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(54) Title: MRI COMPATIBLE TACHYCARDIA LEAD

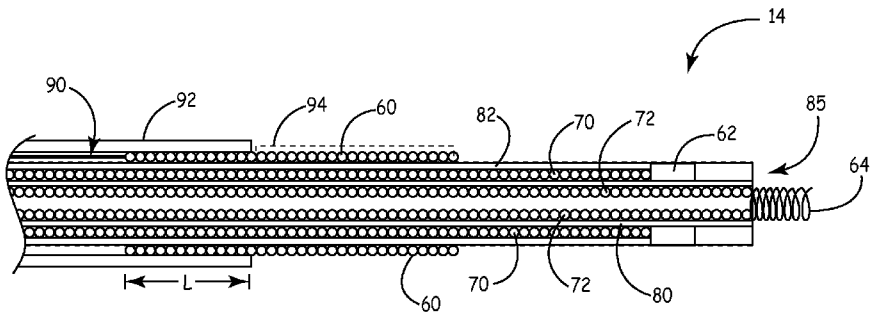

FIG. 2

(57) Abstract: A medical device lead includes a proximal connector configured to couple the lead to a pulse generator, an insulative lead body extending distally from the proximal connector, and a conductor assembly extending distally from the proximal connector within the lead body. The conductor assembly includes a conductor having a proximal end electrically coupled to the connector and a distal end electrically coupled to a defibrillation coil. A first portion of the defibrillation coil is exposed at an outer surface of the medical device lead and a second portion of the defibrillation coil is insulated at the outer surface of the medical device lead.

MRI COMPATIBLE TACHYCARDIA LEAD

TECHNICAL FIELD

[0001] The present invention relates to implantable medical devices. More particularly, the present invention relates to MRI-compatible tachycardia lead constructions.

BACKGROUND

[0002] Magnetic resonance imaging (MRI) is a non-invasive imaging procedure that utilizes nuclear magnetic resonance techniques to render images within a patient's body. Typically, MRI systems employ the use of a magnetic coil having a magnetic field strength of between about 0.2 to 3 Teslas. During the procedure, the body tissue is briefly exposed to RF pulses of electromagnetic energy in a plane perpendicular to the magnetic field. The resultant electromagnetic energy from these pulses can be used to image the body tissue by measuring the relaxation properties of the excited atomic nuclei in the tissue.

[0003] During imaging, the electromagnetic radiation produced by the MRI system may be picked up by implantable device leads used in implantable medical devices such as pacemakers or cardiac defibrillators. This energy may be transferred through the lead to the electrode in contact with the tissue, which may lead to elevated temperatures at the point of contact. The degree of tissue heating is typically related to factors such as the length of the lead, the conductivity or impedance of the lead, and the surface area of the lead electrodes. Exposure to a magnetic field may also induce an undesired voltage on the lead.

SUMMARY

[0004] The present invention relates to a medical device lead including a proximal connector configured to couple the lead to a pulse generator, an insulative lead body extending distally from the proximal connector, a conductor assembly extending distally from the proximal connector within the lead body. The conductor assembly includes a conductor having a proximal end electrically coupled to the connector and a distal end electrically coupled to a defibrillation coil. A first portion of the defibrillation coil is exposed at an outer surface of the medical device lead and

a second portion of the defibrillation coil is insulated at the outer surface of the medical device lead.

[0005] In another aspect, a medical device lead includes a first connector configured to couple the lead to a pulse generator, an insulative lead body extending distally from the first connector, and a first conductor extending distally from the first connector within the lead body and having a proximal end electrically coupled to the first connector. A first defibrillation coil is exposed at an outer surface of the medical device lead, and a first high impedance coil is connected between the first conductor and the first defibrillation coil. The first high impedance coil is insulated at the outer surface of the medical device lead and has an impedance greater than the first conductor.

[0006] In a further aspect, a medical device lead includes one or more proximal connectors each configured to couple to a pulse generator, an insulative lead body extending distally from the one or more proximal connectors, and one or more conductors each extending distally from and electrically connected to one of the one or more proximal connectors. One or more defibrillation coils are each connected to a distal end of one of the one or more conductors. A first portion of each defibrillation coil is exposed at an outer surface of the medical device lead and a second portion of each defibrillation coil is insulated at the outer surface of the medical device lead.

[0007] 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

[0008] FIG. 1 is a schematic view of a cardiac rhythm management (CRM) system including a pulse generator and a lead implanted in a patient's heart according to an embodiment of the present invention.

[0009] FIG. 2 is a cross-sectional view of a distal portion of a lead according to an embodiment of the present invention including a defibrillation coil that is partially insulated.

[0010] FIG. 3A is a cross-sectional view of a distal portion of a lead according to another embodiment of the present invention including two defibrillation coils that are each partially insulated.

[001 1] FIG. 3B is a cross-sectional view of a portion of the lead proximal to the distal portion of the lead shown in FIG. 3A.

[0012] FIG. 4 is a schematic view of an implantable medical device including a lead having a plurality of high impedance coils in series with a conductive cable that extends through the lead body according to a further embodiment of the present invention.

