled to the implanted device 12. In some embodiments, for example, the receiver 58 comprises an ultrasonic transducer sensitive to the frequency of the acoustic signal 56 transmitted from the source ultrasonic transducer 48. The acoustic signal 56 received by the target ultrasonic transducer 58 is then converted into electrical energy that can be used to recharge the battery 46.

[0028] During delivery, the source ultrasonic transducer 48 on the charging catheter 14 can be positioned in close proximity to the target ultrasonic transducer 58 of the implanted device 12. In certain embodiments, for example, the distal section 36 of the charging catheter 14 can be positioned such that the source ultrasonic transducer 48 is located a distance of between about 1 mm to about 10 mm apart from the target ultrasonic transducer 58. The distance at which the two transducers 48,58 are spaced apart from each other may be greater or lesser, however, depending on the type of transducers 48,58 employed, the intensity and frequency characteristics of the acoustic signal 56 transmitted, the anatomy surrounding the transducers 48,58, as well as other factors. In some embodiments, the positioning of the charging catheter 14 can be accomplished under the aid of fluoroscopy. A radiopaque marker band 60 placed at or near the distal end of the charging catheter 14 can be used in conjunction with a fluoroscope to visualize the location of the charging catheter 14 during delivery so as to minimize the distance between the transducers 48,58.

[0029] Once the distal section 36 of the charging catheter 14 is positioned at a target location within the body adjacent to the implanted device 12, the ultrasonic transducer 48 can be activated to transmit an acoustic signal 56 to the implanted device 12 for recharging the battery 46 in vivo. The time required to deliver a sufficient amount of charging energy to recharge the battery 46 may be affected by several factors, including the location of the device 12 within the body, the location of the

charging catheter 14 within the body, the distance between the source and target ultrasonic transducers 48,58, and the intensity and frequency of the acoustic signal 56. Typically, the acoustic intensity of the acoustic signal 56 falls off inversely proportional to the square of the distance from the ultrasonic transducer 48. Thus, for a given flux of energy, there is an initial rapid decrease in intensity in the near field followed by a more gradual decline further away from the transducer 48.

[0030] By placing the source and target transducers 48,58 in close proximity to each other, the attenuation loss associated with the rapid fall off of acoustic energy in the near field is reduced, resulting in an increase in charge coupling efficiency. This increase in efficiency reduces the overall time required to recharge the battery 46, and subjects the body to less energy than would otherwise be required to recharge the battery 46 via an external recharging approach with the source ultrasonic transducer transmitting the charging energy directly into the body. This results in a higher intensity field in the vicinity of the implanted device 12 while maintaining a lower overall energy flux transmitted into the body. In addition, because the source transducer 48 is located in close proximity to the target transducer 58, a smaller portion of the transmitted acoustic energy is absorbed and/or scattered within the body, resulting in more efficient charging with reduced body tissue and fluid heating.

[0031] Although the illustrative charging catheter 14 of Figure 2 includes an ultrasonic transducer 48 for acoustically recharging the implanted device 12, in other embodiments the charging element 44 can use other energy transfer modes for transmitting charging energy to the device 12. Examples of other types of energy transfer modes can include, but are not limited to, inductive, electromagnetic, RF, optical (e.g., infrared light, visible light, ultraviolet light, and X-ray), vibration (e.g., transverse and longitudinal mechanical vibrations), radioactive energy, heat, and/or pressure. In one alternative embodiment, for example, the charging

element 44 comprises a transmitter adapted to transmit electromagnetic energy to the implanted device 12. The electromagnetic energy transmitted by the charging element 44 is received by an antenna or coil coupled to the implanted device 12, which is then converted into electrical energy for recharging the battery 46. As with an acoustic energy transfer mode, the transmitter can be positioned in close proximity to the antenna or coil in order to reduce attenuation and absorption of the transmitted electromagnetic energy. In certain embodiments, for example, the charging catheter 14 can be positioned such that the charging element 44 is located a distance of between about 1 mm to about 10 mm apart from the antenna or coil for the implanted device 12.

[0032] In some embodiments, the charging catheter 14 further includes a focusing or collimating element adapted to direct and focus the charging energy transmitted to the implanted device 12. In those embodiments in which the charging element 44 includes an ultrasonic transducer 48, for example, the charging element 44 may further include an acoustic baffle or lens for focusing the acoustic signal 56 in the direction of the target transducer 58. In some embodiments, focusing of the acoustic signal 56 may occur by selectively activating one or more ultrasonic transducer elements within a transducer array, by adjusting the timing or phase of one or more ultrasonic transducer elements, and/or by adjusting the intensity levels of one or more ultrasonic transducer elements. Other techniques for focusing the transmitted acoustic signal 56 are also possible.

[0033] In certain embodiments, the charging element 44 is configured to provide charging energy to the implanted device 12 by directly contacting a surface on the device 12. In one such embodiment, for example, the charging element 44 includes an electrode adapted to electrically contact a corresponding electrode on the implanted device 12. During delivery, the distal section 36 of the charging catheter 14 can be

positioned within the body such that the two electrodes make electrical contact with each other. Once positioned, the electrode on the charging catheter 14 can be energized, causing current to flow to the electrode on the implanted device 12. As with other energy transmission modes discussed herein, the charging energy received by the implanted device 12 can then be used to recharge the battery 46.

[0034] Figure 3 is a partial cross-sectional view showing the distal section 62 of a charging catheter 64 in accordance with another illustrative embodiment including a sensor. As shown in Figure 3, the distal section 62 of the charging catheter 64 includes a charging element 68 adapted to transmit energy to the implanted device 12, which can be used to charge a rechargeable battery 46 within the device 12. In certain embodiments, for example, the charging element 68 includes an ultrasonic transducer 70, or alternatively, multiple ultrasonic transducers 70 each electrically coupled to an external power source via a number of wires 72 extending through an interior lumen 74 of the charging catheter 64. In use, the ultrasonic transducer(s) 70 can be activated to transmit an acoustic signal 76 to the implanted device 12 for recharging the battery 46 in vivo in a manner similar to that described above with respect to the charging catheter 14 of Figure 2.

[0035] In some embodiments, and as further shown in Figure 3, the distal section 62 of the charging catheter 64 further includes at least one sensor 78 electrically coupled to the power source 50 via a wire 80 and adapted to monitor one or more parameters associated with the operation of the charging catheter 64 and/or the surrounding environment. Example parameters related to the operation of the charging catheter 64 that can be monitored can include, but are not limited to, parameters related to the energy transmitted by the ultrasonic transducer(s) 70 such as peak power, average power, or power gradient. Example parameters related to the surrounding environment that can be monitored can include, but are not

limited to, temperature, electrical impedance, electrical potential, dielectric coefficient, and/or changes in one or more of these parameters. The sensor 78 can also be configured to sensor other parameters associated with the operation of the charging catheter, the implanted device 12, and/or the surrounding environment.

[0036] In certain embodiments, the sensor 78 is a temperature sensor 78 adapted to measure the temperature of body tissue and/or the local blood temperature at or near the location of the implanted device 12. In some embodiments, for example, the temperature sensor 78 can be configured to sense the local blood temperature of blood in the path of the acoustic signal 76, which can be used to estimate the temperature of the body tissue adjacent to the implanted device 12. The charging catheter 64 can be positioned within the vessel such that the temperature sensor 78 contacts the body tissue within the vessel, allowing the sensor 78 to directly sense the body tissue temperature adjacent to the implanted device 12. Based on the monitored temperature, the system can then either reduce the power of the acoustic energy transmitted by the ultrasonic transducer(s) 70, or alternatively, disable one or more of the transducers 70 in the event the temperature exceeds a maximum temperature threshold value. The monitored temperature can also be provided as feedback to notify a clinician of a potentially hazardous condition related to the operation of the charging catheter 64. The temperature sensor 78 can also be utilized to perform other tasks such as calibrating the charging element 68.

