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(71) **Applicant: BOSTON SCIENTIFIC NEUROMODULATION CORPORATION** [US/US]; 25155 Rye Canyon Loop, Valencia, CA 91355 (US).

(72) **Inventors: MOFFITT, Michael, A.**; 6120 Penfield Ln., Solon, OH 44139 (US). **CARCIERI, Stephen**; 2314 Vista Gordo Dr., Los Angeles, CA 90026 (US).

(74) **Agent: BLACK, Bruce, E.**; Lowe Graham Jones PLLC, 701 5th Ave., Suite 4800, Seattle, WA 98104 (US).

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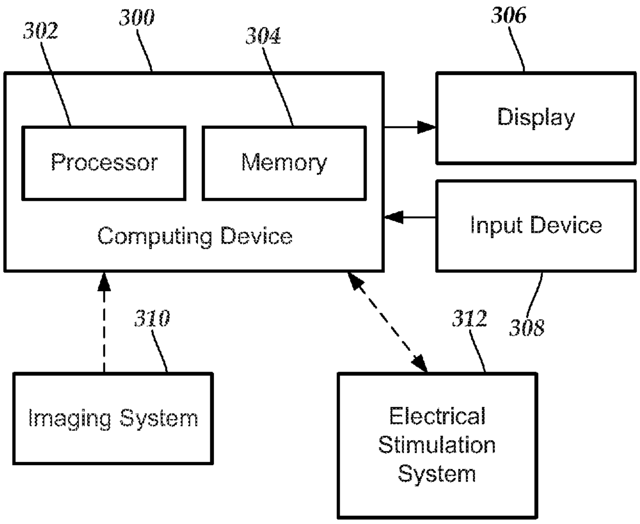

Fig. 3

(57) **Abstract:** Methods and systems can facilitate identifying effective electrodes and other stimulation parameters, as well as determining whether to use cathodic and anodic stimulation. Alternately, the methods and systems may identify effective electrodes and other stimulation parameters based on preferential stimulation of different types of neural elements. These methods and systems can further facilitate programming an electrical stimulation system for stimulating patient tissue.

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MULTI-MODE ELECTRICAL STIMULATION SYSTEMS AND METHODS OF MAKING AND USING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Serial No. 62/663,908, filed April 27, 2018, which is incorporated herein by reference.

FIELD

The present disclosure is directed to the area of implantable electrical stimulation systems and methods of making and using the systems. The present disclosure is also directed to electrical stimulation systems with multiple modes, such as anodic or cathodic stimulation modes, and methods of making and using.

BACKGROUND

Implantable electrical stimulation systems have proven therapeutic in a variety of diseases and disorders. For example, spinal cord stimulation systems have been used as a therapeutic modality for the treatment of chronic pain syndromes. Peripheral nerve stimulation has been used to treat chronic pain syndrome and incontinence, with a number of other applications under investigation. Functional electrical stimulation systems have been applied to restore some functionality to paralyzed extremities in spinal cord injury patients. Stimulation of the brain, such as deep brain stimulation, can be used to treat a variety of diseases or disorders.

Stimulators have been developed to provide therapy for a variety of treatments. A stimulator can include a control module (with a pulse generator), one or more leads, and an array of stimulator electrodes on each lead. The stimulator electrodes are in contact with or near the nerves, muscles, or other tissue to be stimulated. The pulse generator in the control module generates electrical pulses that are delivered by the electrodes to body tissue.

BRIEF SUMMARY

One aspect is a system for programming electrical stimulation of a patient using an implantable electrical stimulation system including an implantable pulse generator and a lead having a plurality of electrodes. The system includes a processor configured to receive a first response for each of a plurality of first monopolar stimulations performed using a subset of one or more of the electrodes of the lead as a cathode for each of the first monopolar stimulations; select a first subset of one or more of the electrodes based on the first responses; receive a second response for each of a plurality of second monopolar stimulations performed using a subset of one or more of the electrodes of the lead as an anode for each of the second monopolar stimulations; select a second subset of one or more of the electrodes based on the second responses; select a programming subset of one or more of the electrodes based, at least in part, on the responses associated with the first subset and second subset; receive a third response for each of a plurality of third monopolar stimulations performed using the programming subset with each of the third monopolar stimulation having a different stimulation amplitude; select a programming stimulation amplitude based on the third responses; receive direction to program the implantable pulse generator with the programming subset of one or more of the electrodes and the programming stimulation amplitude; and initiate a signal that provides the implantable pulse generator of the electrical stimulation system with the programming subset of one or more of the electrodes and the programming stimulation amplitude for generating electrical stimulation for the patient through the electrodes of the lead.

Another aspect is a method for programming electrical stimulation of a patient using an implantable electrical stimulation system including an implantable pulse generator and a lead having a plurality of electrodes. The method includes receiving a first response for each of a plurality of first monopolar stimulations performed using a subset of one or more of the electrodes of the lead as a cathode for each of the first monopolar stimulations; selecting a first subset of one or more of the electrodes based on the first responses; receiving a second response for each of a plurality of second monopolar stimulations performed using a subset of one or more of the electrodes of the lead as an anode for each of the second monopolar stimulations; selecting a second subset of one or more of the electrodes based on the second responses; selecting a programming subset of one or more of the electrodes based, at least in part, on the responses associated with the first subset and second subset; receiving a third response for each of a plurality of third monopolar stimulations performed using the programming subset with each of the third monopolar stimulation having a different stimulation amplitude; selecting a programming stimulation amplitude based on the third responses; receiving direction to program the implantable pulse generator with the programming subset of one or more of the electrodes and the programming stimulation amplitude; and initiating a signal that provides the implantable pulse generator of the electrical stimulation system with the programming subset of one or more of the electrodes and the programming stimulation amplitude for generating electrical stimulation for the patient through the electrodes of the lead.

A further aspect is non-transitory computer-readable medium having computer executable instructions stored thereon that, when executed by a processor, cause the processor to perform the method described above.

In at least some aspects, receiving a first response includes receiving a first quantitative or qualitative indication of at least one therapeutic effect and receiving a second response includes receiving a second quantitative or qualitative indication of at least one therapeutic effect. In at least some aspects, receiving a first response includes receiving a first quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof and receiving a second response includes receiving a second quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof. In at least some aspects, selecting the set of program stimulation parameters includes selecting the set of program stimulation parameters based on the first and second quantitative or qualitative indications.

In at least some aspects, the processor is further configured to, or the method further includes steps to, receive a third response for each of a plurality of cathodic/anodic stimulations performed using a subset of one or more of the electrodes of the lead as an anode and one or more of the electrodes of the lead as a cathode for each of the cathodic/anodic stimulations; and select a third subset of one or more of the electrodes based on the third responses; wherein selecting the programming subset of one or more of the electrodes includes selecting the programming subset of one or more of the electrodes based, at least in part, on the first, second, and third responses associated with the first subset, second subset, and third subset.

In at least some aspects, receiving a first response including receiving the first response from a clinician or patient. In at least some aspects, receiving a first response including receiving the first response from a sensor.

Another aspect is a system for programming electrical stimulation of a patient using an implantable electrical stimulation system including an implantable pulse generator and a lead having a plurality of electrodes. The system includes a processor configured to receive a first response for each of a plurality of first stimulations performed using a subset of one or more of the electrodes of the lead for each of the first stimulations, wherein the first stimulations are configured to preferentially stimulate a first type of neural element; select a first subset of one or more of the electrodes based, at least in part, on the first responses; receive a second response for each of a plurality of second stimulations performed using a subset of one or more of the electrodes for each of the second stimulations, wherein the second stimulations are configured to preferentially stimulate a second type of neural element which is different from the first type of neural element; select a second subset of one or more of the electrodes based, at least in part, on the second responses; select a programming subset of one or more of the electrodes based on the responses associated with the first subset and second subset; receive direction to program the implantable pulse generator with the programming subset of one or more of the electrodes and the programming stimulation amplitude; and initiate a signal that provides the implantable pulse generator of the electrical stimulation system with the programming subset of one or more of the electrodes and the programming stimulation amplitude for generating electrical stimulation for the patient through the electrodes of the lead.

Yet another aspect is a method for programming electrical stimulation of a patient using an implantable electrical stimulation system including an implantable pulse generator and a lead having a plurality of electrodes. The method includes receiving a first response for each of a plurality of first stimulations performed using a subset of one or more of the electrodes of the lead for each of the first stimulations, wherein the first stimulations are configured to preferentially stimulate a first type of neural element; selecting a first subset of one or more of the electrodes based, at least in part, on the first responses; receiving a second response for each of a plurality of second stimulations performed using a subset of one or more of the electrodes for each of the second stimulations, wherein the second stimulations are configured to preferentially stimulate a second type of neural element which is different from the first type of neural element; selecting a second subset of one or more of the electrodes based, at least in part, on the second responses; selecting a programming subset of one or more of the electrodes based on the responses associated with the first subset and second subset; receiving direction to program the implantable pulse generator with the programming subset of one or more of the electrodes and the programming stimulation amplitude; and initiating a signal that provides the implantable pulse generator of the electrical stimulation system with the programming subset of one or more of the electrodes and the programming stimulation amplitude for generating electrical stimulation for the patient through the electrodes of the lead.

A further aspect is non-transitory computer-readable medium having computer executable instructions stored thereon that, when executed by a processor, cause the processor to perform the method described above.

In at least some aspects, receiving a first response includes receiving a first quantitative or qualitative indication of at least one therapeutic effect and receiving a second response includes receiving a second quantitative or qualitative indication of at least one therapeutic effect. In at least some aspects, receiving a first response includes receiving a first quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof and receiving a second response includes receiving a second quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof. In at least some aspects, selecting the set of program stimulation parameters includes selecting the set of program stimulation parameters based on the first and second quantitative or qualitative indications.

In at least some aspects, the processor is further configured to, or the method further includes steps to, receive a third response for each of a plurality of third stimulations performed using a subset of one or more of the electrodes for each of the third stimulations, wherein the third stimulations are configured to preferentially stimulate a third type of neural element which is different from the first and second types of neural element; and select a third subset of one or more of the electrodes based, at least in part, on the third responses; wherein selecting the programming subset of one or more of the electrodes includes selecting the programming subset of one or more of the electrodes based, at least in part, on the first, second, and third responses associated with the first subset, second subset, and third subset.

In at least some aspects, receiving a first response including receiving the first response from a clinician or patient. In at least some aspects, receiving a first response including receiving the first response from a sensor.

Another aspect is a system for programming electrical stimulation of a patient using an implantable electrical stimulation system including an implantable pulse generator and a lead having a plurality of electrodes. The system includes a processor configured to receive a first response for each of a plurality of first monopolar stimulations performed using at least one of the electrodes of the lead as a cathode, each of the first monopolar stimulations having a set of first stimulation parameters associated with the first stimulation; receive a second response for each of a plurality of second monopolar stimulations performed using at least one of the electrodes of the lead as an anode, each of the second monopolar stimulations having a set of second stimulation parameters associated with the second stimulation; select, from the sets of first stimulation parameters and sets of second stimulation parameters, a set of program stimulation parameters for a first stimulation program based on the first and second responses; receive direction to program the implantable pulse generator with the set of program stimulation parameters; and initiate a signal that provides the implantable pulse generator of the electrical stimulation system with the set of program stimulation parameters for generating electrical stimulation for the patient through the electrodes of the lead.