[0013] 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

[0014] FIG. 1 is a schematic view of a cardiac rhythm management (CRM) system 10 according to an embodiment of the present invention. As shown in FIG. 1, the CRM system 10 includes a pulse generator 12 coupled to a plurality of leads 14, 16 deployed in a patient's heart 18. As further shown in FIG. 1, the heart 18 includes a right atrium 24 and a right ventricle 26 separated by a tricuspid valve 28. During normal operation of the heart 18, deoxygenated blood is fed into the right atrium 24 through the superior vena cava 30 and the inferior vena cava 32. The major veins supplying blood to the superior vena cava 30 include the right and left axillary veins 34 and 36, which flow into the right and left subclavian veins 38 and 40. The right and left external jugular 42 and 44, along with the right and left internal jugular 46 and 48, join the right and left subclavian veins 38 and 40 to form the right and left brachiocephalic veins 50 and 52, which in turn combine to flow into the superior vena cava 30.

[0015] The leads 14, 16 operate to convey electrical signals and stimuli between the heart 18 and the pulse generator 12. In the illustrated embodiment, the lead 14 is implanted in the right ventricle 26, and the lead 16 is implanted in the right

atrium 24. In other embodiments, the CRM system 10 may include additional leads, e.g., a lead extending into a coronary vein for stimulating the left ventricle in a bi-ventricular pacing or cardiac resynchronization therapy system. As shown, the leads 14, 16 enter the vascular system through a vascular entry site 54 formed in the wall of the left subclavian vein 40, extend through the left brachiocephalic vein 52 and the superior vena cava 30, and are implanted in the right ventricle 26 and right atrium 24, respectively. In other embodiments of the present invention, the leads 14, 16 may enter the vascular system through the right subclavian vein 38, the left axillary vein 36, the left external jugular 44, the left internal jugular 48, or the left brachiocephalic vein 52.

[0016] The pulse generator 12 is typically implanted subcutaneously within an implantation location or pocket in the patient's chest or abdomen. The pulse generator 12 may be any implantable medical device known in the art or later developed, for delivering an electrical therapeutic stimulus to the patient. In various embodiments, the pulse generator 12 is a pacemaker, an implantable cardiac defibrillator, and/or includes both pacing and defibrillation capabilities. The portion of the leads 14, 16 extending from the pulse generator 12 to the vascular entry site 54 are also located subcutaneously or submuscularly. The leads 14, 16 are each connected to the pulse generator 12 via proximal connectors. Any excess lead length, i.e., length beyond that needed to reach from the pulse generator 12 location to the desired intracardiac implantation site, is generally coiled up in the subcutaneous pocket near the pulse generator 12.

[0017] FIG. 2 is a cross-sectional view of the lead 14 according to an embodiment of the present invention. The lead 14 includes a defibrillation coil 60, and pacing or sensing electrodes 62 and 64. The defibrillation coil 60 may be used to deliver a high voltage therapy signal to a portion of the heart 18. The pacing or sensing electrodes 62 and 64 may be used for pacing, sensing, or both. In the embodiment shown, the electrode 62 is a ring electrode, and the electrode 64 includes a fixation helix. In some embodiments, the electrodes 62 and 64 include platinum or titanium coated with a combination of iridium oxide (IrOx), titanium/nickel (Ti/Ni), black platinum (Pt black), or tantalum oxide (TaO). The defibrillation coil 60 and the pacing or sensing electrodes 62 and 64 are located near a distal end portion of the lead 14. In alternative embodiments, the defibrillation and pacing or sensing

electrodes are located elsewhere on the lead 14. The lead 14 may also alternatively include fewer or more electrodes.

[0018] The electrode 62 is coupled to a first conductive coil 70, and the electrode 64 is coupled to a second conductive coil 72. The second conductive coil 72 is surrounded by an insulative layer 80 to insulate the conductive coil 72 from other elements of the lead 14. In some embodiments, the insulative layer 80 extends from the proximal end to the distal end of the lead 14. An insulative layer 82 is also formed around the first conductor 70. In some embodiments, the insulative layer 82 extends from the proximal end of the lead 14 to the electrode 62. With this arrangement, the electrode 62 is exposed at the outer surface of the lead 14 to allow contact with adjacent tissue. The insulative layers 80 and 82 may be comprised of, for example, silicone material, Teflon, expanded polytetrafluoroethylene (ePTFE), polytetrafluoroethylene (PTFE), ethylene tetrafluoroethylene (ETFE), or another suitable non-conductive material. The electrodes 62 and 64, the conductive coils 70 and 72, and the insulative layers 80 and 82 combine to form the low voltage pacing/sensing portion 85 of the lead 14.

[0019] The first conductive coil 70 and the second conductive coil 72 extend through the lead 14 and are adapted for connection to the pulse generator 12 at the proximal end of the lead 14. In some embodiments, the first conductive coil 70 and the second conductive coil 72 are each coupled to a proximal connector at the proximal end of the lead 14. The connectors at the proximal end of the lead 14 are sized and shaped to interface with a connector block or other component of the pulse generator 12. The signals carried by the first conductive coil 70 and the second conductive coil 72 may be independently controlled by the pulse generator 12 such that different signals may be delivered to and/or received from the electrodes 62 and 64.