[0037] In some embodiments, the sensor 78 can be configured to monitor for the presence of any electrical leakage from the charging element 68. For example, the sensor 78 can comprise a sensor adapted to detect the presence of any current leakage from the ultrasonic transducer(s) 70 into the surround anatomy. The monitoring of electrical leakage from the ultrasonic transducers 70 can be accomplished, for

example, by measuring the current into and out of the transducers 70 using a differential current transformer, a bridge circuit, or the like. If an electrical leakage is detected, and depending on its magnitude, the system can then either adjust the operating power provided to one or more of the ultrasonic transducers 70 or disable the transducers 70 in order to reduce or eliminate the electrical leakage. This may be useful, for example, in acoustic charging systems that deliver relatively high voltages to the transducer elements. The charging system can also be configured to notify the clinician if a fault condition has occurred in the charging catheter 64.

[0038] The implanted device 12 can be further configured to monitor a number of parameters associated with the acoustic signal 76 received from the charging catheter 64. For example, in those embodiments in which the implanted device 12 includes an energy exchanger (e.g., an ultrasonic transducer), the implanted device 12 can be configured to monitor the power or intensity of the acoustic signal 76 transmitted by the charging catheter 64 to determine whether the signal 76 is within an acceptable range. If the received acoustic signal 76 exceeds a maximum power or intensity value, for example, the implanted device 12 can be configured to communicate a signal back to the charging catheter 64, which can be used by the catheter 64 as feedback to adjust the intensity or power of the signal 76. In some embodiments, the feedback signal can also be used by the clinician to aid in repositioning the charging catheter 64 within the vessel to maximize the charge coupling efficiency between the catheter 64 and the implanted device 12. In one embodiment, for example, the feedback signal can be used to adjust the placement location of charging catheter 64, and in particular the location of the charging element 68 within the vessel, in order to optimize the charging energy received by the implanted device 12.

[0039] Figure 4 is a partial cross-sectional view showing the distal section 82 of charging catheter 84 in accordance with another illustrative embodiment including a thermocouple wire for sensing temperature. As shown in Figure 4, the distal section 82 of the charging catheter 84 includes a charging element 86 adapted to transmit a signal 88 to the implanted device 12. In certain embodiments, the charging element 86 includes an ultrasonic transducer 90, or alternatively, multiple ultrasonic transducers 90 each electrically coupled to an external power source via a number of wires 92 extending through an interior lumen 94 of the charging catheter 84.

[0040] In some embodiments, and as further shown in Figure 4, the charging catheter 84 includes a thermocouple wire 96 adapted to sense the temperature of the body tissue and/or local blood temperature within the vessel at or near the location of the implanted device 12. The thermocouple wire 96 can be embedded within the charging catheter 84 at a location at or near the charging element 86, and can be electrically coupled to sensing electronics within the external power source 50 via a wire 98. The thermocouple wire 96 can be fabricated from a relatively thin gauge metal capable of sensing relatively small changes in temperature. In some embodiments, the sensing electronics can comprise a differential amplifier adapted to convert sensed thermal potential differences into an electrical potential difference indicative of a change in temperature due to the transmitted charging energy.

[0041] In use, the thermocouple wire 94 can be configured to sense temperature at the distal section 82 of the charging catheter 84, which can then be used to estimate the temperature of the body tissue and/or blood in the path of the acoustic signal 88. In some embodiments, an exposed portion 100 of the thermocouple wire 96 may permit the wire 96 to sense the local temperature within the blood vessel or, if placed into contact with the vessel wall, the body tissue temperature. The exposed portion 100 of

the thermocouple wire 96 can also be used to sense other parameters within the vessel. In certain embodiments, for example, the exposed portion 100 of the thermocouple wire 96 may also function as a voltimeter probe to detect the presence of any electrical leakage from the charging element 86 by measuring electrical potentials within the vessel.

[0042] In another embodiment, the thermocouple wire 96 can be coupled directly to the charging element 86 for monitoring the temperature of the element 86 itself. For an acoustic recharging system including an ultrasonic transducer 90, for example, the thermocouple wire 96 can be attached to a portion of the transducer 90 to monitor the temperature of the transducer 90 during recharging. Since heating in the vessel is due in part to heat conduction from the ultrasonic transducer 90, the temperature within the vessel can be monitored indirectly using the thermocouple wire 96. The sensed temperature on the ultrasonic transducer 70 can then be used as feedback for regulating the operating power provided to the transducer 70.

[0043] Figure 5 is a partial cross-sectional view showing the distal section 102 of a charging catheter 104 in accordance with another illustrative embodiment including a cooling lumen. As shown in Figure 5, the charging catheter 104 includes an elongate shaft 106 having an internal lumen 108 in fluid communication with a cooling medium 110 that can be used for cooling a charging element 112 and/or the body tissue and fluids surrounding the distal section 102 of the catheter 104. The cooling medium 110 may comprise a liquid or gas delivered to the distal section 102 of the charging catheter 104 from a source operatively coupled to the proximal section of the catheter 104. In some embodiments, the cooling medium 110 can be configured to change its aggregation state from a liquid to gas when heated. In certain embodiments, for example, the cooling medium 110 comprises a pressurized source of liquid nitrogen operatively coupled to the charging

catheter 104 at a location external to the body. Upon heating from the charging element 112, the liquid nitrogen can be configured to change from an initial liquid state to a gaseous state, absorbing heat produced by activation of the element 112 during recharging. Examples of other suitable cooling mediums 110 can include, but are not limited to, air, carbon dioxide, helium, neon, argon, saline, water, or a Freon-based solution.

[0044] In some embodiments, an additional lumen 114 can be used as a return line to return the cooling medium 110 back to the proximal section of the charging catheter 104 once heated. During recharging, the cooling medium 110 can be circulated through the interior of the distal section 102 to dissipate the heat generated by the charging element 112 and to reduce heating of the body tissue and fluids surrounding the catheter 104. In some embodiments, the temperature of the cooling medium 110 can be reduced to a temperature below room temperature to further aid in dissipating heat generated by the charging element 112.

[0045] During recharging, the presence of the cooling medium 110 within the lumens 108,114 facilitates operation of the charging element 112 at higher intensity levels without causing significant heating in the surrounding body tissue and fluids. When the charging catheter 104 is implanted in a pulmonary artery, for example, the presence of the cooling medium 110 facilitates operation of the charging element 112 at greater intensity levels without heating the blood within the artery. The ability to operate at higher intensity levels without heating may reduce the overall time required to recharge the battery within the implanted device.

[0046] Figure 6 is a partial cross-sectional view showing the distal section 116 of a charging catheter 118 in accordance with another illustrative embodiment including a cooling lumen. Similar to the embodiment of Figure 5, the charging catheter 118 includes an elongate shaft 120 having one or more internal lumens 122,124 in fluid

communication with a cooling medium 110 that can be used for cooling a charging element 126 and/or body tissue and fluids surrounding the distal section 116 of the catheter 118. In the embodiment of Figure 6, the lumens 122,124 terminate distally at an exit port 126 disposed at or near the distal end 128 of the charging catheter 118. In some embodiments, multiple exit ports may be provided at or near the distal end 128 of the elongate shaft 120 and/or may be provided at various other locations along the length of the shaft 120.

[0047] During recharging, a pressurized cooling medium 110 (e.g., saline) contained within the lumens 122,124 is ejected through the port 126 and into the surrounding anatomy. In recharging applications where the catheter 118 is positioned in a pulmonary artery adjacent to an implanted pressure sensor, for example, the cooling medium 110 may be ejected through the exit port 126 and into the artery for cooling the blood within the artery as well as the pressure sensor. As with the embodiment of Figure 5, the passage of the cooling medium 110 through the lumens 122,124 further dissipates heat generated by the charging element 126.