Yet another aspect is a method for programming electrical stimulation of a patient using an implantable electrical stimulation system including an implantable pulse generator and a lead having a plurality of electrodes. The method includes receiving a first response for each of a plurality of first monopolar stimulations performed using at least one of the electrodes of the lead as a cathode, each of the first monopolar stimulations having a set of first stimulation parameters associated with the first stimulation; receiving a second response for each of a plurality of second monopolar stimulations performed using at least one of the electrodes of the lead as an anode, each of the second monopolar stimulations having a set of second stimulation parameters associated with the second stimulation; selecting, from the sets of first stimulation parameters and sets of second stimulation parameters, a set of program stimulation parameters for a first stimulation program based on the first and second responses;

receiving direction to program the implantable pulse generator with the set of program stimulation parameters; and initiating a signal that provides the implantable pulse generator of the electrical stimulation system with the set of program stimulation parameters for generating electrical stimulation for the patient through the electrodes of the lead.

A further aspect is non-transitory computer-readable medium having computer executable instructions stored thereon that, when executed by a processor, cause the processor to perform the method described above.

In at least some aspects, receiving a first response includes receiving a first quantitative or qualitative indication of at least one therapeutic effect and receiving a second response includes receiving a second quantitative or qualitative indication of at least one therapeutic effect. In at least some aspects, receiving a first response includes receiving a first quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof and receiving a second response includes receiving a second quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof. In at least some aspects, selecting the set of program stimulation parameters includes selecting the set of program stimulation parameters based on the first and second quantitative or qualitative indications.

In at least some aspects, receiving a first response including receiving the first response from a clinician or patient. In at least some aspects, receiving a first response including receiving the first response from a sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments of the present invention are described with reference to the following drawings. In the drawings, like reference numerals refer to like parts throughout the various figures unless otherwise specified.

For a better understanding of the present invention, reference will be made to the following Detailed Description, which is to be read in association with the accompanying drawings, wherein:

FIG. 1 is a schematic view of one embodiment of an electrical stimulation system;

FIG. 2 is a schematic side view of one embodiment of an electrical stimulation lead;

FIG. 3 is a schematic block diagram of one embodiment of a system for determining stimulation parameters;

FIG. 4A is a flowchart of one embodiment of a method for programming electrical stimulation of a patient;

FIG. 4B is a flowchart of additional steps that can be added to the flowchart of FIG. 4A;

FIG. 5A is a flowchart of another embodiment of a method for programming electrical stimulation of a patient;

FIG. 5B is a flowchart of additional steps that can be added to the flowchart of FIG. 5A;

FIG. 6A is a flowchart of a third embodiment of a method for programming electrical stimulation of a patient;

FIG. 6B is a flowchart of additional steps that can be added to the flowchart of FIG. 6A;

FIG. 7 is a flowchart of one embodiment of a method obtaining stimulation parameters that can be used in conjunction with the flowcharts of FIGS. 4A to 6B; and

FIG. 8 is a flowchart of one embodiment of a method generate a graph of response to stimulations that can be used in conjunction with the flowcharts of FIGS. 4A to 6B.

DETAILED DESCRIPTION

The present disclosure is directed to the area of implantable electrical stimulation systems and methods of making and using the systems. The present disclosure is also directed to electrical stimulation systems with multiple modes, such as anodic or cathodic stimulation modes, and methods of making and using.

Suitable implantable electrical stimulation systems include, but are not limited to, a least one lead with one or more electrodes disposed on a distal end of the lead and one or more terminals disposed on one or more proximal ends of the lead. Leads include, for example, percutaneous leads, paddle leads, cuff leads, or any other arrangement of electrodes on a lead. Examples of electrical stimulation systems with leads are found in, for example, U.S. Patents Nos. 6,181,969; 6,516,227; 6,609,029; 6,609,032; 6,741,892; 7,244,150; 7,450,997; 7,672,734;7,761,165; 7,783,359; 7,792,590; 7,809,446; 7,949,395; 7,974,706; 8,175,710; 8,224,450; 8,271,094; 8,295,944; 8,364,278; 8,391,985; and 8,688,235; and U.S. Patent Applications Publication Nos. 2007/0150036; 2009/0187222; 2009/0276021; 2010/0076535; 2010/0268298; 2011/0005069; 2011/0004267; 2011/0078900; 2011/0130817; 2011/0130818; 2011/0238129; 2011/0313500; 2012/0016378; 2012/0046710; 2012/0071949; 2012/0165911; 2012/0197375; 2012/0203316; 2012/0203320; 2012/0203321; 2012/0316615; 2013/0105071; and 2013/0197602, all of which are incorporated by reference. In the discussion below, a percutaneous lead will be exemplified, but it will be understood that the methods and systems described herein are also applicable to paddle leads and other leads.

A percutaneous lead for electrical stimulation (for example, deep brain or spinal cord stimulation) includes stimulation electrodes that can be ring electrodes, segmented electrodes that extend only partially around the circumference of the lead, or any other type of electrode, or any combination thereof. The segmented electrodes can be provided in sets of electrodes, with each set having electrodes circumferentially distributed about the lead at a particular longitudinal position. For illustrative purposes, the leads are described herein relative to use for deep brain stimulation, but it will be understood that any of the leads can be used for applications other than deep brain stimulation, including spinal cord stimulation, peripheral nerve stimulation, or stimulation of other nerves, muscles, and tissues. In particular, stimulation may stimulate specific targets. Examples of such targets include, but are not limited to, the subthalamic nucleus (STN), internal segment of the globus pallidus (GPi), external segment of the globus pallidus (GPe), and the like. In at least some embodiments, an anatomical structure is defined by its physical structure and a physiological target is defined by its functional attributes. In at least one of the various embodiments, the lead may be positioned at least partially within the target, but in other embodiments, the lead may be near, but not inside, the target.

Turning to Figure 1, one embodiment of an electrical stimulation system 10 includes one or more stimulation leads 12 and an implantable pulse generator (IPG) 14.

The system 10 can also include one or more of an external remote control (RC) 16, a clinician's programmer (CP) 18, an external trial stimulator (ETS) 20, or an external charger 22.

The IPG 14 is physically connected, optionally via one or more lead extensions 24, to the stimulation lead(s) 12. Each lead carries multiple electrodes 26 arranged in an array. The IPG 14 includes pulse generation circuitry that delivers electrical stimulation energy in the form of, for example, a pulsed electrical waveform (i.e., a temporal series of electrical pulses) to the electrode array 26 in accordance with a set of stimulation parameters. The IPG 14 can be implanted into a patient’s body, for example, below the patient’s clavicle area or within the patient’s buttocks or abdominal cavity. The IPG 14 can have eight stimulation channels which may be independently programmable to control the magnitude of the current stimulus from each channel. In at least some embodiments, the IPG 14 can have more or fewer than eight stimulation channels (for example, 4-, 6-, 16-, 32-, or more stimulation channels). The IPG 14 can have one, two, three, four, or more connector ports, for receiving the terminals of the leads.

The ETS 20 may also be physically connected, optionally via the percutaneous lead extensions 28 and external cable 30, to the stimulation leads 12. The ETS 20, which may have similar pulse generation circuitry as the IPG 14, also delivers electrical stimulation energy in the form of, for example, a pulsed electrical waveform to the electrode array 26 in accordance with a set of stimulation parameters. One difference between the ETS 20 and the IPG 14 is that the ETS 20 is often a non-implantable device that is used on a trial basis after the neurostimulation leads 12 have been implanted and prior to implantation of the IPG 14, to test the responsiveness of the stimulation that is to be provided. Any functions described herein with respect to the IPG 14 can likewise be performed with respect to the ETS 20.

The RC 16 may be used to telemetrically communicate with or control the IPG 14 or ETS 20 via a uni- or bi-directional wireless communications link 32. Once the IPG 14 and neurostimulation leads 12 are implanted, the RC 16 may be used to telemetrically communicate with or control the IPG 14 via a uni- or bi-directional communications link 34. Such communication or control allows the IPG 14 to be turned on or off and to be programmed with different stimulation parameter sets. The IPG 14 may also be operated to modify the programmed stimulation parameters to actively control the characteristics of the electrical stimulation energy output by the IPG 14. The CP 18 allows a user, such as a clinician, the ability to program stimulation parameters for the IPG 14 and ETS 20 in the operating room and in follow-up sessions.

The CP 18 may perform this function by indirectly communicating with the IPG 14 or ETS 20, through the RC 16, via a wireless communications link 36. Alternatively, the CP 18 may directly communicate with the IPG 14 or ETS 20 via a wireless communications link (not shown). The stimulation parameters provided by the CP 18 are also used to program the RC 16, so that the stimulation parameters can be subsequently modified by operation of the RC 16 in a stand-alone mode (i.e., without the assistance of the CP 18).

For purposes of brevity, the details of the RC 16, CP 18, ETS 20, and external charger 22 will not be further described herein. Details of exemplary embodiments of these devices are disclosed in U.S. Pat. No. 6,895,280, which is expressly incorporated herein by reference. Other examples of electrical stimulation systems can be found at U.S. Patents Nos. 6,181,969; 6,516,227; 6,609,029; 6,609,032; 6,741,892; 7,949,395; 7,244,150; 7,672,734; and 7,761,165; 7,974,706; 8,175,710; 8,224,450; and 8,364,278; and U.S. Patent Application Publication No. 2007/0150036, as well as the other references cited above, all of which are incorporated by reference.

Figure 2 illustrates one embodiment of a lead 100 with electrodes 125 disposed at least partially about a circumference of the lead 100 along a distal end portion of the lead 100 and terminals 135 disposed along a proximal end portion of the lead 100.
The lead 100 can be implanted near or within the desired portion of the body to be stimulated such as, for example, the brain, spinal cord, or other body organs or tissues. In one example of operation for deep brain stimulation, access to the desired position in the brain can be accomplished by drilling a hole in the patient's skull or cranium with a cranial drill (commonly referred to as a burr), and coagulating and incising the dura mater, or brain covering. The lead 100 can be inserted into the cranium and brain tissue with the assistance of a stylet (not shown). The lead 100 can be guided to the target location within the brain using, for example, a stereotactic frame and a microdrive motor system. In at least some embodiments, the microdrive motor system can be fully or partially automatic. The microdrive motor system may be configured to perform one or

more the following actions (alone or in combination): insert the lead 100, advance the lead 100, retract the lead 100, or rotate the lead 100.

In at least some embodiments, measurement devices coupled to the muscles or other tissues stimulated by the target neurons, or a unit responsive to the patient or clinician, can be coupled to the IPG 14 or microdrive motor system. The measurement device, user, or clinician can indicate a response by the target muscles or other tissues to the stimulation or recording electrode(s) to further identify the target neurons and facilitate positioning of the stimulation electrode(s). For example, if the target neurons are directed to a muscle experiencing tremors, a measurement device can be used to observe the muscle and indicate changes in, for example, tremor frequency or amplitude in response to stimulation of neurons. Alternatively, the patient or clinician can observe the muscle and provide feedback.

The lead 100 for deep brain stimulation can include stimulation electrodes, recording electrodes, or both. In at least some embodiments, the lead 100 is rotatable so that the stimulation electrodes can be aligned with the target neurons after the neurons have been located using the recording electrodes.

Stimulation electrodes may be disposed on the circumference of the lead 100 to stimulate the target neurons. Stimulation electrodes may be ring-shaped so that current projects from each electrode equally in every direction from the position of the electrode along a length of the lead 100. In the embodiment of Figure 2, two of the electrodes 125 are ring electrodes 120. Ring electrodes typically do not enable stimulus current to be directed from only a limited angular range around a lead. Segmented electrodes 130, however, can be used to direct stimulus current to a selected angular range around a lead. When segmented electrodes are used in conjunction with an implantable pulse generator that delivers constant current stimulus, current steering can be achieved to more precisely deliver the stimulus to a position around an axis of a lead (i.e., radial positioning around the axis of a lead). To achieve current steering, segmented electrodes can be utilized in addition to, or as an alternative to, ring electrodes.