[0020] The defibrillation coil 60 is coupled to a conductive cable 90, which extends through the lead 14 and is adapted for connection to the pulse generator 12 at the proximal end of the lead 14. The conductive cable 90 may extend through the lead 14 in a lumen parallel to the conductive coils 70 and 72. The conductive cable 90 is surrounded by an insulating layer 92 at an exterior surface of the lead 14. In some embodiments, the conductive cable 90 is coupled to a proximal connector at the proximal end of the lead 14 that is sized and shaped to interface with a connector

block or other component of the pulse generator 12. The conductive cable 90 delivers a high voltage defibrillation signal from the pulse generator 12 to the defibrillation coil 60. The lead 14 is arranged in the heart 18 such that the signal delivered by the defibrillation coil 60 depolarizes a critical mass of the heart muscle, terminates an arrhythmia, and allows normal sinus rhythm to be reestablished.

[0021] In a magnetic resonance imaging (MRI) environment, the radio frequency (RF) fields can induce a current in the conductive elements of the lead 14. This current may then be dissipated at the point of contact between the lead electrodes and adjacent tissue, resulting in elevated temperatures in the tissue. To reduce the RF current that is transmitted to the defibrillation coil 60 by the conductive cable 90, a length L of the defibrillation coil 60 is insulated at the exterior surface of the lead 14 by insulating layer 92. The insulated length L of the defibrillation coil 60 acts as an RF filter between the conductive cable 90 and the exposed portion of the defibrillation coil 60. More specifically, the inductance of a coil is directly proportional to the square of the radius of the coil. Thus, the inductance of the defibrillation coil 60 is large due to its large diameter. In some embodiments, the outside diameter of the defibrillation coil 60 is in the range of about 0.08 to 0.12 inch (about 2.0 to 3.0 mm). Consequently, the insulated length L of the defibrillation coil 60 reduces the amount of MRI-induced energy that is transmitted to the defibrillation coil 60 via the conductive cable 90. In some embodiments, the proximal and distal ends of the exposed portion of the defibrillation coil 60 are short circuited with an optional low impedance connection 94 (shown in phantom) to evenly distribute the high voltage signal across the exposed portion.

[0022] The inductance of a coil is also directly proportional to the square of the number of turns in the coil. Thus, in order to further reduce the amount of energy that is transmitted to the defibrillation coil 60, the turns of the defibrillation coil 60 may be tightly wound to maximize the inductance of the coil. Also, a unifilar coil may be used to minimize the space between adjacent turns and maximize the number of turns in the defibrillation coil 60. In some embodiments, filar of the defibrillation coil 60 has a diameter in the range of about 0.005 to 0.012 inch (about 0.125 mm to 0.305 mm).

[0023] In one exemplary implementation, the defibrillation coil 60 has a length of about 80 mm and an outside diameter of about 2.5 mm. The defibrillation coil 60

is a unifilar coil having a filar diameter of about 0.10 mm. The length L of the defibrillation coil 60 that is insulated is about 30 mm, and the distance separating the defibrillation coil 60 from the ring electrode 62 is about 12.5 mm. A lead 14 having this arrangement showed a reduction in heating of about 5-10°C at the insulation-exposed coil interface of the defibrillation coil 60 compared to leads including a defibrillation coil 60 without a proximal insulated portion.

[0024] In alternative embodiments in which the defibrillation coil 60 is multifilar and/or in which the turns of the defibrillation coil 60 are not tightly wound, the length L of the defibrillation coil 60 that is insulated may be increased to increase the impedance of the insulated length L.

[0025] Thus, the length L, the number of turns, and the number of filars in the insulated section of the defibrillation coil 60 are selected to provide a reduction in MRI-induced energy in the exposed (i.e., non-insulated) section of the defibrillation coil 60 while minimizing the increase in resistance prior to the exposed portion of the defibrillation coil 60. In some embodiments, these parameters are selected to provide a total DC resistance in the conductive cable 90 and the insulated length L of less than about 5 Ω.

[0026] FIG. 3A is a cross-sectional view of a distal portion of a lead 100 according to another embodiment of the present invention. FIG. 3B is a cross-sectional view of a portion of the lead 100 proximal to the distal portion of the lead shown in FIG. 3A. The lead 100 is another exemplary configuration that may be employed as lead 14 in FIG. 1. As is shown, the proximal end of the distal portion of lead 100 shown in FIG. 3A is electrically coupled to the distal end of the proximal portion of lead 100 shown in FIG. 3B.

[0027] The lead 100 includes a distal defibrillation coil 102, a proximal defibrillation coil 104, a ring electrode 106, and a tip electrode 108. The distal defibrillation coil 102 and proximal defibrillation coil 104 may be used to deliver a high voltage therapy signal to different portions of the heart 18. The ring electrode 106 and/or the tip electrode 108 may be used for pacing, sensing, or both. In the embodiment shown, the ring electrode 106 is common with the distal defibrillation coil 102 and the tip electrode 108 includes a fixation helix. By making the ring electrode 106 common with the distal defibrillation coil 102, the diameter of the lead 100 is minimized. When shock therapy is not being delivered through the

defibrillation coils 102 and 104, a pacing voltage may be generated between the electrodes 106 and 108. In alternative embodiments, the pacing or sensing electrodes are located elsewhere on the lead 100. The lead 100 may also alternatively include fewer or more electrodes.

[0028] The tip electrode 108 is coupled to a conductive coil 110, which is surrounded by an insulative layer 112 to insulate the conductive coil 110 from other elements of the lead 100. In some embodiments, the insulative layer 112 extends from the proximal end to the distal end of the lead 100. The insulative layer 112 may be comprised of, for example, silicone material, Teflon, expanded polytetrafluoroethylene (ePTFE), polytetrafluoroethylene (PTFE), ethylene tetrafluoroethylene (ETFE), or another suitable non-conductive material. The electrodes 106 and 108, the conductive coil 110, and the insulative layer 112 combine to form the low voltage pacing/sensing portion 114 of the lead 100.