[0048] Figure 7 is a schematic view of another illustrative system 130 for recharging a medical device 12 implanted within a body lumen. In the illustrative embodiment of Figure 7, a charging catheter 132 including an elongate shaft 134 having a proximal section (not shown) and a distal section 136 is inserted into a different body vessel in close proximity to the vessel containing the implanted device 12. In an implantable pressure sensor disposed within a pulmonary artery, for example, the distal section 136 of the charging catheter 132 may be positioned within an adjacent body vessel such as the aorta 138. Delivery of the charging catheter 132 to the aorta 138 can be accomplished, for example, via a catheterization approach through a coronary artery. Other delivery techniques, however, are possible.

[0049] By positioning the charging catheter 132 into a different vessel than the implanted device 12, access to a target site for recharging may be easier and/or may be less invasive than inserting the catheter 132 directly into the same vessel as the device 12. In some cases, for example, the implanted device 12 may be implanted within a body lumen that is difficult to access. In such case, delivery of the charging catheter 132 to a different vessel within the body (e.g., the aorta, the right pulmonary artery, the esophagus, etc.) may reduce the overall time and difficulty associated with the recharging process.

[0050] Once the charging catheter 132 is positioned at a target location within an adjacent body lumen (e.g., the aorta 138), a charging element 140 coupled to the catheter 132 can be activated to transmit charging energy into the adjacent vessel (e.g., the left pulmonary artery 30) for recharging the implanted device 12. In those embodiments in which the charging element 140 includes an ultrasonic transducer 142, for example, the transducer 142 can be configured to transmit an acoustic signal 144 that can be received by the implanted device 12 and converted into electrical energy for recharging the device 12.

[0051] In some embodiments, the charging catheter 132 can be used to perform other functions within the body and/or to provide therapy to the patient. In certain embodiments, for example, the charging catheter 132 may be used during a diagnostic or therapeutic coronary artery catheterization (e.g., a right heart catheterization) for treating coronary artery disease within the body. In one such embodiment, the charging element 140 may be provided as part of a coronary balloon catheter for performing an angioplasty procedure on the patient. In such case, recharging of the implanted device 12 may be performed in conjunction with the therapy using the same catheterization.

[0052] Figure 8 is a schematic view showing another illustrative system 146 for recharging a medical device 12 implanted within a body

lumen. The system 146, illustratively a system for recharging a pressure sensor implanted within a pulmonary artery, includes a charging catheter 148 having a distal section 150 inserted at a target location within the patient's body, an external charging element 152 coupled to a proximal section 154 of the charging catheter 148, and a power source 156.

[0053] The charging catheter 148 includes an elongate shaft 158 having an interior lumen 160 adapted to transmit charging energy generated by the charging element 152 from a location outside of the patient to the distal section 150 of the charging catheter 148. In some embodiments, for example, the charging element 152 comprises an external ultrasonic transducer that, when energized by the power source 156, generates an acoustic signal 162 that is transmitted through the interior lumen 160 to the distal section 150 of the catheter 148. In some embodiments, the ultrasonic transducer 152 comprises an array of ultrasonic transducer elements each of which can be selectively actuated to generate the acoustic signal 162. During recharging, the interior lumen 160 acts as an acoustic waveguide for the acoustic signal 162, reducing attenuation and scattering that would normally occur during transmission of the signal 162 directly through the body. Because the charging element 152 is located outside of the patient's body, the transducer 152 can be of any size and power without significantly impacting the acoustic energy transmitted into the body.

[0054] Figure 9 is a partial cross-sectional view showing the distal section 150 of the charging catheter 148 of Figure 8 inserted at a target location within the body adjacent to an implanted device 12. As can be further seen in Figure 9, the distal section 150 of the charging catheter 148 includes a port 164 adapted to direct the acoustic signal 162 transmitted through the interior lumen 118 in a direction towards the implanted device 12. In some embodiments, the interior lumen 160 may contain a liquid or solid material (e.g., saline), which acts as an interface to

facilitate transmission of the acoustic energy through the interior lumen 160. In certain embodiments, the distal section 150 of the charging catheter 148 may further include a focusing or collimating element 166 such as an acoustic baffle or lens to further focus the acoustic signal 162 in a direction towards the implanted device 12.

[0055] In some embodiments, the charging catheter 148 may include other components for use in focusing the charging energy generated by the charging element 152, either passively or actively. In the embodiment of Figure 9, for example, the charging catheter 148 includes a sensor 168 adapted to sense various parameters of the acoustic signal 162 as it is transmitted from the port 164 towards the implanted device 12. In one embodiment, the sensor 168 is an ultrasonic pressure sensor adapted to sense the intensity and/or phase of the acoustic signal 162 as it exits the port 164. The sensor 168 can be configured to relay pressure sensor readings to an external controller 170 via a wired or wireless communications link. Based on the sensor readings, the external controller 170 can be configured to run an adaptive algorithm or routine that is used to optimize the direction, focusing, phase, intensity, timing, and/or bandwidth of the acoustic signal 162 generated by the charging element 152. In some embodiments, for example, the sensor readings can be used to analyze the intensity and phase of the acoustic signal 162 exiting the port 164, and responsive to these parameters, adjust the intensity and timing of the electrical signal 172 provided to one or more transducer elements of the charging element 152, either simultaneously or sequentially.

[0056] Alternatively, and in other embodiments, the distal section 150 of the charging catheter 148 may include a passive element such as a reflector or an active element such as a repeater adapted to generate a signal 172 that is received by an array of transducer elements. In certain embodiments, for example, the reflected or repeated signal may serve as

a reference signal for a time-reversal acoustic algorithm that can be used to generate time reversals on one or more of the transducer elements in order to focus the acoustic signal 162 towards the implanted device 12. The sensor 168 on the charging catheter 148 can be configured to sense an acoustic signal transmitted by the implanted device 12. The sensed acoustic signal can then be transmitted to the external controller 170 for computing phase delays for each of the transducer elements. The external controller 170 can then adjust one or more parameters associated with the ultrasonic elements to focus or steer the acoustic signal 162 towards the implanted device 12. Example parameters that can be adjusted include, but are not limited to, direction, focusing, phase, intensity, timing, and/or bandwidth.

[0057] The sensor 168 can be used to perform other functions within the body such as calibrating the implanted device 12. In those embodiments in which the implanted device 12 comprises a pressure sensor, for example, the sensor 168 may be used as a reference pressure sensor to calibrate the device 12. In one embodiment, the reference pressure sensor and charging element can be combined into a single catheter. The ability to calibrate the implanted device 12 without subjecting the patient to an additional catheterization process may reduce the time and complexity associated with servicing the implanted device 12.

[0058] Figure 10 is a schematic view of another illustrative system 174 for recharging a medical device 12 implanted within a body lumen using a transesophageal approach. In the embodiment of Figure 10, a charging device 176 is inserted transesophageally into the esophagus 178 of the patient. The esophagus 178 is located posterior to the heart 16 and the airway 180, and extends downwardly to the stomach 182 at a location adjacent to the aorta 40 and the posterior wall 184 of the heart 16, as shown.

[0059] As can be further understood in conjunction with Figure 11, the charging device 176 includes an elongate shaft 186 having a proximal section 188 and a distal section 190. The distal section 190 of the charging device 176 includes a cylindrically-shaped charging element 192 adapted to transmit energy from a position within the esophagus 178 to acoustically recharge an implanted device 12 located in an adjacent body lumen such as a pulmonary artery. In some embodiments, the charging element 192 comprises an array of ultrasonic transducers 194 which, when energized via an external controller 196, generate a radial, omnidirectional acoustic signal that is transmitted through the esophageal wall and into the adjacent pulmonary artery for recharging the implanted device 12. In some embodiments, the charging element 192 can include a polymeric coating or layer that matches the acoustic impedance of the charging element 192 with the surrounding fluid and tissue in the esophagus 178. In one embodiment, the charging element 192 and external controller 196 may be provided as part of a transesophageal echocardiogram (TEE) device.