The lead 100 includes a lead body 110, terminals 135, one or more ring electrodes 120, and one or more sets of segmented electrodes 130 (or any other combination of electrodes). The lead body 110 can be formed of a biocompatible, non-conducting material such as, for example, a polymeric material. Suitable polymeric materials include, but are not limited to, silicone, polyurethane, polyurea, polyurethane-urea, polyethylene, or the like. Once implanted in the body, the lead 100 may be in contact with body tissue for extended periods of time. In at least some embodiments, the lead 100 has a cross-sectional diameter of no more than 1.5 mm and may be in the range of 0.5 to 1.5 mm. In at least some embodiments, the lead 100 has a length of at least 10 cm and the length of the lead 100 may be in the range of 10 to 70 cm.

The electrodes 125 can be made using a metal, alloy, conductive oxide, or any other suitable conductive biocompatible material. Examples of suitable materials include, but are not limited to, platinum, platinum iridium alloy, iridium, titanium, tungsten, palladium, palladium rhodium, or the like. Preferably, the electrodes 125 are made of a material that is biocompatible and does not substantially corrode under expected operating conditions in the operating environment for the expected duration of use.

Each of the electrodes 125 can either be used or unused (OFF). When an electrode is used, the electrode can be used as an anode or cathode and carry anodic or cathodic current. In some instances, an electrode might be an anode for a period of time and a cathode for a period of time.

Deep brain stimulation leads may include one or more sets of segmented electrodes. Segmented electrodes may provide for superior current steering than ring electrodes because target structures in deep brain stimulation are not typically symmetric about the axis of the distal electrode array. Instead, a target may be located on one side of a plane running through the axis of the lead. Through the use of a radially segmented electrode array (“RSEA”), current steering can be performed not only along a length of the lead but also around a circumference of the lead. This provides precise three-dimensional targeting and delivery of the current stimulus to neural target tissue, while potentially avoiding stimulation of other tissue. Examples of leads with segmented electrodes include U.S. Patents Nos. 8,473,061; 8,571,665; and 8,792,993; U.S. Patent Application Publications Nos. 2010/0268298; 2011/0005069; 2011/0130803; 2011/0130816; 2011/0130817; 2011/0130818; 2011/0078900; 2011/0238129; 2012/0016378; 2012/0046710; 2012/0071949; 2012/0165911; 2012/197375; 2012/0203316; 2012/0203320; 2012/0203321; 2013/0197424; 2013/0197602; 2014/0039587; 2014/0353001; 2014/0358208; 2014/0358209; 2014/0358210;

2015/0045864; 2015/0066120; 2015/0018915; 2015/0051681; U.S. Patent Applications Serial Nos. 14/557,211 and 14/286,797; and U.S. Provisional Patent Application Serial No. 62/113,291, all of which are incorporated herein by reference.

Figure 3 illustrates one embodiment of a system for practicing the invention. The system can include a computing device 300 or any other similar device that includes a processor 302 and a memory 304, a display 306, an input device 308, and, optionally, an electrical stimulation system 312. The system 300 may also optionally include one or more imaging systems 310.

The computing device 300 can be a computer, tablet, mobile device, or any other suitable device for processing information. The computing device 300 can be local to the user or can include components that are non-local to the computer including one or both of the processor 302 or memory 304 (or portions thereof). For example, in at least some embodiments, the user may operate a terminal that is connected to a non-local computing device. In other embodiments, the memory can be non-local to the user.

The computing device 300 can utilize any suitable processor 302 and the term “a processor” can include one or more hardware processors within the computing device or other components of the system or may be local to the user or non-local to the user or other components of the computing device. The processor 302 is configured to execute instructions provided to the processor 302, as described below.

Any suitable memory 304 can be used for the computing device 302. The memory 304 illustrates a type of computer-readable media, namely computer-readable storage media. Computer-readable storage media may include, but is not limited to, nonvolatile, non-transitory, removable, and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data. Examples of computer-readable storage media include RAM, ROM, EEPROM, flash memory, or other memory technology, CD-ROM, digital versatile disks (“DVD”) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by a computing device.

Communication methods provide another type of computer readable media; namely communication media. Communication media typically embodies computer-readable instructions, data structures, program modules, or other data in a modulated data signal such as a carrier wave, data signal, or other transport mechanism and include any information delivery media. The terms “modulated data signal,” and “carrier-wave signal” includes a signal that has one or more of its characteristics set or changed in such a manner as to encode information, instructions, data, and the like, in the signal. By way of example, communication media includes wired media such as twisted pair, coaxial cable, fiber optics, wave guides, and other wired media and wireless media such as acoustic, RF, infrared, and other wireless media.

The display 306 can be any suitable display device, such as a monitor, screen, display, or the like, and can include a printer. The input device 308 can be, for example, a keyboard, mouse, touch screen, track ball, joystick, voice recognition system, or any combination thereof, or the like.

One or more imaging systems 310 can be used including, but not limited to, MRI, computed tomography (CT), ultrasound, or other imaging systems. The imaging system 310 may communicate through a wired or wireless connection with the computing device 300 or, alternatively or additionally, a user can provide images from the imaging system 310 using a computer-readable medium or by some other mechanism.

The electrical stimulation system 312 can include, for example, any of the components illustrated in Figure 1. The electrical stimulation system 312 may communicate with the computing device 300 through a wired or wireless connection or, alternatively or additionally, a user can provide information between the electrical stimulation system 312 and the computing device 300 using a computer-readable medium or by some other mechanism. In at least some embodiments, the computing device 300 may include part of the electrical stimulation system, such as, for example, the IPG 14, CP 18, RC 16, ETS 20, or any combination thereof.

The methods and systems described herein may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Accordingly, the methods and systems described herein may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. Systems referenced herein typically include memory and typically include methods for communication with other devices including mobile devices. Methods of communication can include both wired and wireless (for example, RF, optical, or infrared) communications methods and such methods provide another type of computer readable media; namely communication media. Wired communication can include communication over a twisted pair, coaxial cable, fiber optics, wave guides, or the like, or any combination thereof. Wireless communication can include RF, infrared, acoustic, near field communication, Bluetooth™, or the like, or any combination thereof.

Stimulation therapy can be used to treat a number of diseases, disorders, and conditions including, but not limited to, pain, Parkinson's Disease, Alzheimer's Disease, essential tremor, epilepsy, dystonia, depression, obsessive-compulsive disorder, addiction, Tourette's syndrome, eating disorders (such as anorexia, bulimia, or obesity), other neurological diseases and disorders, or the like. To provide a stimulation therapy, the stimulation parameters for the therapy may be determined during a programming session. In at least some embodiments, in a programming session a clinician will vary stimulation parameters and measure the resulting stimulation effects or side effects. For example, a score can be associated with any stimulation effect or side effect associated with the set of stimulation parameters. For example, in a patient afflicted with Parkinson's Disease, the score may be based on any suitable rating scale (for example, the Unified Parkinson's Disease Rating Scale (UPDRS)).

In many electrical stimulation systems, cathodic stimulation is used to stimulate patient tissue. Cathodic stimulation is known to preferentially activate neural fibers near the cathode or cathodes. In contrast to cathodic stimulation, anodic stimulation (e.g., stimulation near an anode) can activate different neural elements, such as neural cells. Moreover, the threshold for stimulation of many neural elements is different for anodic and cathodic stimulation. As an example, U.S. Patent No. 6,560,490, incorporated herein by reference in its entirety, demonstrates in Figures 1 and 2 that cathodic stimulation activates nerve fibers at much lower stimulation amplitudes than neuronal cells. In contrast, anodic stimulation activates neuronal cells at lower stimulation amplitudes than nerve fibers.

Because anodic stimulation activates neural tissue differently from cathodic stimulation, it may be difficult to know which type of stimulation may best produce desired therapeutic effects or best avoid undesirable side-effects. Systems can be programmed with methods to facilitate selection of beneficial programming using cathodic or anodic stimulation or any combination thereof. Embodiment of such systems can include, for example, the system illustrated in Figure 3, the CP 18 or RC 16 of Figure 1, or any other suitable system or device.

In many instances, for monopolar cathodic stimulation, the anode of the electrical stimulation system is located on the case of the implantable pulse generator or at another site relatively distant from the cathode or cathodes on the lead. Monopolar cathodic stimulation may also include instances where the anode is distributed over a large number of (for example, at least four, five, six, seven, or more) electrodes on the lead or where the anode is positioned on the lead at a substantial distance away from the cathode (for example, the anode is near the proximal end of the array of electrodes and the cathode is near the proximal end of the electrodes.) Similarly, monopolar anodic stimulation may include instances where the cathode of the electrical stimulation system is located on the case of the implantable pulse generator or at another site relatively distant from the anode or anodes on the lead or instances where the cathode is distributed over a large number of (for example, at least four, five, six, seven, or more) electrodes on the lead or where the cathode is positioned on the lead at a substantial distance away from the anode (for example, the anode is near the proximal end of the array of electrodes and the cathode is near the proximal end of the electrodes.) Another method for identifying the anodic or cathodic nature of stimulation can be found in U.S. Patent No. 8,190,250, incorporated herein by reference in its entirety, which observes the angle of an electric field at particular points with respect to the lead.

Figure 4A illustrates one method of selecting stimulation parameters for an electrical stimulation system. In step 402, responses are received for multiple monopolar stimulations performed using a subset of one or more electrodes of a lead as a cathode for each of the monopolar stimulations. In at least some embodiments, other stimulation parameters, such as stimulation amplitude, pulse width, and pulse duration, may be the same for all of the stimulations. In other embodiments, other stimulation parameters, such as stimulation amplitude, pulse width, and pulse duration, may be different for at least some of the stimulations. For example, if a particular stimulation is painful or generates unacceptable side effects, the stimulation amplitude may be reduced and stimulation using the same electrode(s) may be performed with the reduced stimulation amplitude.

The responses to stimulation can be any quantitative or qualitative assessment of the stimulation itself, one or more therapeutic effects, or one or more side-effects, or any combination thereof. For example, the response may include a rating of the stimulation itself on a scale of numbers or qualitative scale (e.g., ineffective, good, poor, unacceptable). As another example, the response may include a rating of one or more beneficial therapeutic effects or side-effects on a scale of numbers or qualitative scale. If more than one effect is rated, the rating may be an overall rating or there may be multiple ratings for each effect. The response may be from the programmer or other clinician directing the stimulations or from the patient or from one or more sensors or other device that monitor the patient or from any combination of these sources.

In step 404, the responses are evaluated and, based on the responses, one or more electrodes are selected for cathodic stimulation. Any suitable criteria can be used. For example, the electrode(s) which provided the most beneficial therapeutic effect may be selected. As another example, the electrode(s) that provided the most beneficial therapeutic effect with no side-effects (or with side-effects below a selected threshold) may be selected.

In step 406, responses are received for multiple monopolar stimulations performed using a subset of one or more electrodes of a lead as an anode for each of the monopolar stimulations. The responses may be assessed using the same or a different assessment as those in step 402. In some embodiments, the stimulation parameters used for the stimulations of step 402 are also used in step 406. In other embodiments, different stimulation parameters (for example, a different stimulation amplitude, pulse width, or pulse duration, or any combination thereof) may be used due to the differences in neural activation between anodic and cathodic stimulation.

The monopolar stimulations in steps 402 and 406 may be performed in any order and may be intermingled. For example, the monopolar stimulations in step 402 may be performed first followed by the monopolar stimulations in step 406. In another example, the monopolar stimulations in step 406 may be performed first followed by the monopolar stimulations in step 402. In yet another example, one or more monopolar stimulations in step 402 may be performed followed by one or more monopolar stimulations in step 406 followed by further monopolar stimulation(s) in step 402, and so on. For example, cathodic stimulation using a particular subset of one or more electrodes can be performed in step 402 followed by anodic stimulation using the same subset of one or more electrodes in step 406 and this pattern can be repeated for multiple different subsets of one or more electrodes.