[0029] The conductive coil 110 extends through the lead 100 and is adapted for connection to the pulse generator 12 at the proximal end of the lead 100. In some embodiments, the conductive coil 110 is coupled to a proximal connector at the proximal end of the lead 100. The connectors at the proximal end of the lead 100 are sized and shaped to interface with a connector block or other component of the pulse generator 12.

[0030] The distal defibrillation coil 102 is coupled to a conductive cable 120, and the proximal defibrillation coil 104 is coupled to a conductive cable 122. The conductive cables 120 and 122 extend through the lead 100 and are adapted for connection to the pulse generator 12 at the proximal end of the lead 100. In some embodiments, the conductive cables 120 and 122 may extend through the lead 100 in separate lumens parallel to the conductive coil 110. The conductive cable 120 is surrounded by an insulating layer 112 at an exterior surface of the lead 100. In some embodiments, the conductive cables 120 and 122 are each coupled to a proximal connector at the proximal end of the lead 100 that is sized and shaped to interface with a connector block or other component of the pulse generator 12. The conductive cables 120 and 122 delivers a high voltage defibrillation signal from the pulse generator 12 to the defibrillation coils 102 and 104, respectively.

[0031] To reduce the RF current that is transmitted to the defibrillation coils 102, 104 by the conductive cables 120 and 122, a length L_1 of the defibrillation coil

102 and a length L_2 of the defibrillation coil 104 are insulated at the exterior surface of the lead 100 by insulating layer 124. The insulated lengths L_{-i}, L_2 act as RF filters between the conductive cables 120, 122 and the exposed portions of the defibrillation coils 102, 104, respectively. Consequently, the insulated lengths L_{-i}, L_2 reduce the amount of MRI-induced energy that is transmitted to the defibrillation coils 102, 104, respectively. In addition, the portion of the defibrillation coil 102 that is insulated between the ring electrode 106 and the exposed portion of the defibrillation coil 102 may provide a further reduction in the amount of MRI-induced energy that is transmitted to the defibrillation coil 102 and/or the ring electrode 106.

[0032] The inductance of a coil is also directly proportional to the square of the number of turns in the coil. Thus, in order to further reduce the amount of energy that is transmitted to the defibrillation coils 102, 104, the turns of the defibrillation coils 102, 104 may be tightly wound to maximize the inductance of the coil. Also, unifilar coils may be used to minimize the space between adjacent turns and maximize the number of turns in the defibrillation coils 102, 104. In alternative embodiments in which the defibrillation coil is multifilar and/or in which the turns of the defibrillation coil are not tightly wound, the lengths L_{-i}, L_2 of the defibrillation coils 102, 104 that are insulated may be increased to increase the impedance of the insulated lengths L_{-i}, L_2.

[0033] Thus, the lengths L_{-i}, L_2, the number of turns, and the number of filars in the insulated section of the defibrillation coils 102, 104 are selected to provide a reduction in MRI-induced energy in the exposed (i.e., non-insulated) sections of the defibrillation coils while minimizing the increase in resistance prior to the exposed portion of the defibrillation coils 102, 104. In some embodiments, these parameters are selected to provide a total DC resistance of the conductive cable 120 and the insulated length L_1 of less than about 5 Ω, and a total DC resistance of the conductive cable 122 and the insulated length L_2 of less than about 5 Ω.

[0034] In an alternative embodiment, the diameters of the exposed portions of the defibrillation coils 102, 104 may be increased to make the outer diameter of the defibrillation coils 102, 104 substantially equal to the outer diameter of the insulating layer 124. As a result, the lead 100 has a uniform outer diameter along its length. In one example implementation, a second, larger coil having an outer diameter substantially equal to the outer diameter of the insulating layer 124 is arranged

around and in contact with the exposed portion of each of the defibrillation coils 102, 104. In another example implementation, the thickness of the insulating layer 112 is increased under the exposed portion of each of the defibrillation coils 102, 104 to increase the outer diameter of the defibrillation coils 102, 104 to be substantially equal to the outer diameter of the insulating layer 124.

[0035] FIG. 4 is a schematic view of an implantable medical device 150 including a pulse generator 12 and a lead 152 according to a further embodiment of the present invention. The lead 152 includes features that may be incorporated into either lead 14 or lead 100 described above. The lead 152 includes a defibrillation coil 154, a ring electrode 156 and a tip electrode 158. The defibrillation coil 154, the ring electrode 156, and the tip electrode 158 are located near a distal end portion of the lead 152. The lead 152 may also alternatively include fewer or more electrodes.

[0036] The defibrillation coil 154 is coupled to a conductive cable 160, which extends through the lead 150 and is adapted for connection to the pulse generator 12 at the proximal end of the lead 150. While not shown in FIG. 4, electrodes 156 and 158 are also electrically coupled to the pulse generator, such as via conductive coils as shown in FIGS. 2, 3A, and 3B, for example. In some embodiments, the conductive cable 160 is coupled to a proximal connector at the proximal end of the lead 14 that is sized and shaped to interface with a connector block 162 or other component of the pulse generator 12. The conductive cable 160 delivers a high voltage defibrillation signal from the pulse generator 12 to the defibrillation coil 154. The lead 152 is arranged in the heart 18 such that the signal delivered by the defibrillation coil 154 depolarizes a critical mass of the heart muscle, terminates an arrhythmia, and allows normal sinus rhythm to be reestablished.