[0060] The external controller 196 can include a signal generator 198 and a tuning circuit 200 that can be used to tune the frequency of the acoustic signal generated by the ultrasonic transducers 194 to a particular frequency or range of frequencies based on the resonance characteristics of the ultrasonic transducer elements used to transmit and receive the acoustic charging energy. In certain embodiments, for example, the signal generator 198 and tuning circuit 200 can be used to tune the ultrasonic transducer elements to a frequency of about 40 kHz, which can correspond to a resonance frequency of the ultrasonic transducer on the implanted device 12. In some embodiments, the signal generator 198 and tuning circuit 200 can be used to tune the ultrasonic transducer elements to operate over a desired range of frequencies (e.g., between about 10

kHz to 200 kHz). Other operating frequencies and frequency ranges are possible, however.

[0061] To recharge an implanted device 12 positioned in or near the heart 16, the distal section 190 of the charging device 176 can be inserted into the patient's esophagus 178 and advanced to a position within the esophagus 178 adjacent to the implantation location of the device 12. In those embodiments in which the implanted device 12 is located within a pulmonary artery 30, for example, the distal section 190 of the charging device 176 can be inserted into the esophagus 178 and positioned such that the charging element 192 is located in the mediastinum immediately posterior to the artery 30, as shown, for example, in Figure 10. In some embodiments, the distal section 190 of the charging catheter 176 can be configured to substantially fill the lumen of the esophagus 178 such that a portion of the charging element 192 contacts the esophageal wall. In this position, the charging element 192 is located a short distance (e.g. 1cm to 2cm) from the adjacent artery 30, and provides a direct acoustic path between the charging element 192 and the implanted device 12. The esophagus 178 comprises primarily water and soft tissue, and is therefore acoustically matched with the impedance of the transducer elements, which helps to reduce losses in acoustic energy due to impedance mismatches.

[0062] Once the charging device 176 is positioned within the esophagus 178 adjacent to the body vessel or lumen containing the implanted device 12, the charging element 192 can be activated to generate an acoustic signal that travels through the esophageal wall. As can be further seen in a transverse view of the patient's thorax in Figure 12, the charging element 192 can be positioned within the esophagus 178 at a location immediately adjacent to a device 12 implanted within the right pulmonary artery 28. In this position, the charging element 192 can be activated to generate an acoustic signal 204 that can be received by the

implanted device 12 and converted into electrical energy for recharging the device 12. During recharging, the direct acoustic pathway and relatively short distance between the esophagus 178 and the artery 28 results in an increase in charge coupling efficiency between the charging element 192 and the implanted device 12. As with other embodiments discussed herein, this increase in efficiency reduces the overall time required to recharge the battery within the implanted device 12, and subjects the body to less energy than would otherwise be required to recharge the device 12 via an external recharging approach.

[0063] Various modifications and additions can be made to the exemplary embodiments discussed without departing from the scope of the present invention. For example, while the embodiments described above refer to particular features, the scope of this invention also includes embodiments having different combinations of features and embodiments that do not include all of the described features. Accordingly, the scope of the present invention is intended to embrace all such alternatives, modifications, and variations as fall within the scope of the claims, together with all equivalents thereof.

CLAIMS

What is claimed is:

1. A method of recharging a medical device implanted within a body lumen of a body, the medical device including a rechargeable power source and a receiver, the method comprising:

delivering a charging device to a location within the body adjacent to the implanted medical device, the charging device including a charging element operatively coupled to a power source;

activating the charging element and transmitting energy to the implanted medical device; and

charging the power source within the implanted medical device using the transmitted energy from the charging element.

2. The method of claim 1, wherein the charging element is coupled to a distal section of the charging device.

3. The method of claim 1, wherein the charging element is coupled to a proximal section of the charging device, and wherein transmitting energy to the implanted medical device includes transmitting energy through an interior lumen of the charging device.

4. The method of claim 1, wherein the charging element is an acoustic transducer, and wherein transmitting energy to the implanted medical device includes transmitting acoustic energy to an acoustic transducer coupled to the implanted medical device.

5. The method of claim 1, wherein the charging element is an electromagnetic transmitter, and wherein transmitting energy to the implanted medical device includes transmitting electromagnetic energy to an antenna or coil coupled to the implanted medical device.

6. The method of claim 1, wherein the charging device includes a means for cooling the charging element.

7. The method of claim 6, wherein the cooling means includes at least one cooling lumen within the charging device in fluid communication with a cooling medium.

8. The method of claim 1, wherein the charging device is a therapy delivery device, and further including providing therapy to the body.

9. The method of claim 1, wherein the charging device includes a focusing or collimating element adapted to focus the energy transmitted to the implanted medical device.

10. The method of claim 1, wherein delivering the charging device to a location adjacent to the implanted medical device includes inserting the charging device into the same body lumen as the implanted medical device.

11. The method of claim 1, wherein delivering the charging device to a location adjacent to the implanted medical device includes inserting the charging device into another body lumen adjacent to the body lumen containing the implanted medical device.

12. The method of claim 1, wherein delivering the charging device to a location adjacent to the implanted medical device includes inserting the charging device into the esophagus adjacent to the body lumen containing the implanted device.

13. The method of claim 1, wherein the charging device further includes a pressure sensor, and further including calibrating the implanted device using the pressure sensor.

14. The method of claim 1, wherein the charging device further includes a temperature sensor, and further including calibrating the charging device using the temperature sensor.

15. The method of claim 14, wherein the temperature sensor comprises a thermocouple wire embedded in a distal section of the charging device.

16. The method of claim 1, wherein the charging device includes a means for sensing electrical leakage from the charging element.

17. A method of recharging a medical device implanted within a body lumen of a body, the medical device including a rechargeable power source and a receiver, the method comprising:

delivering a charging device to a location within the body adjacent to the implanted medical device, the charging device including an acoustic transducer operatively coupled to a power source and at least one sensor;

activating the acoustic transducer and transmitting an acoustic signal to the implanted medical device;

sensing at least one parameter associated with the transmitted acoustic signal;

adjusting at least one operating parameter of the acoustic transducer based at least in part on the at least one sensed parameter; and

charging the power source within the implanted medical device.

18. A recharging system, comprising:

a pressure sensor implanted within a body lumen of a patient's body, the pressure sensor including a rechargeable power source and a receiver;

a charging device insertable within the body, the charging device including an elongate shaft having a proximal section and a distal section, and an acoustic charging element adapted to transmit charging energy to the receiver from an intrabody location adjacent to the pressure sensor.

19. The recharging system of claim 18, wherein the charging element is coupled to the distal section of the charging device.

20. The recharging system of claim 18, wherein the charging element is coupled to the proximal section of the charging device and is adapted to transmit energy through an interior lumen of the charging device.

21. The recharging system of claim 18, wherein the charging device includes at least one cooling lumen in fluid communication with a cooling medium.

22. The recharging system of claim 18, wherein the charging device is a therapy delivery device.

23. The recharging system of claim 18, further comprising a means for calibrating the charging device.

24. The recharging system of claim 23, wherein said means for calibrating the charging device includes a pressure sensor.

25. The recharging system of claim 23, wherein said means for calibrating the charging device includes a temperature sensor.