In step 408, these responses are evaluated and, based on the responses, one or more electrodes are selected for anodic stimulation. The criteria used for selecting the one or more electrodes may be the same or different as those in step 404.

In some embodiments, the steps 406' and 408' of Figure 4B can be added one or more times after step 408. In step 406', responses are received for multiple bipolar or multipolar stimulations utilizing both anodic and cathodic stimulation (i.e., cathodic/anodic stimulation). In step 408', these responses are evaluated and, based on the responses, one or more electrodes are selected for cathodic/anodic stimulation. In such instances, multiple electrodes (one or more anodes and one or more cathodes) will be used to provide the stimulation. For example, steps 406' and 408' may be performed using a combination of 50% anodic and 50% cathodic stimulation, or 25% anodic and 75% cathodic, or any other combination. Steps 406' and 408' may be performed one, two, three, four, or more times using different relative amounts of anodic and cathodic stimulation. It will be understood that that the relative strengths of anode and cathode on the lead can be different, and this may be accomplished by putting some current of one polarity at the case or housing of the IPG (or other distant location). The sum of the currents for a given polarity must be equal to the sum of the currents for the other polarity.

Returning to Figure 4A, in step 410, the selected electrode(s) of step 404 or the selected electrode(s) of step 408 (or, optionally, any selected electrode(s) from one or more instances of step 408' of Figure 4B) is selected as programming electrode(s). Any criteria can be used for selecting between the electrode(s) identified in steps 404 and 408 (and, optionally, any selected electrode(s) from one or more instances of step 408' of Figure 4B). For example, the electrode(s) which provided the most beneficial therapeutic effect may be selected. As another example, the electrode(s) that provided the most beneficial therapeutic effect with no side-effects (or with side-effects below a selected threshold) may be selected.

In step 412, responses are received for stimulations performed using the programming electrode(s) selected in step 410 at a series of different stimulation amplitudes.

In step 414, a programming stimulation amplitude is selected based on the responses received in step 412. Any criteria can be used for selecting the programming stimulation amplitude. For example, the stimulation amplitude that provided the most beneficial therapeutic effect with no side-effects (or with side-effects below a selected threshold) may be selected.

In some embodiments, steps 412 and 414 may be repeated for other stimulation parameters in place of stimulation amplitude. For example, in some embodiments, steps 412 and 414 may be repeated for pulse width instead of stimulation amplitude. In some embodiments, steps 412 and 414 may be repeated for pulse duration or pulse rate instead of stimulation amplitude. Any subset of additional stimulation parameters may be titrated and selected using the procedure of steps 412 and 414; typically, with previously selected stimulation parameters being held at their selected value.

In step 416, the system is directed to program the implantable pulse generator. In at least some embodiments, this direction may be automatic upon selecting the electrodes and stimulation amplitude (and, optionally, other stimulation parameter(s)). In some embodiments, the direction is made by a clinician, programmer, or other user.

In step 418, a signal is initiated by the system to program the implantable pulse generator with stimulation parameters including the programming electrode(s) and programming stimulation amplitude (and, optionally, other stimulation parameter(s)). The implantable pulse generator can then use this programming to stimulate the patient through the attached lead and electrodes.

Figure 5A illustrates one method of selecting stimulation parameters for an electrical stimulation system. In step 502, responses are received for multiple first stimulations performed using different subsets of one or more electrodes of a lead. The first stimulations are selected to preferentially stimulate a first type of neural element.

Examples types of neural elements include fibers, cells, neuron terminals, synapses, or neurons with different biophysical properties (such as specific ion channel properties), or the like. Other types may be more specific including, for example, large fibers small fibers, specific types of cells, and the like. The type of neural element may be based on the trajectory of the neural element relative to the lead. For example, one type may be fibers aligned parallel to the lead and another type may be fibers aligned perpendicular to the lead. Such trajectories may be defined by ranges of angles or other geometrical properties.

Preferential stimulation may be based on a variety of factors such as, for example, the geometry of the electrodes (for example, using electrodes near tissue having a relatively high concentration of the particular neural element) or may include stimulation polarity (for example, anodic or cathodic), pulse width, pulse rate, stimulation amplitude, or other electrical factors. As example, cathodic stimulation may activate fibers preferentially with respect to neural cells. Conversely, anodic stimulation may activate neural cells preferentially with respect to fibers.

In at least some embodiments, other stimulation parameters, such as stimulation amplitude, pulse width, and pulse duration, may be the same for all of the stimulations. In other embodiments, other stimulation parameters, such as stimulation amplitude, pulse width, and pulse duration, may be different for at least some of the stimulations. For example, if a particular stimulation is painful or generates unacceptable side effects, the stimulation amplitude may be reduced and stimulation using the same electrode(s) may be performed with the reduced stimulation amplitude.

The responses to stimulation can be any quantitative or qualitative assessment of the stimulation itself, one or more therapeutic effects, or one or more side-effects, or any combination thereof. For example, the response may include a rating of the stimulation itself on a scale of numbers or qualitative scale (e.g., ineffective, good, poor, unacceptable). As another example, the response may include a rating of one or more beneficial therapeutic effects or side-effects on a scale of numbers or qualitative scale. If more than one effect is rated, the rating may be an overall rating or there may be multiple ratings for each effect. The response may be from the programmer or other clinician directing the stimulations or from the patient or from one or more sensors or other device that monitor the patient or from any combination of these sources.

In step 504, the responses are evaluated and, based on the responses, one or more electrodes are selected for preferential stimulation of the first type of neural element. Any suitable criteria can be used. For example, the electrode(s) which provided the most beneficial therapeutic effect may be selected. As another example, the electrode(s) that provided the most beneficial therapeutic effect with no side-effects (or with side-effects below a selected threshold) may be selected.

In step 506, responses are received for multiple second stimulations performed using different subsets of one or more electrodes of a lead. The second stimulations are selected to preferentially stimulate a second type of neural element that is different from the first type of neural element. The responses may be assessed using the same or a different assessment as those in step 502. In some embodiments, the stimulation parameters used for the stimulations of step 502 are also used in step 506. In other embodiments, different stimulation parameters (for example, a different stimulation amplitude, pulse width, or pulse duration, or any combination thereof) may be used due to the differences in neural activation between stimulation of the first and second types of neural elements.

The monopolar stimulations in steps 502 and 506 may be performed in any order and may be intermingled. For example, the stimulations in step 502 may be performed first followed by the stimulations in step 506. In another example, the stimulations in step 506 may be performed first followed by the stimulations in step 502. In yet another example, one or more stimulations in step 502 may be performed followed by one or more stimulations in step 506 followed by further stimulation(s) in step 502, and so on. For example, preferential stimulation of the first type of neural element using a particular subset of one or more electrodes can be performed in step 502 followed by preferential stimulation of the second type of neural element using the same subset of one or more electrodes in step 506 and this pattern can be repeated for multiple different subsets of one or more electrodes.

In step 508, these responses are evaluated and, based on the responses, one or more electrodes are selected for preferential stimulation of the second type of neural element. The criteria used for selecting the one or more electrodes may be the same or different as those in step 504.

In some embodiments, the steps 506' and 508' of Figure 5B can be performed one, two, three, or more times after step 508. In step 506', responses are received for multiple third (or fourth, fifth, …) stimulations performed using different subsets of one or more electrodes of a lead. The third (or fourth, fifth, …) stimulations are selected to preferentially stimulate a third (or fourth, fifth, …) type of neural element that is different from the first and second (and any other previously selected) types of neural element. The responses may be assessed using the same or different assessment as those in step 502. In step 508', these responses are evaluated and, based on the responses, one or more electrodes are selected for the stimulation of the third (or fourth, fifth, …) type of neural element. The criteria used for selecting the one or more electrodes may be the same or different as those in step 504.

Returning to Figure 5A, in step 510, the selected electrode(s) of step 504 or the selected electrode(s) of step 508 (or, optionally, any selected electrode(s) from one or more instances of step 508' of Figure 5B) is selected as programming electrode(s). Any criteria can be used for selecting between the electrode(s) identified in steps 504 and 508 (and, optionally, any selected electrode(s) from one or more instances of step 508' of Figure 5B). For example, the electrode(s) which provided the most beneficial therapeutic effect may be selected. As another example, the electrode(s) that provided the most beneficial therapeutic effect with no side-effects (or with side-effects below a selected threshold) may be selected.

In step 512, responses are received for stimulations performed using the programming electrode(s) selected in step 510 at a series of different stimulation amplitudes.

In step 514, a programming stimulation amplitude is selected based on the responses received in step 512. Any criteria can be used for selecting the programming stimulation amplitude. For example, the stimulation amplitude that provided the most beneficial therapeutic effect with no side-effects (or with side-effects below a selected threshold) may be selected.

In some embodiments, steps 512 and 514 may be repeated for other stimulation parameters in place of stimulation amplitude. For example, in some embodiments, steps 512 and 514 may be repeated for pulse width instead of stimulation amplitude. In some embodiments, steps 512 and 514 may be repeated for pulse duration or pulse rate instead of stimulation amplitude. Any subset of additional stimulation parameters may be titrated and selected using the procedure of steps 512 and 514; typically, with previously selected stimulation parameters being held at their selected value.

In step 516, the system is directed to program the implantable pulse generator. In at least some embodiments, this direction may be automatic upon selecting the electrodes and stimulation amplitude (and, optionally, other stimulation parameter(s)). In some embodiments, the direction is made by a clinician, programmer, or other user.

In step 518, a signal is initiated by the system to program the implantable pulse generator with stimulation parameters including the programming electrode(s) and programming stimulation amplitude (and, optionally, other stimulation parameter(s)). The implantable pulse generator can then use this programming to stimulate the patient through the attached lead and electrodes.

Figure 6A illustrates one method of selecting stimulation parameters for an electrical stimulation system. In step 602, responses are received for multiple monopolar cathodic stimulations performed using different first sets of stimulation parameters. Each of the cathodic stimulations uses a subset of one or more electrodes of a lead as a cathode as part of the first set of stimulation parameters. The responses to stimulation can be any quantitative or qualitative assessment of the stimulation itself, one or more therapeutic effects, or one or more side-effects, or any combination thereof. For example, the response may include a rating of the stimulation itself on a scale of numbers or qualitative scale (e.g., ineffective, good, poor, unacceptable). As another example, the response may include a rating of one or more beneficial therapeutic effects or side-effects on a scale of numbers or qualitative scale. If more than one effect is rated, the rating may be an overall rating or there may be multiple ratings for each effect. The response may be from the programmer or other clinician directing the stimulations or from the patient or from one or more sensors or other device that monitor the patient or from any combination of these sources.

In step 604, responses are received for multiple monopolar anodic stimulations performed using different second sets of stimulation parameters as part of the first set of stimulation parameters. Each of the anodic stimulations uses a subset of one or more electrodes of a lead as an anode. The responses may be assessed using the same or a different assessment as those in step 602.

The monopolar stimulations in steps 602 and 604 may be performed in any order and may be intermingled. For example, the monopolar stimulations in step 602 may be performed first followed by the monopolar stimulations in step 604. In another example, the monopolar stimulations in step 604 may be performed first followed by the monopolar stimulations in step 602. In yet another example, one or more monopolar stimulations in step 602 may be performed followed by one or more monopolar stimulations in step 604 followed by further monopolar stimulation(s) in step 602, and so on. For example, cathodic stimulation using a particular subset of one or more electrodes can be performed in step 602 followed by anodic stimulation using the same subset of one or more electrodes in step 604 and this pattern can be repeated for multiple different subsets of one or more electrodes.