[0037] As in the embodiments described above, a length L of the defibrillation coil 154 is insulated to increase the inductance between the conductive cable 160 and the exposed portion of the defibrillation coil 154. In the embodiment shown in FIG. 4, high impedance coils 170 are coupled in series with the conductive cable 160. The high impedance coils 170 provide an additional reduction in the amount of MRI-induced energy that is transmitted to the defibrillation coil 154. In addition, a high impedance coil 170 may be connected in series with the conductive cable 160 proximate the pulse generator 12 to reduce heating of the pulse generator housing. The high impedance coils 170 may be arranged periodically along the length of the

conductive cable 160. In some embodiments, the length of the conductive cable 160 between adjacent high impedance coils 170 is less than one quarter wavelength ($\lambda/4$) of a signal carried by the conductive cable 160. This minimizes the energy picked up by the conductive cable 160 in an MRI environment.

[0038] In summary, embodiments of the present invention relate to a medical device lead including a proximal connector configured to couple the lead to a pulse generator, an insulative lead body extending distally from the proximal connector, a conductor assembly extending distally from the proximal connector within the lead body. The conductor assembly includes a conductor having a proximal end electrically coupled to the connector and a distal end electrically coupled to a defibrillation coil. A first portion of the defibrillation coil is exposed at an outer surface of the medical device lead and a second portion of the defibrillation coil is insulated at the outer surface of the medical device lead. The insulated portion of the defibrillation coil, which has a high impedance due to its relatively large diameter, acts as a filter for the radio frequency (RF) energy that is picked up by the conductor in a magnetic resonance imaging (MRI) environment. This reduces the transfer of RF energy to the defibrillation electrode, thereby decreasing the amount of heating of the tissue around the electrode.

[0039] 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

We claim:

1. A medical device lead comprising:

a proximal connector configured to couple the lead to a pulse generator;

an insulative lead body extending distally from the proximal connector;

a conductor assembly extending distally from the proximal connector within the lead body and including a conductor having a proximal end electrically coupled to the connector and a distal end electrically coupled to a defibrillation coil, wherein a first portion of the defibrillation coil is exposed at an outer surface of the medical device lead and a second portion of the defibrillation coil is insulated at the outer surface of the medical device lead.

2. The medical device lead of claim 1, wherein the defibrillation coil is unifilar.

3. The medical device lead of claim 1, wherein opposing ends of the first portion of defibrillation coil are short circuited.

4. The medical device lead of claim 1, wherein the conductor comprises a conductive cable.

5. The medical device lead of claim 4, wherein the conductor further comprises one or more conductive coils in series with the conductive cable.

6. The medical device lead of claim 5, wherein the conductor comprises two or more conductive coils in series with the conductive cable, and wherein a length of the conductive cable between adjacent conductive coils is less than one quarter wavelength of a signal carried by the conductive assembly.

7. The medical device lead of claim 1, wherein the conductive assembly and the second portion have a total DC resistance of less than about 5 Ω.

8. A medical device lead comprising:

a first connector configured to couple the lead to a pulse generator;

an insulative lead body extending distally from the first connector;

a first conductor extending distally from the first connector within the lead body and having a proximal end electrically coupled to the first connector;

a first defibrillation coil exposed at an outer surface of the medical device lead; and

a first high impedance coil connected between the first conductor and the first defibrillation coil, wherein the first high impedance coil is insulated at the outer surface of the medical device lead and has an impedance greater than the first conductor.

9. The medical device lead of claim 8, wherein the first defibrillation coil is unifilar.

10. The medical device lead of claim 8, wherein opposing ends of the first defibrillation coil are short circuited.

11. The medical device lead of claim 8, wherein the first conductor comprises a conductive cable.

12. The medical device lead of claim 11, wherein the first conductor further comprises one or more conductive coils in series with the conductive cable.

13. The medical device lead of claim 12, wherein the first conductor comprises two or more conductive coils in series with the first conductive cable, and

wherein a length of the first conductive cable between adjacent conductive coils is less than one quarter wavelength of a signal carried by the first conductor.

14. The medical device lead of claim 8, wherein the first high impedance coil and the first conductor have a total DC resistance of less than about 5 Ω.

15. The medical device lead of claim 8, and further comprising:

a second connector configured to couple the lead to the pulse generator;

a second conductor having a proximal end electrically coupled to the second connector;

a second defibrillation coil exposed at an outer surface of the medical device lead; and

a second high impedance coil connected between the conductor and the defibrillation coil, wherein the second high impedance coil is insulated at the outer surface of the medical device lead and has an impedance greater than the second conductor.

16. A medical device lead comprising:

one or more proximal connectors each configured to couple to a pulse generator;

an insulative lead body extending distally from the one or more proximal connectors;

one or more conductors each extending distally from and electrically connected to one of the one or more proximal connectors;

one or more defibrillation coils each connected to a distal end of one of the one or more conductors, wherein a first portion of each defibrillation coil is exposed at an outer surface of the medical

device lead and a second portion of each defibrillation coil is insulated at the outer surface of the medical device lead.