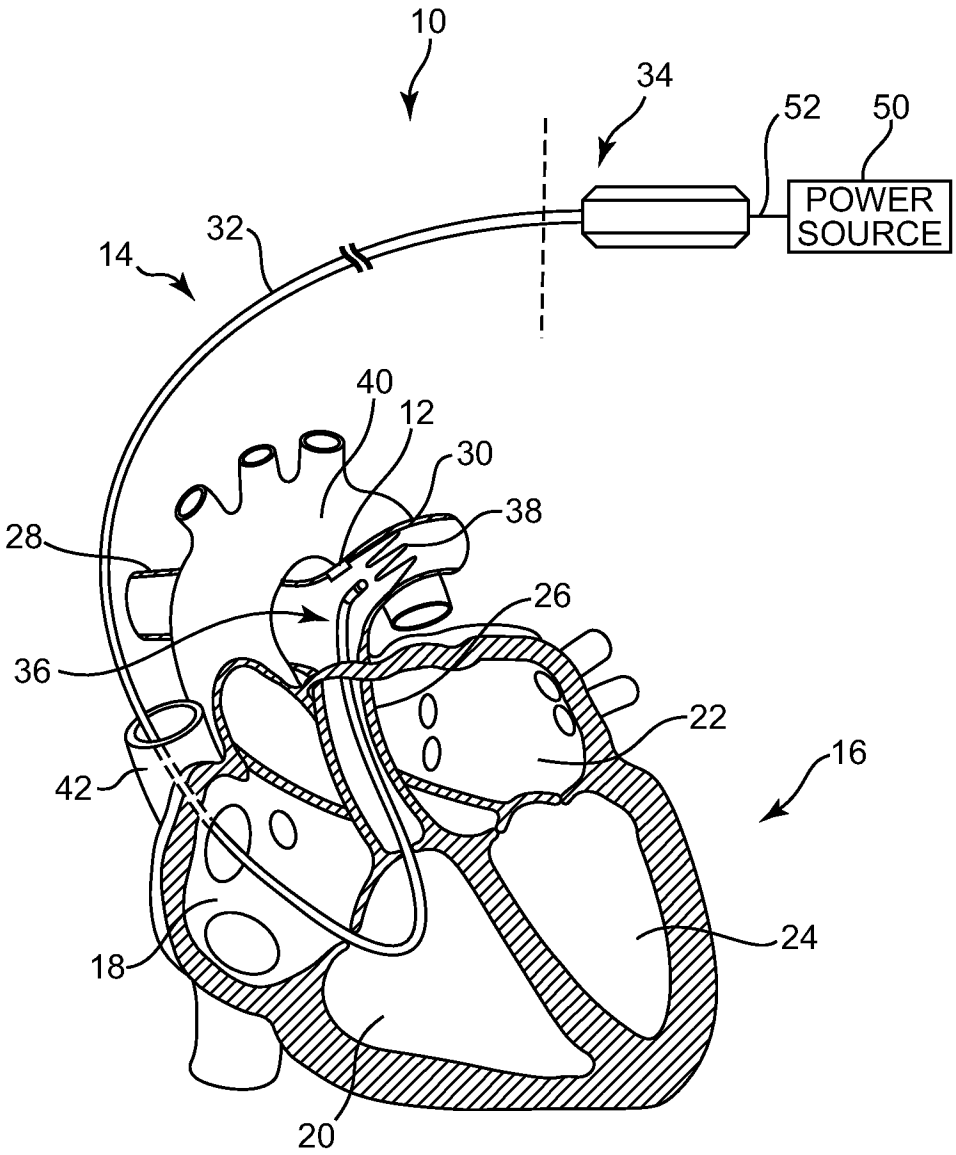

Fig. 1

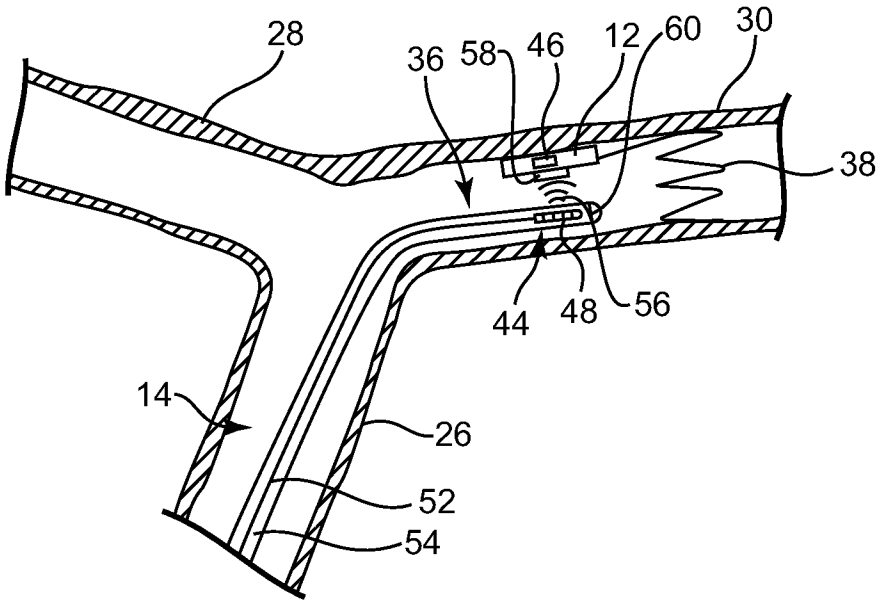

Fig. 2

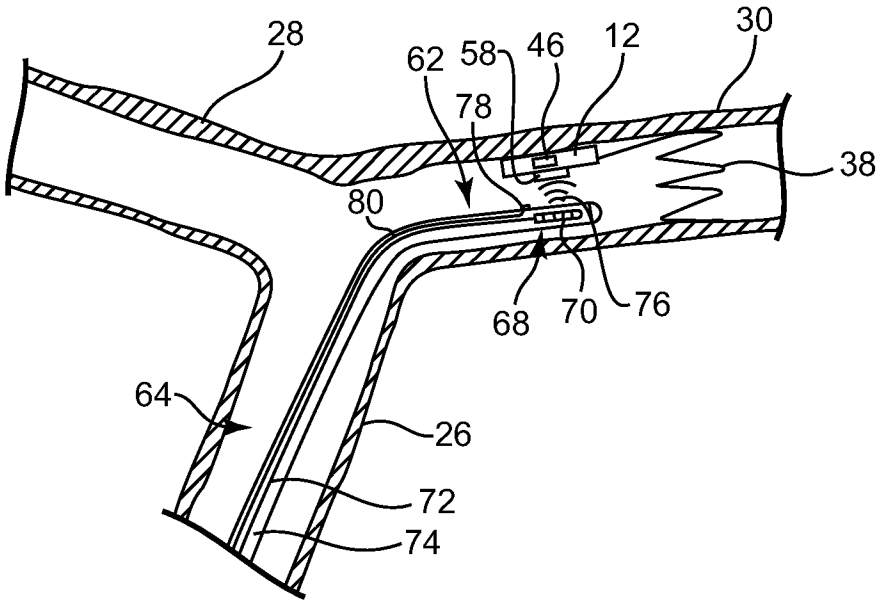

Fig. 3

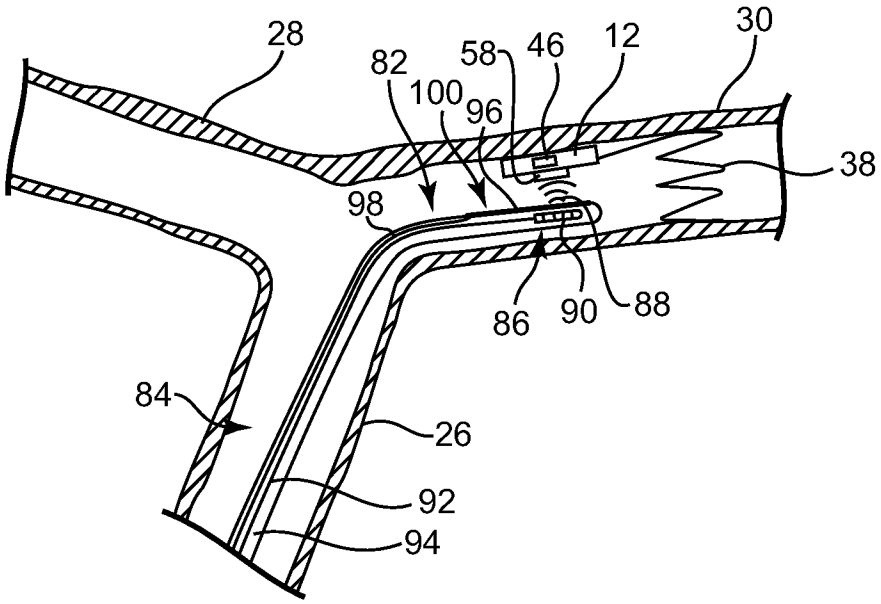

Fig. 4

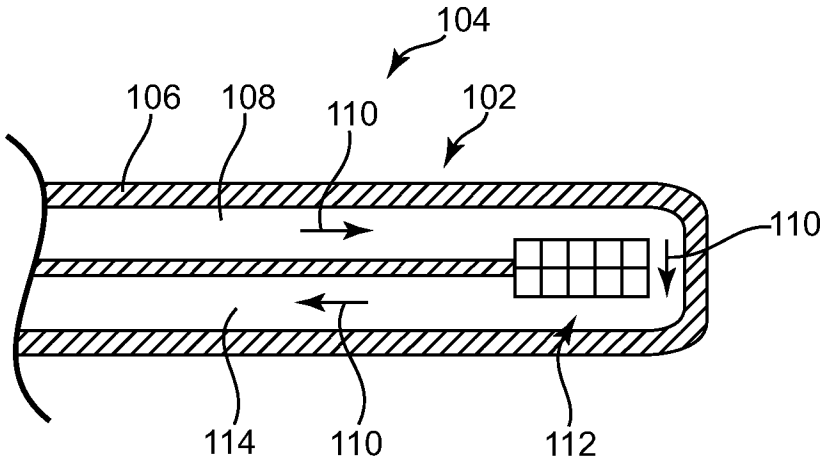

Fig. 5