In some embodiments, the step 604' of Figure 6B can be added one or more times after step 604. In step 604', responses are received for multiple bipolar or multipolar stimulations utilizing both anodic and cathodic stimulation (i.e., cathodic/anodic stimulation). For example, step 604' may be performed using a combination of 50% anodic and 50% cathodic stimulation, or 25% anodic and 75% cathodic, or any other combination. Step 604' may be performed one, two, three, four, or more times using different relative amounts of anodic and cathodic stimulation. It will be understood that that the relative strengths of anode and cathode on the lead can be different, and this may be accomplished by putting some current of one polarity at the case or housing of the IPG (or other distant location). The sum of the currents for a given polarity must be equal to the sum of the currents for the other polarity.

Returning to Figure 6A, in step 606, one of the sets of first or second (or, optionally, third, fourth, fifth, …) stimulation parameters is selected as a program set of stimulation parameters. Any criteria can be used for selecting between the sets of first or second (or, optionally, third, fourth, fifth, …) stimulation parameters. For example, the set of stimulation parameters which provided the most beneficial therapeutic effect may be selected. As another example, the set of stimulation parameters that provided the most beneficial therapeutic effect with no side-effects (or with side-effects below a selected threshold) may be selected.

In step 608, the system is directed to program the implantable pulse generator. In at least some embodiments, this direction may be automatic upon selecting the set of program stimulation parameters. In some embodiments, the direction is made by a clinician, programmer, or other user.

In step 610, a signal is initiated by the system to program the implantable pulse generator with set of program stimulation parameters. The implantable pulse generator can then use this programming to stimulate the patient through the attached lead and electrodes.

During programming sessions, as well as at other times, it can be helpful to visualize the region that will be stimulated. Stimulation region visualization systems and methods can be used to predict or estimate a region of stimulation for a given set of stimulation parameters. In at least some embodiments, the systems and methods further permit a user to modify stimulation parameters and visually observe how such modifications can change the predicted or estimated stimulation region. Such algorithms and systems may provide greater ease of use and flexibility and may enable or enhance stimulation therapy. The terms "stimulation field map" (SFM), "volume of activation" (VOA), or "volume of tissue activated (VTA)" are often used to designate an estimated region of tissue that will be stimulated for a particular set of stimulation parameters. Any suitable method for determining the VOA/SFM/VTA can be used including those described in, for example, U.S. Patents Nos. 8,326,433; 8,379,952; 8,649,845; 8,675,945; 8,831,731; 8,849,632; 8,855,773; 8,913,804; 8,918,183; 8,958,615; 9,026,317; 9,050,470; 9,072,905; 9,081,488; 9,084,896; 9,135,400; 9,235,685; 9,254,387; 9,227,074; 9,272,153; 9,302,110; 9,308,372; 9,310,985; 9,364,665; 9,526,902; 9,586,053; 9,792,412; 9,821,167; 9,925,382; and 9,959,940; U.S. Patent Application Publications Nos. 2009/0287272; 2009/0287273; 2012/0314924; 2013/0116744; 2014/0122379; and 2015/0066111; U.S. Patent Applications Serial Nos. 15/706,004 and 15/937,264; and U.S. Provisional Patent Applications Serial Nos. 62/030,655 and 62/532,869, all of which are incorporated herein by reference in their entireties.

In at least some embodiments, as a precursor or during any of the methods described above (including those methods described using the flowcharts of Figures 4A to 6B), a set of stimulation parameters or a set of electrodes may be determined or suggested using a VOA/SFM/VTA visualization system. In at least some embodiments, a system, such as, for example, the system illustrated in Figure 3, the CP 18 or RC 16 of Figure 1, or any other suitable system or device, can be configured to determine, visualize, or otherwise use VOAs/SFMs/VTAs. In addition to the references cited above, other methods and systems for visualization of VOAs/SFMs/VTAs for anodic and cathodic stimulation are described in U.S. Provisional Patent Application No. 62/663,895 entitled "Systems and Methods for Visualizing and Programming Electrical Stimulation", Attorney Docket No. BSNC-1-699.0, filed on even date herewith, which is incorporated herein by reference in its entirety.

Figure 7 is a flowchart of one embodiment of a method of determining or suggesting a set of stimulation parameters or electrodes. In step 702, a target volume of neural elements is identified. Any suitable method of identification can be used including, but not limited to, methods and systems described in any of the references cited above and U.S. Patents Nos. 8,379,952; 8,649,845; 8,831,731; 8,855,773; 8,913,804; 8,918,183; 9,026,317; 9,050,470; 9,072,905; 9,081,488; 9,084,896; 9,135,400; 9,227,074; 9, 235,685; 9,254,387; 9,272,153; 9,302,110; 9,308,372; 9,310,985; 9,364,665; 9,526,902; 9,586,053; 9,792,412; 9,821,167; 9,925,382; and 9,959,940; U.S. Patent Application Publications Nos. 2016/0375248; 2016/0375258; and 2017/0304633; U.S. Patent Applications Serial Nos. 15/706,004; 15/864,876; and 15/937,264; and U.S. Provisional Patent Applications Serial Nos. 62/030,655 and 62/532,869, all of which are incorporated herein by reference in their entireties.

In step 704, a VOA (or SFM or VTA) is determined that approximates or encompasses the target volume (or at least a threshold amount of the target volume). In at least some embodiments, this determination is performed using a model for the selected type of stimulation (e.g., cathodic, anodic, cathodic/anodic, fiber, cell, or the like or any combination thereof). Any suitable method of determination of a VOA/SFM/VTA can be used including, but not limited to, methods and systems described in any of the references cited above and U.S. Patents Nos. 8,326,433; 8,379,952; 8,649,845; 8,675,945; 8,831,731; 8,849,632; 8,855,773; 8,913,804; 8,918,183; 8,958,615; 9,026,317; 9,050,470; 9,072,905; 9,081,488; 9,084,896; 9,135,400; 9,227,074; 9, 235,685; 9,254,387; 9,272,153; 9,302,110; 9,308,372; 9,310,985; 9,364,665; 9,526,902; 9,586,053; 9,792,412; 9,821,167; 9,925,382; and 9,959,940; U.S. Patent Application Publications Nos. 2009/0287272; 2009/0287273; 2012/0314924; 2013/0116744; 2014/0122379;

2015/0066111; 2016/0375248; 2016/0375258; and 2017/0304633; U.S. Patent Applications Serial Nos. 15/706,004; 15/864,876; and 15/937,264; and U.S. Provisional Patent Applications Serial Nos. 62/030,655 and 62/532,869, all of which are incorporated herein by reference in their entireties.

In step 706, the set of stimulation parameters or set of one or more electrodes of the determined VOA/SFM/VTA is obtained. This set of stimulation parameters or set of one or more electrodes can then be used in the methods described above as one set to test or may be used as a starting point to produce multiple sets to test. In at least some embodiments, the method illustrated in Figure 7 may be performed multiple times for different types of stimulation (e.g., cathodic, anodic, cathodic/anodic, fiber, cell, or the like or any combination thereof).

In at least some embodiments, it is useful to visually graph the stimulation effects (for example, one or more therapeutic effects or side-effects, or any combination thereof) or responses with respect to one or more stimulation parameters such as, for example, electrode selection, stimulation amplitude, or the like, or any combination thereof. Any suitable method and arrangement for graphing stimulation effects can be used including, but not limited to, methods, arrangements, and systems described in U.S. Patents Nos. 9,227,074; 9,358,398; 9,474,903; 9,492,673; 9,643,015; and 9,643,017; U.S. Patent Application Publications Nos. 2014/0277284 and 2017/0100593; U.S. Patent Applications Serial Nos. 15/631,964 and 15/920,153; and U.S. Provisional Patent Application Serial No. 62/532,869, all of which are incorporated herein by reference in their entireties.

As an example, one embodiment of a graph includes a two- or three-dimensional graph with electrode location along one or two dimensions and stimulation amplitude along one or two dimensions. Examples can be found in U.S. Patents Nos. 9,227,074; 9,358,398; 9,474,903; 9,492,673; 9,643,015; and 9,643,017; U.S. Patent Application Publications Nos. 2014/0277284 and 2017/0100593; U.S. Patent Applications Serial Nos. 15/631,964 and 15/920,153; and U.S. Provisional Patent Application Serial No. 62/532,869, all of which are incorporated herein by reference in their entireties. In some embodiments, an inner circle represents the therapeutic effects and an outer ring represents the side-effects with a shading, color, or intensity of the inner circle or outer ring representing the score, value, or intensity of the effect. As a modification of this arrangement, for methods or systems evaluating both anodic or cathodic stimulation using the same electrode, a corresponding marker might include an inner circle and three concentric rings to represent the therapeutic effects of cathodic stimulation, therapeutic effects of anodic stimulation, side-effects of cathodic stimulation, and side-effects of anodic stimulation in any order. As another example of a modification, the inner circle and outer ring may be split in half with one half representing cathodic stimulation and the other half representing anodic stimulation.

In at least some embodiments, during any of the methods described above (including those methods described using the flowcharts of Figures 4A to 6B), a graph of responses to stimulation can be generated. In at least some embodiments, a system, such as, for example, the system illustrated in Figure 3, the CP 18 or RC 16 of Figure 1, or any other suitable system or device, can be configured to generate the graph.

Figure 8 is a flowchart of one embodiment of a method of generating a using a graph of responses to stimulations. In step 802, a graph of responses to the stimulations is generated. Any suitable method, arrangement, or system can be used including, but not limited to, the methods, arrangements, and systems described above in the references cited above.

In step 804, the graph is used to facilitate selection of a set of one or more electrodes or set of stimulation parameters. The graph can provide a useful visualization of the responses to stimulation.

In at least some embodiments, any of the methods described herein, including the methods illustrated in Figures 4A to 6B, may be performed manually. In other embodiments, the methods may be performed using a semi- or wholly automated system. Example of methods for semi- or wholly automating adjustments to stimulation parameters of electrical stimulation systems can be found at, for example, the references cited above and U.S. Patent No. 9,248,280; U.S. Patent Applications Publication Nos. 2016/0136429; 2016/0136443; and 2016/0256693; and U.S. Patent Application Serial No. 15/783,961, all of which are incorporated herein by reference in their entireties. For example, the system may select electrodes and stimulation parameters in automatically or with some feedback from the patient or clinician. In some embodiments, the system may utilize one or more sensors to obtain the response to stimulation and utilize that responses in an automated system to select additional electrodes or stimulation parameters to try or in the selection steps of the methods described above. The optional sensors can be any suitable type of sensor including, but not limited to, optical sensors, piezoelectric sensors, chemical sensors, accelerometers, local field potential sensors, evoked compound action potential (eCAP) sensors, or the like. The sensors may be separate from the implantable pulse generator, lead, or other components of the system or may be disposed on the implantable pulse generator, lead, or other components of the system. The sensors may be identical or may be different (for example, different types of sensors or sensors for different types of chemicals or signals). In at least some embodiments, a sensor can be wire- or wirelessly coupled to an implantable pulse generator, CP, RC, or any other suitable device using wires, leads, Bluetooth™, rf transmission, or any other suitable transmission arrangement.

In some embodiments, the system may select electrodes or generate new stimulator parameter values using machine learning techniques or any other suitable methods including, but not limited to, gradient-descent, genetic algorithms, swarm algorithms, statistical algorithms, brute-force searching, or any of the methods described in U.S. Patent Application Serial No. 15/783,961 or any of the other references cited above, all of which are incorporated by reference in their entirety.

The programming procedure performed in conventional electrical stimulation (such as deep brain or spinal cord stimulation) is often performed in an initial session and, in at least some instances, at later sessions. The methods described herein can be used in this manner.