17. The medical device lead of claim 16, wherein at least one of the one or more defibrillation coils is unifilar.

18. The medical device lead of claim 16, wherein opposing ends of at least one of the one or more defibrillation coils are short circuited.

19. The medical device lead of claim 16, wherein each of the one or more conductors comprises a conductive cable.

20. The medical device lead of claim 19, wherein at least one of the one or more conductors further comprises one or more conductive coils in series with the conductive cable.

21. The medical device lead of claim 20, wherein the at least one of the one or more conductors comprises two or more conductive coils in series with the conductive cable, and wherein a length of the conductive cable between adjacent conductive coils is less than one quarter wavelength of a signal carried by the conductor.

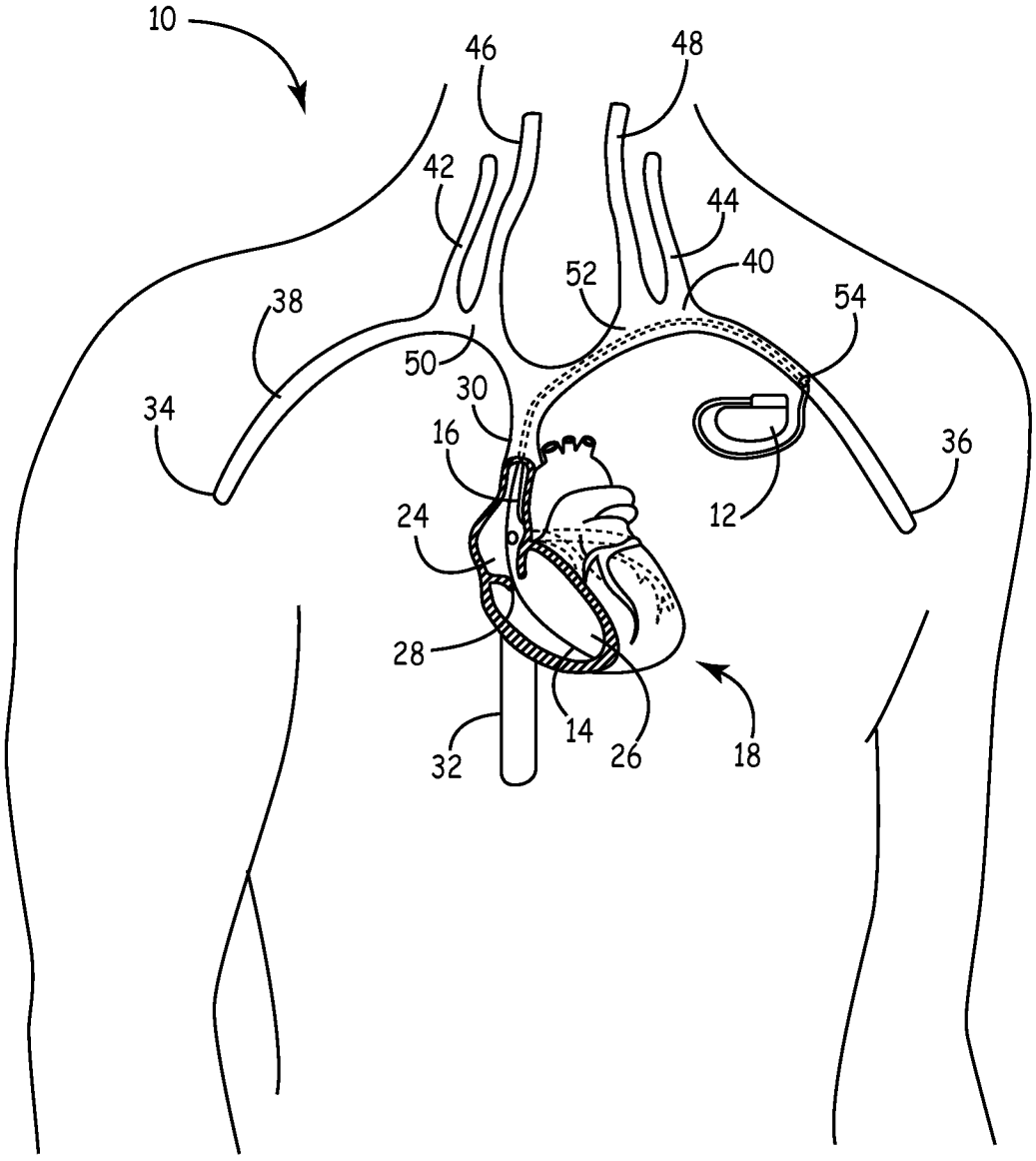

FIG. 1

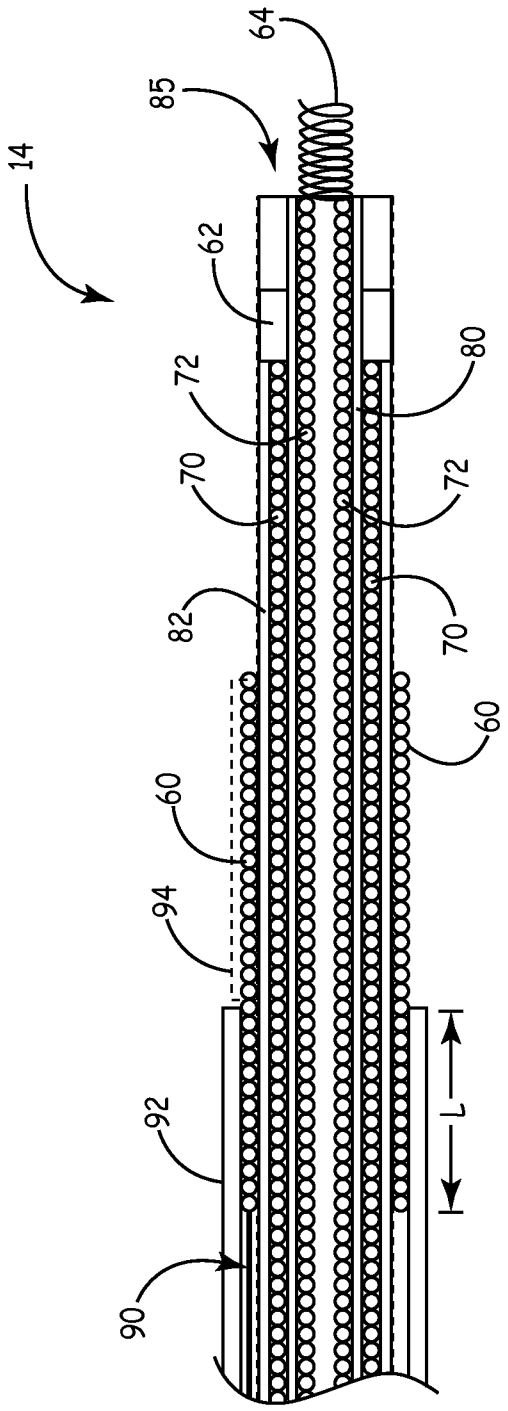

FIG. 2

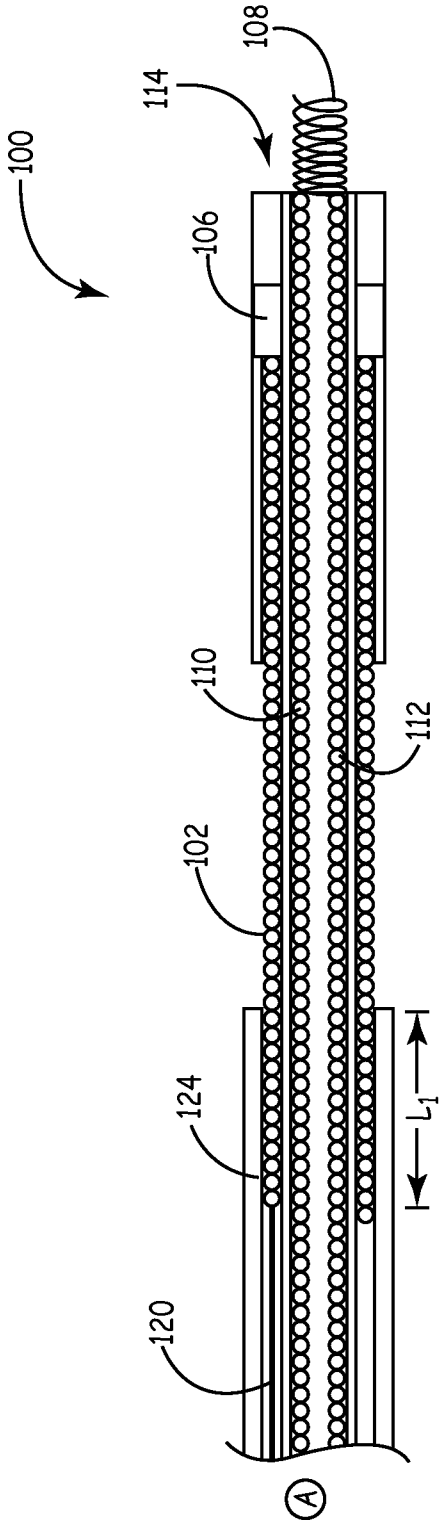
100
114
108
106
110
112
102
124
120
L_1
A

FIG. 3A

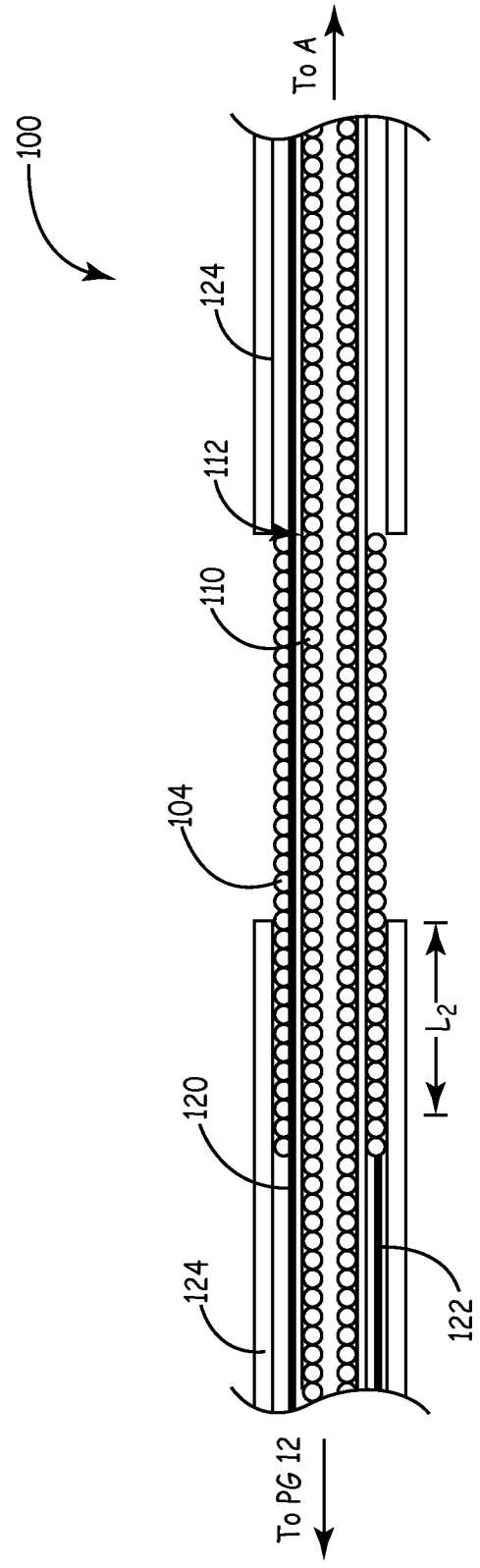
100
To A
124
112
110
104
120
L_2
124
122
To PG 12