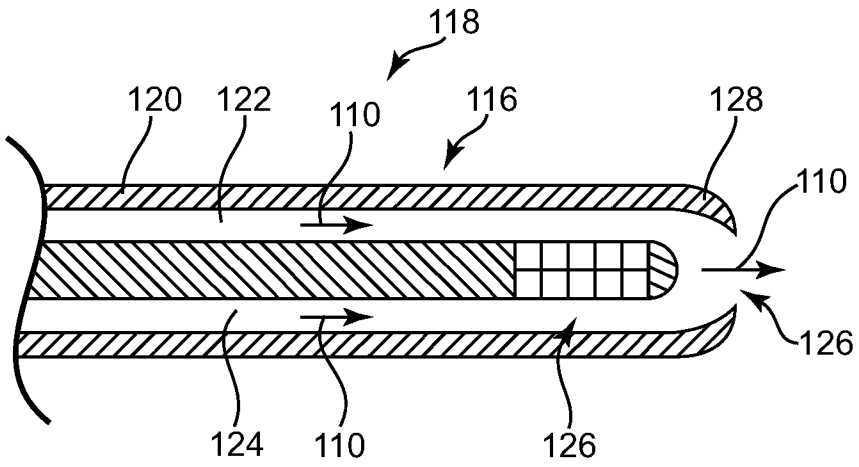

Fig. 6

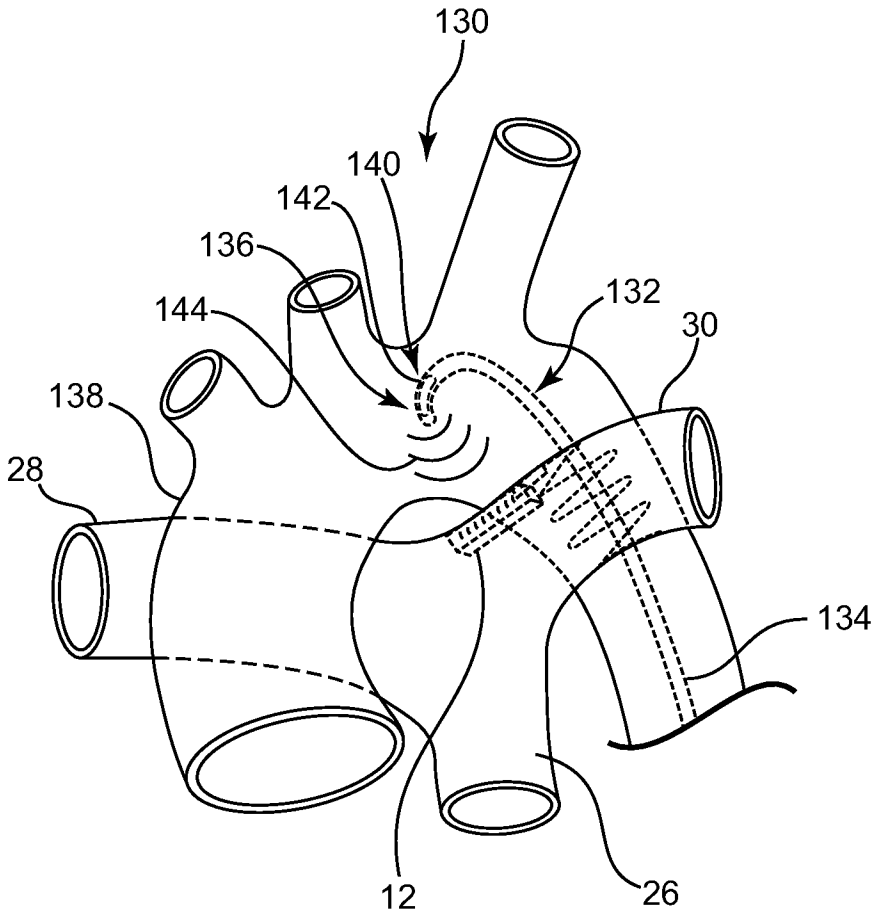

Fig. 7

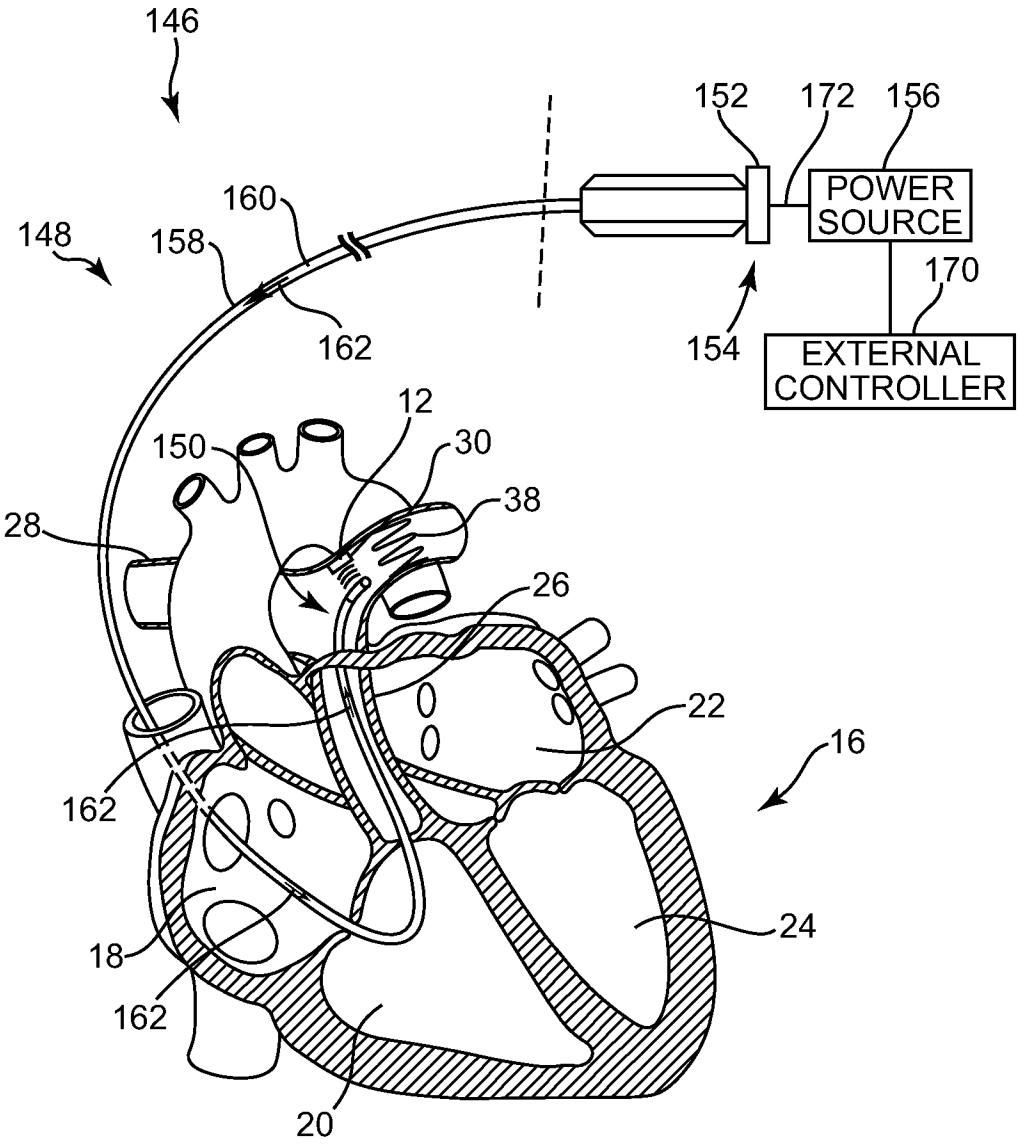
146
152
172
156
POWER SOURCE
160
148
158
162
154
170
EXTERNAL CONTROLLER
12
150
30
38
28
26
22
16
162
18
24
162
20