In other embodiments, the methods described herein, including the methods illustrated in Figures 4A to 6B, can be used in an automated fashion in a feedback loop to monitor a patient and adjust stimulation parameters based on current patient responses. In some embodiments, the methods may be performed periodically; for example, every 1, 2, 4, 8, or 12 hours, or 1, 2, 4, or 7 days, or 2 or 4 weeks or 1 month or any other suitable time interval. In some embodiments, alternatively or additionally, the methods may be performed on user demand for a user such as the patient, clinician, or any other suitable individual. In other embodiments, the methods may be performed continually.

It will be understood that the system can include one or more of the methods described hereinabove with respect to Figures 4A to 8 in any combination. The methods, systems, and units described herein may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Accordingly, the methods, systems, and units described herein may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. The methods described herein can be performed using any type of processor or any combination of processors where each processor performs at least part of the process.

It will be understood that each block of the flowchart illustrations, and combinations of blocks in the flowchart illustrations and methods disclosed herein, can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions, which execute on the processor, create means for implementing the actions specified in the flowchart block or blocks disclosed herein. The computer program instructions may be executed by a processor to cause a series of operational steps to be performed by the processor to produce a computer implemented process. The computer program instructions may also cause at least some of the operational steps to be performed in parallel. Moreover, some of the steps may also be performed across more than one processor, such as might arise in a multi-processor computer system. In addition, one or more processes may also be performed concurrently with other processes, or even in a different sequence than illustrated without departing from the scope or spirit of the invention.

The computer program instructions can be stored on any suitable computer-readable medium including, but not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks ("DVD") or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by a computing device.

The above specification provides a description of the structure, manufacture, and use of the invention. Since many embodiments of the invention can be made without departing from the spirit and scope of the invention, the invention also resides in the claims hereinafter appended.

CLAIMS

What is claimed as new and desired to be protected by Letters Patent of the United States is:

1. A system for programming electrical stimulation of a patient using an implantable electrical stimulation system comprising an implantable pulse generator and a lead having a plurality of electrodes, the system comprising:

a processor configured to:

receive a first response for each of a plurality of first monopolar stimulations performed using a subset of one or more of the electrodes of the lead as a cathode for each of the first monopolar stimulations;

select a first subset of one or more of the electrodes based on the first responses;

receive a second response for each of a plurality of second monopolar stimulations performed using a subset of one or more of the electrodes of the lead as an anode for each of the second monopolar stimulations;

select a second subset of one or more of the electrodes based on the second responses;

select a programming subset of one or more of the electrodes based, at least in part, on the responses associated with the first subset and second subset;

receive a third response for each of a plurality of third monopolar stimulations performed using the programming subset with each of the third monopolar stimulation having a different stimulation amplitude;

select a programming stimulation amplitude based on the third responses;

receive direction to program the implantable pulse generator with the programming subset of one or more of the electrodes and the programming stimulation amplitude; and

initiate a signal that provides the implantable pulse generator of the electrical stimulation system with the programming subset of one or more of the electrodes and the programming stimulation amplitude for generating electrical stimulation for the patient through the electrodes of the lead.

2. The system of claim 1, wherein receiving a first response comprises receiving a first quantitative or qualitative indication of at least one therapeutic effect and receiving a second response comprises receiving a second quantitative or qualitative indication of at least one therapeutic effect.

3. The system of any one of claims 1 or 2, wherein receiving a first response comprises receiving a first quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof and receiving a second response comprises receiving a second quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof.

4. The system of claim 3, wherein selecting the set of program stimulation parameters comprises selecting the set of program stimulation parameters based on the first and second quantitative or qualitative indications.

5. The system of any one of claims 1 to 4, wherein the processor is further configured to:

receive a third response for each of a plurality of cathodic/anodic stimulations performed using a subset of one or more of the electrodes of the lead as an anode and one or more of the electrodes of the lead as a cathode for each of the cathodic/anodic stimulations;

select a third subset of one or more of the electrodes based on the third responses;

wherein selecting the programming subset of one or more of the electrodes comprises selecting the programming subset of one or more of the electrodes based, at least in part, on the first, second, and third responses associated with the first subset, second subset, and third subset.

6. The system of any one of claims 1 to 5, wherein receiving a first response comprising receiving the first response from a clinician or patient.

7. The system of any one of claims 1 to 5, wherein receiving a first response comprising receiving the first response from a sensor.

8. A system for programming electrical stimulation of a patient using an implantable electrical stimulation system comprising an implantable pulse generator and a lead having a plurality of electrodes, the system comprising:

a processor configured to:

receive a first response for each of a plurality of first stimulations performed using a subset of one or more of the electrodes of the lead for each of the first stimulations, wherein the first stimulations are configured to preferentially stimulate a first type of neural element;

select a first subset of one or more of the electrodes based, at least in part, on the first responses;

receive a second response for each of a plurality of second stimulations performed using a subset of one or more of the electrodes for each of the second stimulations, wherein the second stimulations are configured to preferentially stimulate a second type of neural element which is different from the first type of neural element;

select a second subset of one or more of the electrodes based, at least in part, on the second responses;

select a programming subset of one or more of the electrodes based on the responses associated with the first subset and second subset;

receive direction to program the implantable pulse generator with the programming subset of one or more of the electrodes and the programming stimulation amplitude; and

initiate a signal that provides the implantable pulse generator of the electrical stimulation system with the programming subset of one or more of the electrodes and the programming stimulation amplitude for generating electrical stimulation for the patient through the electrodes of the lead.

9. The system of claim 8, wherein receiving a first response comprises receiving a first quantitative or qualitative indication of at least one therapeutic effect and receiving a second response comprises receiving a second quantitative or qualitative indication of at least one therapeutic effect.

10. The system of any one of claims 8 or 9, wherein receiving a first response comprises receiving a first quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof and receiving a second response comprises receiving a second quantitative or qualitative indication of at least one therapeutic effect, at least one side-effect, or any combination thereof.

11. The system of claim 10, wherein selecting the set of program stimulation parameters comprises selecting the set of program stimulation parameters based on the first and second quantitative or qualitative indications.

12. The system of any one of claims 8 to 11, wherein the processor is further configured to:

receive a third response for each of a plurality of third stimulations performed using a subset of one or more of the electrodes for each of the third stimulations, wherein the third stimulations are configured to preferentially stimulate a third type of neural element which is different from the first and second types of neural element;

select a third subset of one or more of the electrodes based, at least in part, on the third responses;

wherein selecting the programming subset of one or more of the electrodes comprises selecting the programming subset of one or more of the electrodes based, at least in part, on the first, second, and third responses associated with the first subset, second subset, and third subset.

13. The system of any one of claims 8 to 12, wherein receiving a first response comprising receiving the first response from a clinician or patient.

14. The system of any one of claims 8 to 13, wherein receiving a first response comprising receiving the first response from a sensor.

15. A system for programming electrical stimulation of a patient using an implantable electrical stimulation system comprising an implantable pulse generator and a lead having a plurality of electrodes, the system comprising:

a processor configured to:

receive a first response for each of a plurality of first monopolar stimulations performed using at least one of the electrodes of the lead as a cathode, each of the first monopolar stimulations having a set of first stimulation parameters associated with the first stimulation;

receive a second response for each of a plurality of second monopolar stimulations performed using at least one of the electrodes of the lead as an anode, each of the second monopolar stimulations having a set of second stimulation parameters associated with the second stimulation;

select, from the sets of first stimulation parameters and sets of second stimulation parameters, a set of program stimulation parameters for a first stimulation program based on the first and second responses;

receive direction to program the implantable pulse generator with the set of program stimulation parameters; and

initiate a signal that provides the implantable pulse generator of the electrical stimulation system with the set of program stimulation parameters for generating electrical stimulation for the patient through the electrodes of the lead.

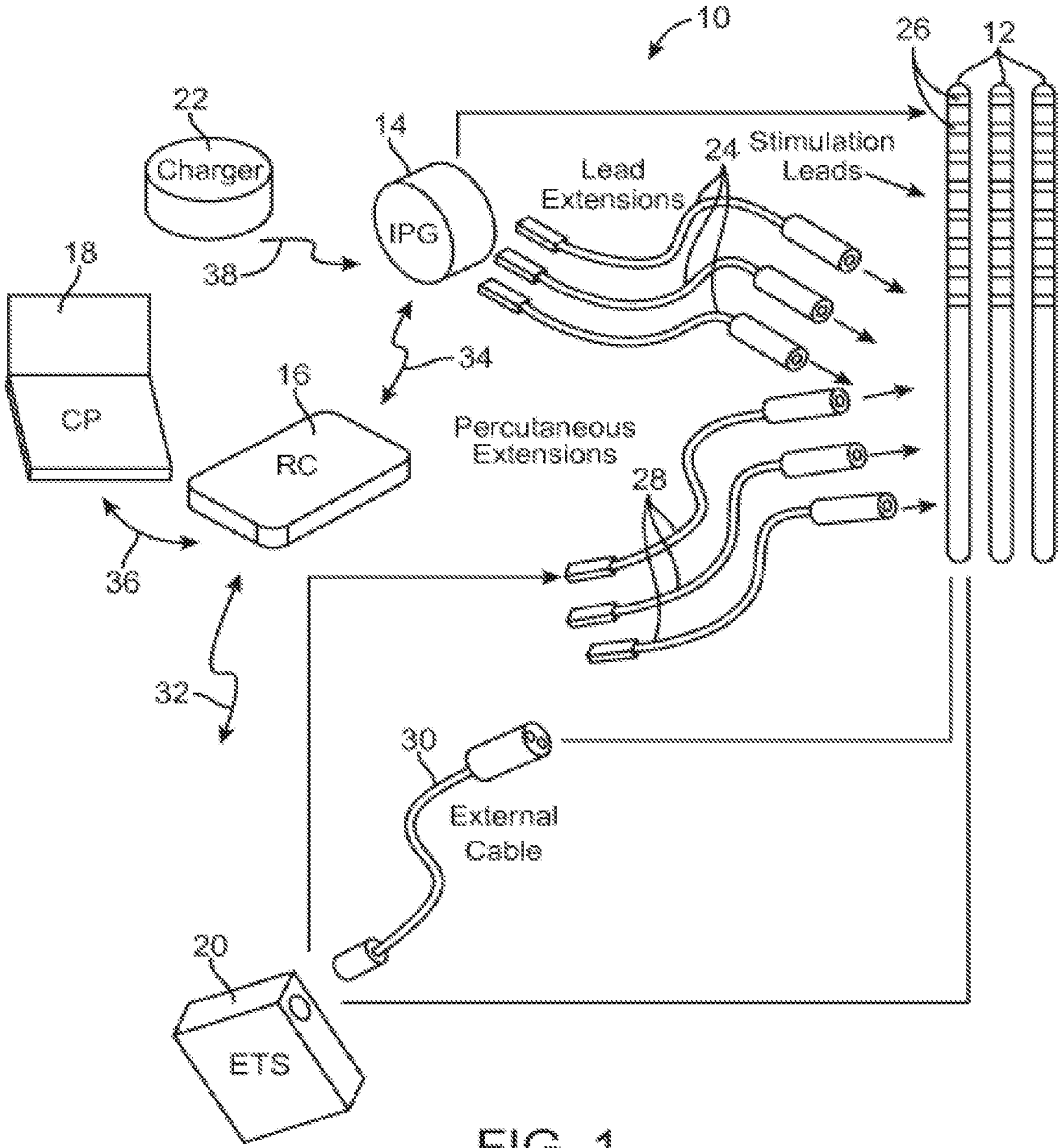
10
26
12
22
Charger
14
24
Stimulation
Leads
Lead
Extensions
IPG
38
18
34
16
CP
RC
Percutaneous
Extensions
28
36
32
30
External
Cable
20
ETS