FIG. 3B

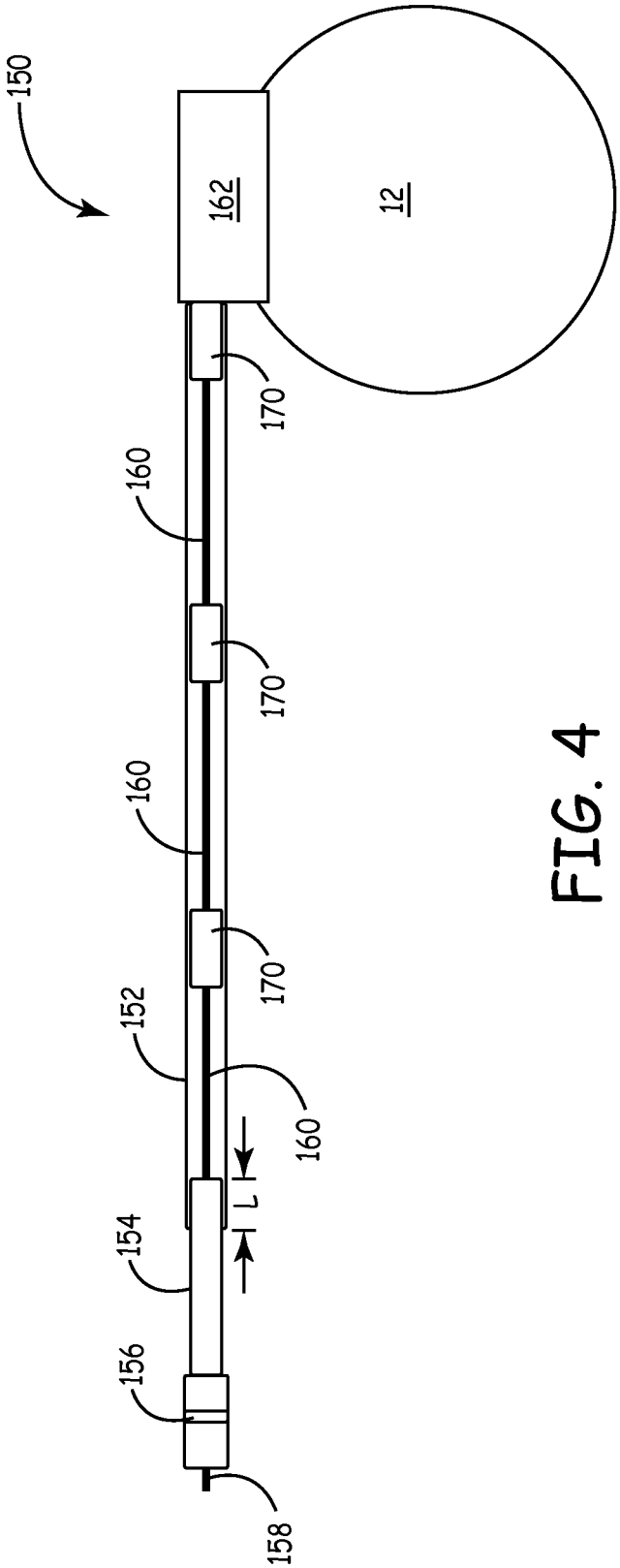

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/048638

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/05
ADD. A61N1/08 A61N1/02

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

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	US 2008/033497 A1 (BULKES CHERIK [US] ET AL) 7 February 2008 (2008-02-07) paragraphs [0061] - [0066], [0090] - [0094]; figures 2,4,17A-17B	1-21
X	US 2007/208383 A1 (WILLIAMS TERRELL N [US]) 6 September 2007 (2007-09-06) paragraph [0012]; figure 1	1,16
A	US 2009/149933 A1 (AMERI MASOUD [US]) 11 June 2009 (2009-06-11) the whole document	1-21

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

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 November 2010	12/11/2010

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	Smit, Jos

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2010/048638

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008033497 A1	07-02-2008	EP 2079511 A1	22-07-2009
		WO 2008051913 A1	02-05-2008
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US 2009149933 A1	11-06-2009	AU 2008335462 A1	18-06-2009
		CN 101842130 A	22-09-2010
		EP 2227289 A2	15-09-2010
		WO 2009076163 A2	18-06-2009