Fig. 8

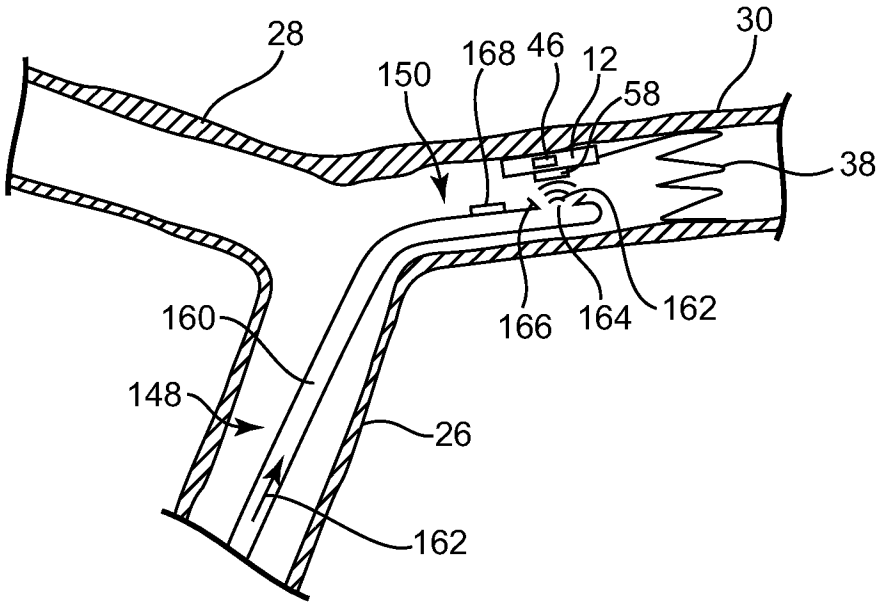

Fig. 9

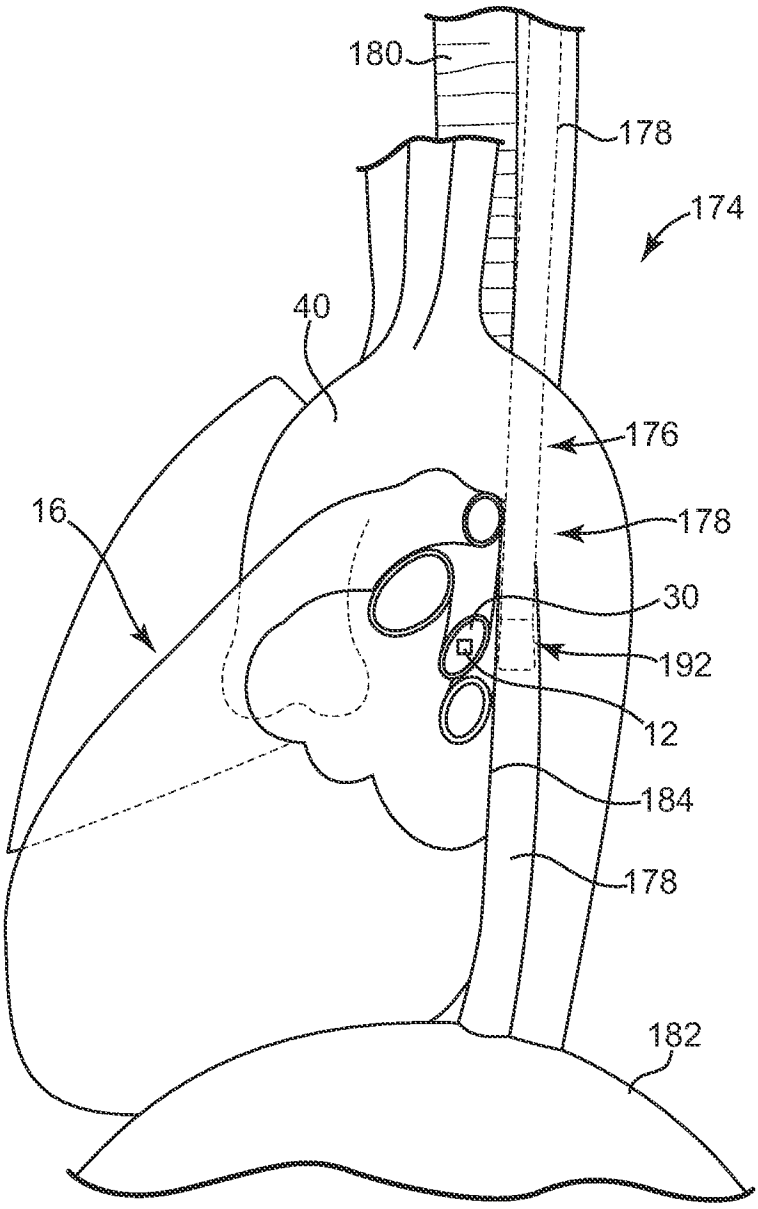

Fig. 10

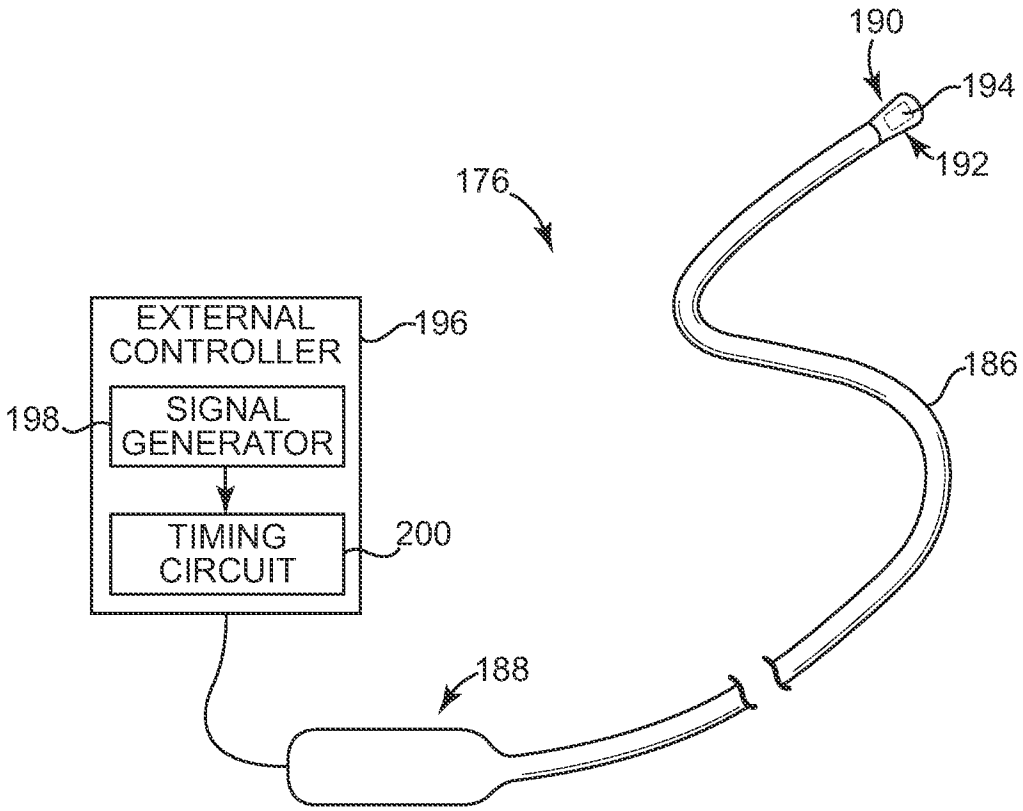
190
194
192
176
EXTERNAL CONTROLLER
196
198
SIGNAL GENERATOR
TIMING CIRCUIT
200
186
188

Fig. 11

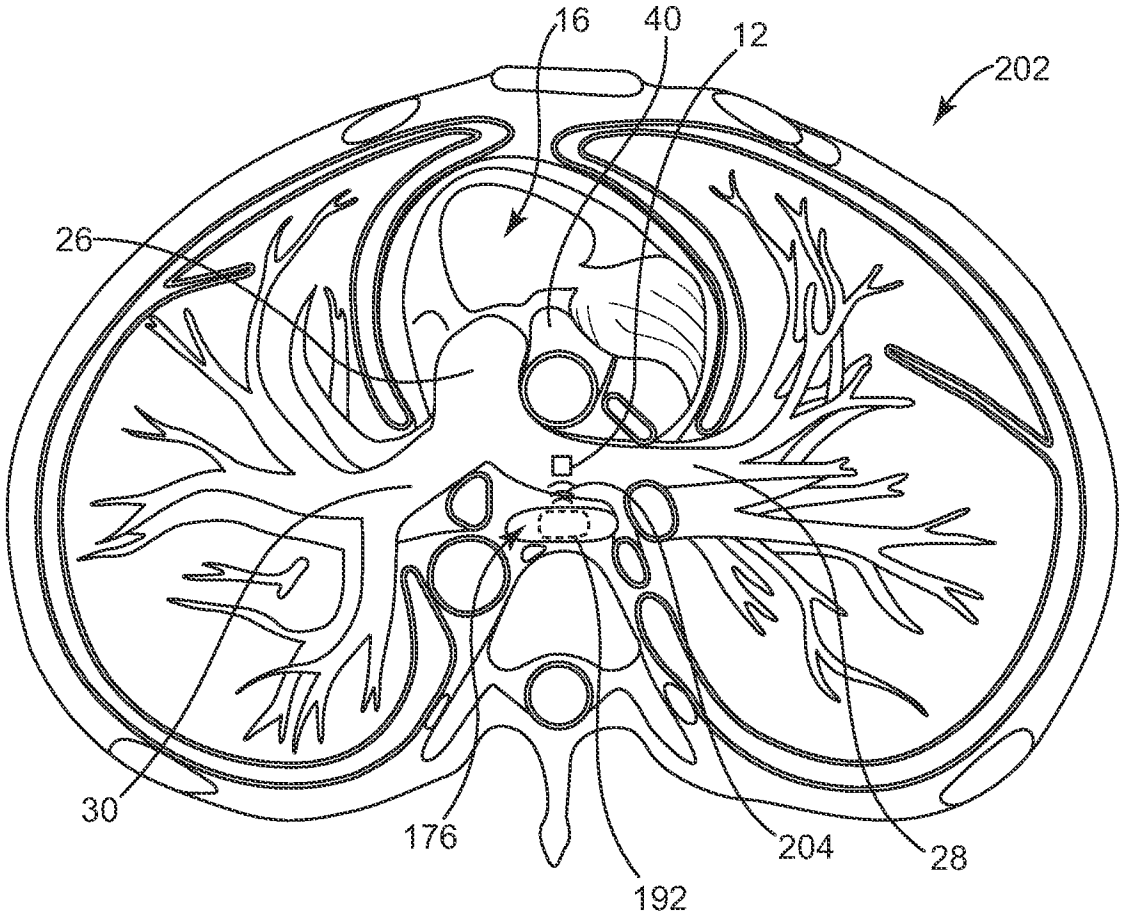

Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/062019

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/378 H01L41/08
ADD. A61N1/362 A61B5/0215 A61B5/026 A61B5/00

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)
A61N H01L

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 03/043688 A1 (REMON MEDICAL TECHNOLOGIES LTD [IL]) 30 May 2003 (2003-05-30) page 6; figure 3	18-25
A	EP 1 962 557 A2 (SIEMENS AUDIOLOGISCHE TECHNIK [DE]) 27 August 2008 (2008-08-27) the whole document	18-25
X	US 2008/015421 A1 (PENNER AVI [IL]) 17 January 2008 (2008-01-17) paragraphs [0068] - [0070]; figure 3	18-25

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* 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 document 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
6 April 2010	12/04/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Edward, Vinod

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/062019

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 1-17
because they relate to subject matter not required to be searched by this Authority, namely:

Due to the step of delivering a charging device to a location within the body, independent claims 1 and 17 relate to a method for treatment of the human or animal body by surgery (Rule 39.1(iv) PCT).

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2009/062019

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 03043688 A1	30-05-2003	AU 2002347447 A1	10-06-2003
		CA 2463293 A1	30-05-2003
		EP 1446188 A1	18-08-2004
EP 1962557 A2	27-08-2008	DE 102007009176 A1	04-09-2008
		US 2008205678 A1	28-08-2008
US 2008015421 A1	17-01-2008	NONE	

专利名称(译)	用于对可植入设备进行再充电的方法和系统		
公开(公告)号	EP2361115A1	公开(公告)日	2011-08-31
申请号	EP2009744561	申请日	2009-10-26
[标]申请(专利权)人(译)	心脏起搏器股份公司		
申请(专利权)人(译)	心脏起搏器，INC.		
当前申请(专利权)人(译)	心脏起搏器，INC.		
[标]发明人	PENNER AVI DORON EYAL STAHMANN JEFFREY E MAILE KEITH R TRAN BINH C LIAO WANGCAI MI BIN HUELSKAMP PAUL J		
发明人	PENNER, AVI DORON, EYAL STAHMANN, JEFFREY, E. MAILE, KEITH R. TRAN, BINH, C. LIAO, WANGCAI MI, BIN HUELSKAMP, PAUL, J.		
IPC分类号	A61N1/378 H01L41/08 A61N1/362 A61B5/0215 A61B5/00		
CPC分类号	A61B5/0215 A61B5/0031 A61B5/01 A61B5/026 A61N1/37217 A61N1/3787		
优先权	61/108635 2008-10-27 US		
外部链接	Espacenet		

摘要(译)

公开了用于对植入体内的医疗装置进行再充电的方法，系统和装置。对植入的医疗设备再充电的说明性方法包括将充电设备递送到与植入的医疗设备相邻的位置，激活耦合到充电设备的充电元件并将充电能量发送到植入的医疗设备的接收器，并且对植入的医疗设备充电使用来自充电装置的传输充电能量的医疗装置。