FIG. 1

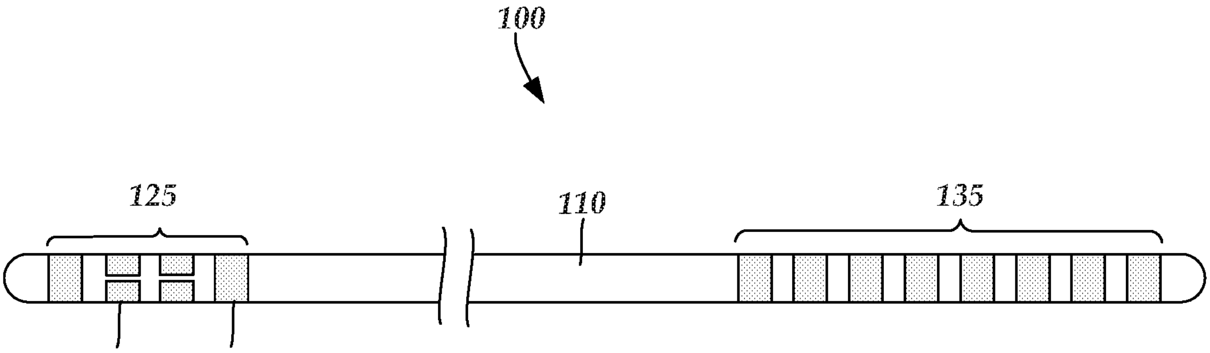
100
125
110
135
130
120

Fig. 2

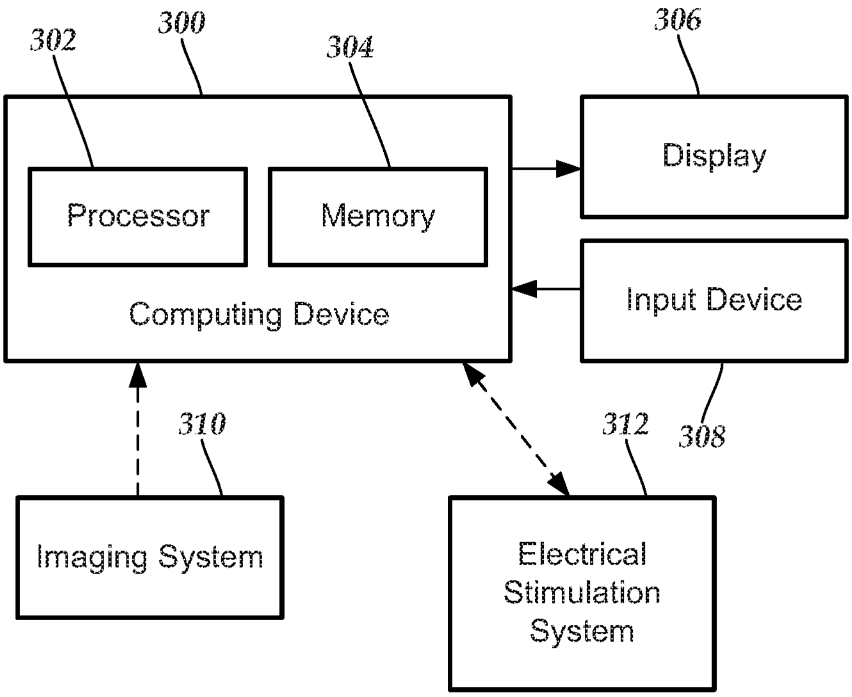
302
300
304
306
Processor
Memory
Computing Device
Display
Input Device
310
312
308
Imaging System
Electrical Stimulation System

Fig. 3

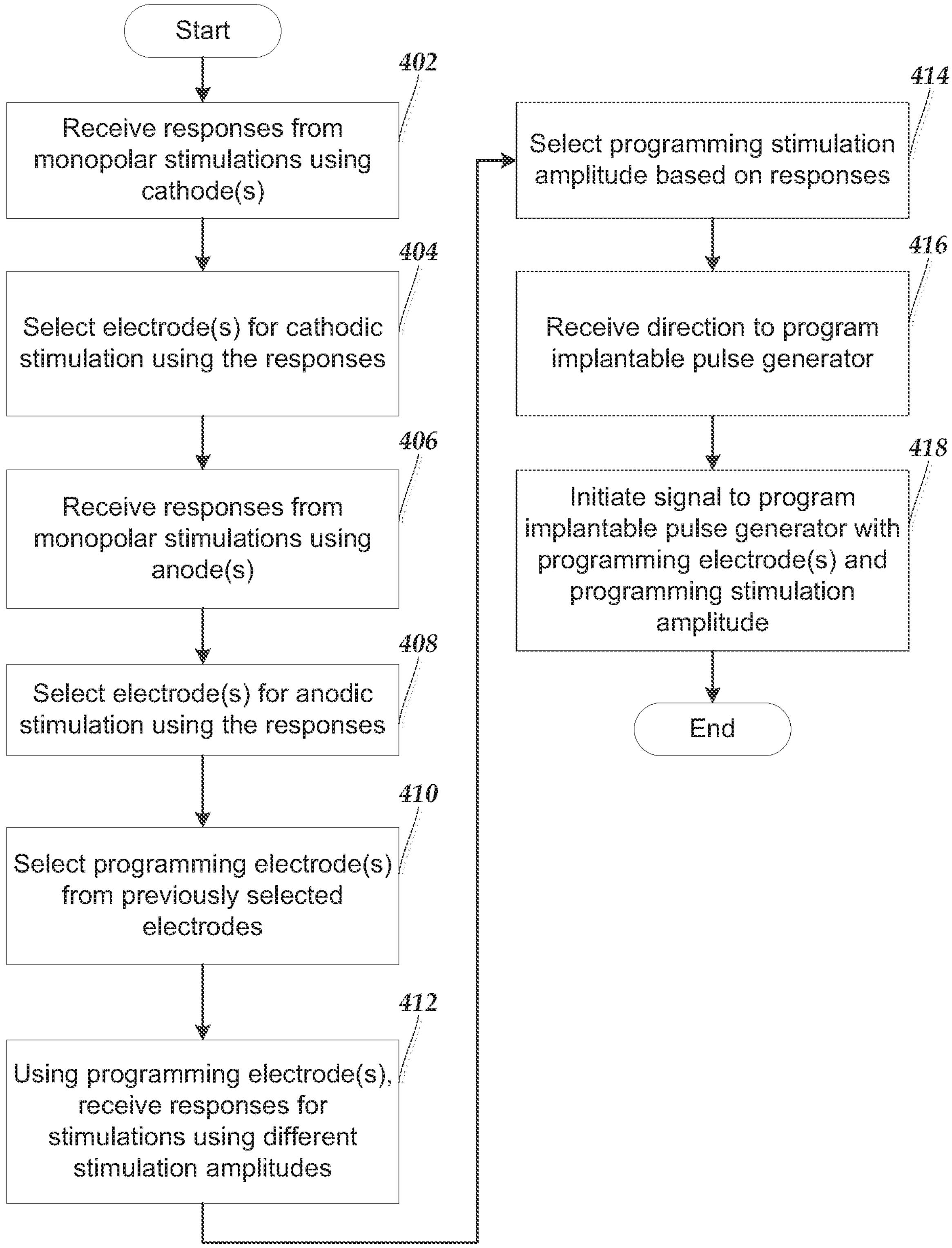
Start
402
Receive responses from monopolar stimulations using cathode(s)
404
Select electrode(s) for cathodic stimulation using the responses
406
Receive responses from monopolar stimulations using anode(s)
408
Select electrode(s) for anodic stimulation using the responses
410
Select programming electrode(s) from previously selected electrodes
412
Using programming electrode(s), receive responses for stimulations using different stimulation amplitudes
414
Select programming stimulation amplitude based on responses
416
Receive direction to program implantable pulse generator
418
Initiate signal to program implantable pulse generator with programming electrode(s) and programming stimulation amplitude
End

Fig. 4A

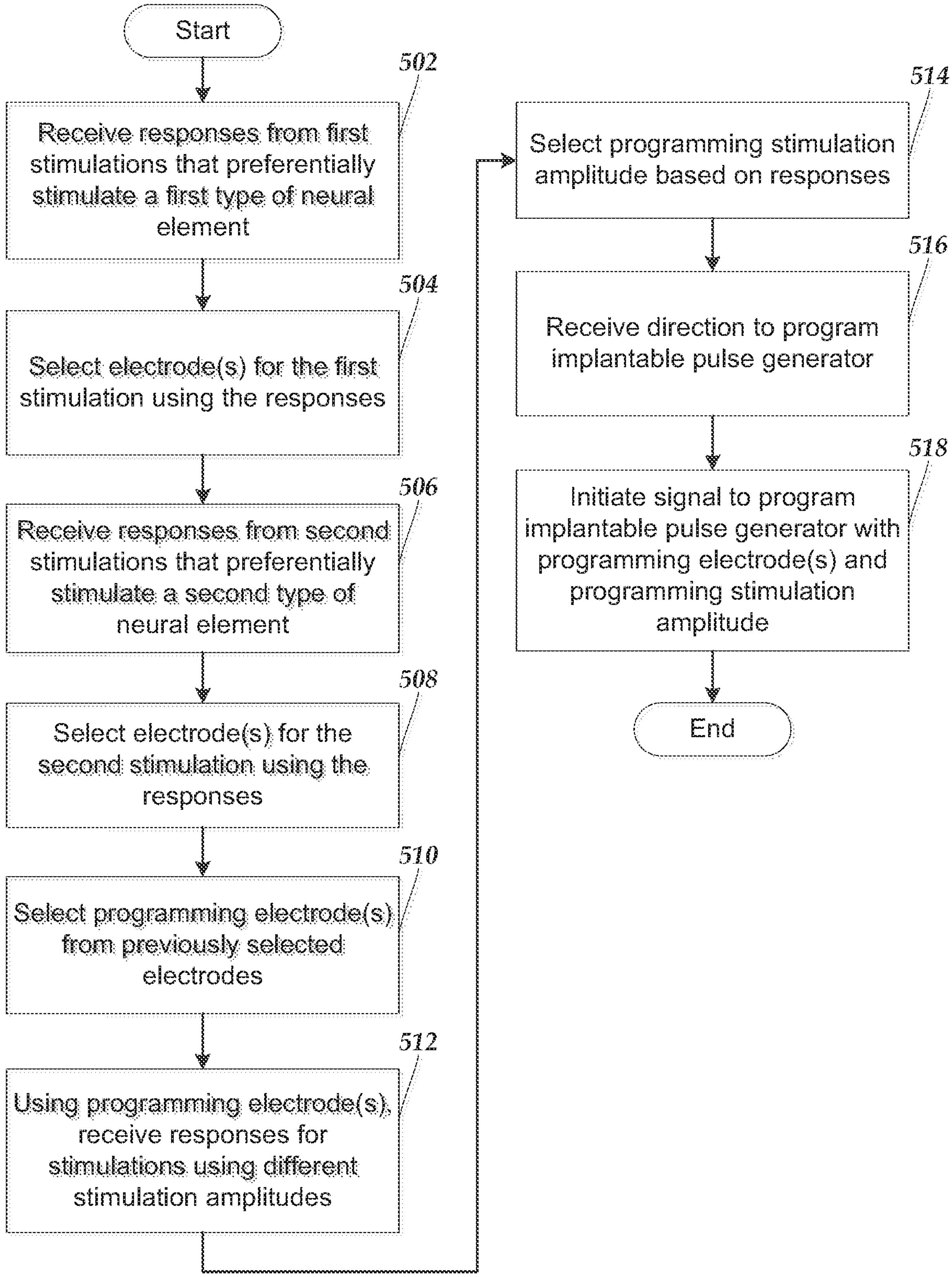
Start
502
Receive responses from first stimulations that preferentially stimulate a first type of neural element
504
Select electrode(s) for the first stimulation using the responses
506
Receive responses from second stimulations that preferentially stimulate a second type of neural element
508
Select electrode(s) for the the second stimulation using the responses
510
Select programming electrode(s) from previously selected electrodes
512
Using programming electrode(s), receive responses for stimulations using different stimulation amplitudes
514
Select programming stimulation amplitude based on responses
516
Receive direction to program implantable pulse generator
518
Initiate signal to program implantable pulse generator with programming electrode(s) and programming stimulation amplitude
End

Fig. 5A

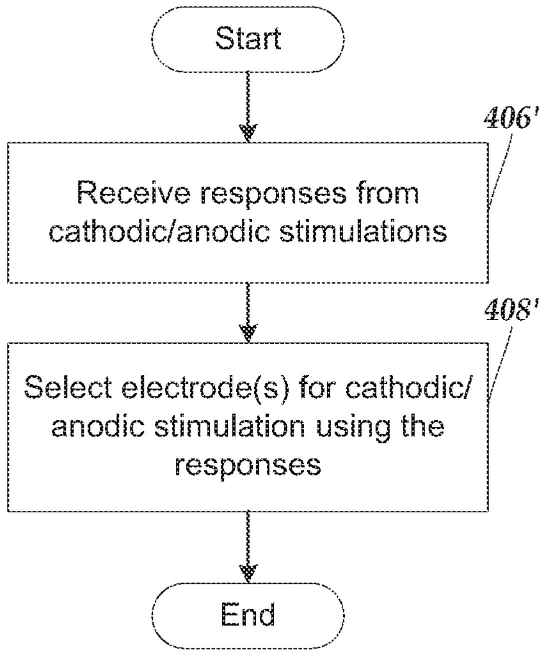
Start
406'
Receive responses from cathodic/anodic stimulations
408'
Select electrode(s) for cathodic/ anodic stimulation using the responses
End

Fig. 4B

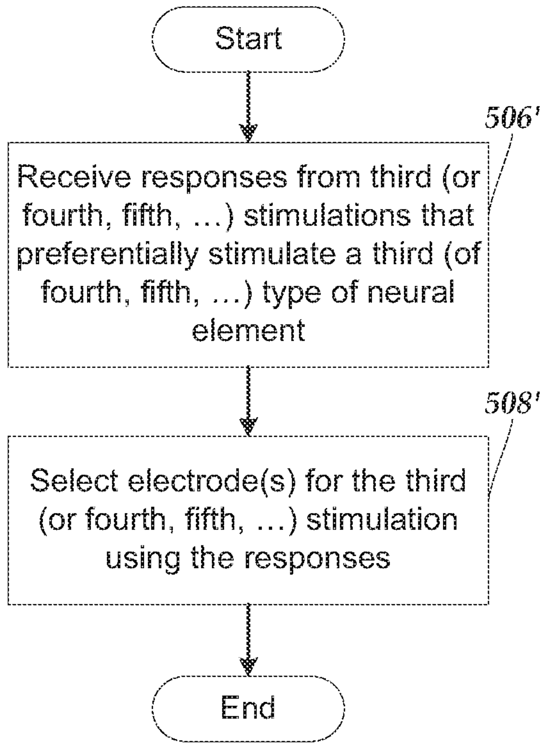
Start
506'
Receive responses from third (or fourth, fifth, …) stimulations that preferentially stimulate a third (of fourth, fifth, …) type of neural element
508'
Select electrode(s) for the third (or fourth, fifth, …) stimulation using the responses
End

Fig. 5B

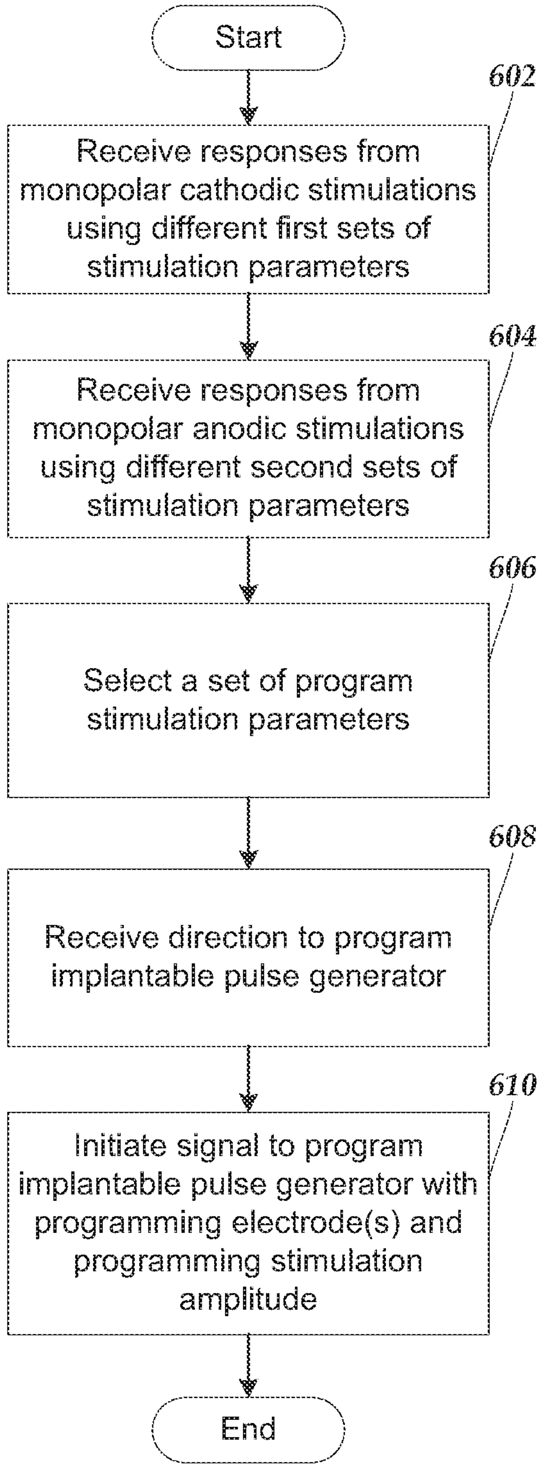
Start
602
Receive responses from monopolar cathodic stimulations using different first sets of stimulation parameters
604
Receive responses from monopolar anodic stimulations using different second sets of stimulation parameters
606
Select a set of program stimulation parameters
608
Receive direction to program implantable pulse generator
610
Initiate signal to program implantable pulse generator with programming electrode(s) and programming stimulation amplitude
End

Fig. 6A

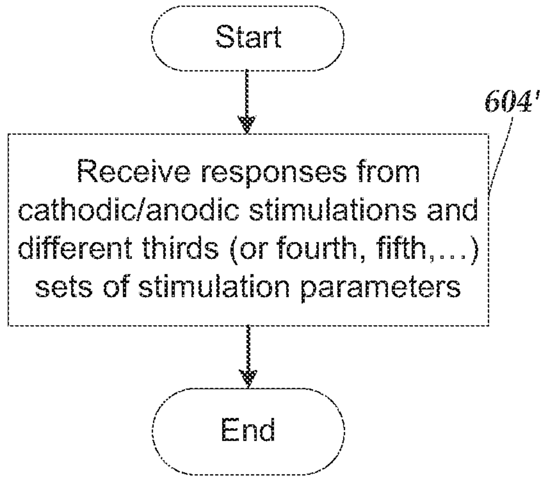
Start
604'
Receive responses from cathodic/anodic stimulations and different thirds (or fourth, fifth,…) sets of stimulation parameters
End

Fig. 6B

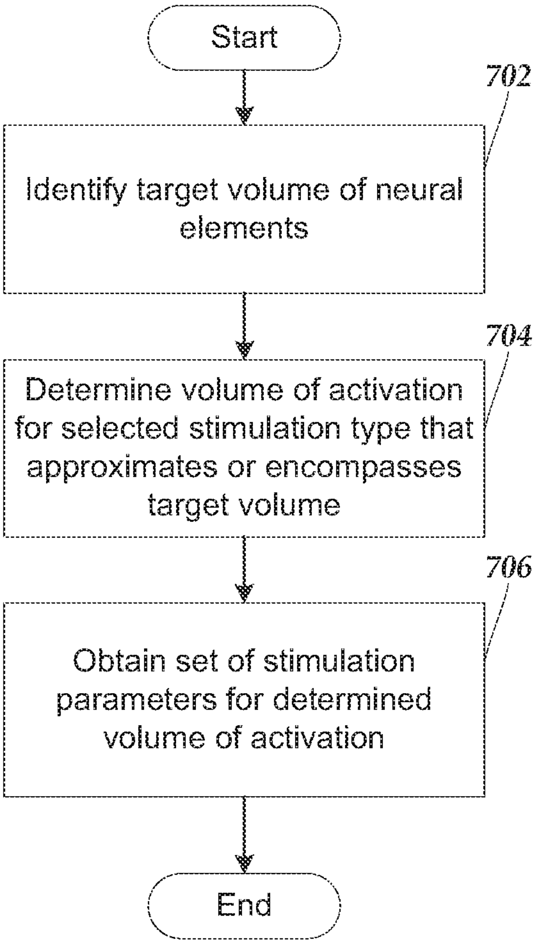
Start
702
Identify target volume of neural elements
704
Determine volume of activation for selected stimulation type that approximates or encompasses target volume
706
Obtain set of stimulation parameters for determined volume of activation
End

Fig. 7

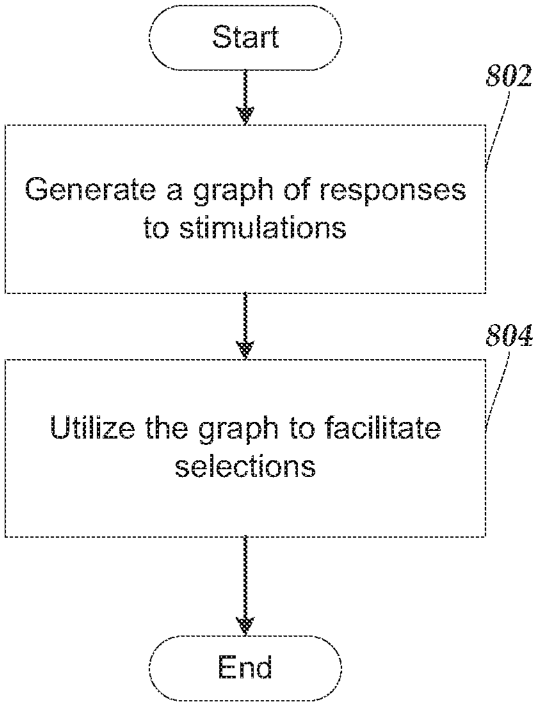
Start
802
Generate a graph of responses to stimulations
804
Utilize the graph to facilitate selections
End

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/029397

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/36
ADD.

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 609 032 B1 (WOODS CARLA MANN [US] ET AL) 19 August 2003 (2003-08-19) the whole document -----	1-15
A	WO 2016/081099 A1 (MEDTRONIC INC [US]) 26 May 2016 (2016-05-26) the whole document -----	1-15
A	WO 2010/006304 A2 (BOSTON SCIENT NEUROMODULATION [US]; THACKER JAMES R [US] ET AL.) 14 January 2010 (2010-01-14) the whole document -----	1-15

☐ 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 application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 June 2019	25/06/2019

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	Sopelana Martínez, J

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2019/029397

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6609032 B1	19-08-2003	US 6393325 B1	21-05-2002
		US 6609032 B1	19-08-2003
WO 2016081099 A1	26-05-2016	CN 107073278 A	18-08-2017
		EP 3221001 A1	27-09-2017
		US 2016144186 A1	26-05-2016
		US 2017056663 A1	02-03-2017
		WO 2016081099 A1	26-05-2016
WO 2010006304 A2	14-01-2010	US 2010010566 A1	14-01-2010
		US 2016158566 A1	09-06-2016
		WO 2010006304 A2	14-01-2010