(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 September 2016 (09.09.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/141046 A1

(51) International Patent Classification:
A61N 1/375 (2006.01) *A61B 5/08* (2006.01)
A61N 1/365 (2006.01) *A61B 5/091* (2006.01)
A61N 1/372 (2006.01) *A61B 5/113* (2006.01)
A61N 1/05 (2006.01) *A61B 5/00* (2006.01)

(21) International Application Number:
PCT/US2016/020432

(22) International Filing Date:
2 March 2016 (02.03.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/128,340 4 March 2015 (04.03.2015) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

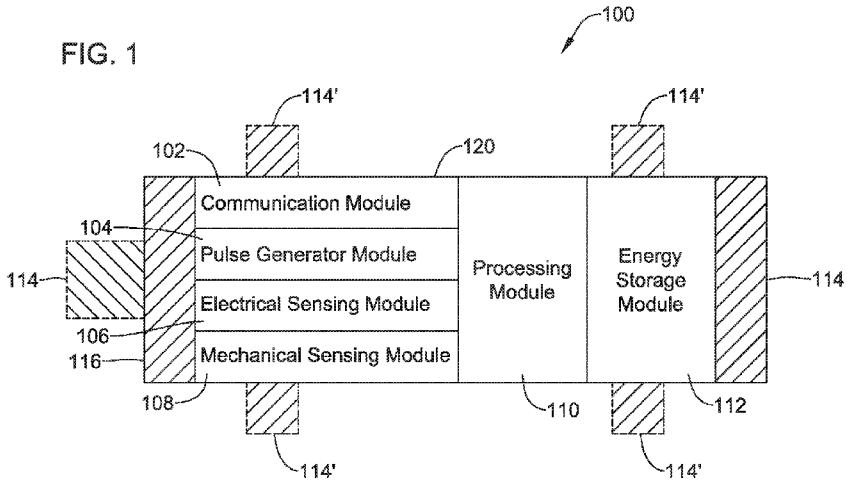
Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) Title: SYSTEMS AND METHODS FOR TREATING CARDIAC ARRHYTHMIAS

FIG. 1



(57) Abstract: Systems and methods for rate-adaptive pacing are disclosed. In one illustrative embodiment, a medical device for delivering electrical stimulation to a heart may include a housing configured to be implanted on the heart or within a chamber of the heart, one or more electrodes connected to the housing, and a controller disposed within the housing. The controller may be configured to sense a first signal and determine a respiration rate based at least in part on the sensed first signal. In at least some embodiments, the controller may be further configured to adjust a rate of delivery of electrical stimulation by the medical device based at least in part on the determined respiration rate.

WO 2016/141046 A1

SYSTEMS AND METHODS FOR TREATING CARDIAC ARRHYTHMIAS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Serial No. 62/128,340 filed on March 4, 2015, the disclosures of each incorporated herein by reference.

TECHNICAL FIELD

The present disclosure generally relates to systems, devices, and methods for treating cardiac arrhythmias, and more particularly, to systems, devices, and methods for implementing rate adaptive pacing.

BACKGROUND

Pacing instruments can be used to treat patients suffering from various heart conditions that result in a reduced ability of the heart to deliver sufficient amounts of blood to a patient's body. These heart conditions may lead to rapid, irregular, and/or inefficient heart contractions. To help alleviate some of these conditions, various devices (e.g., pacemakers, defibrillators, etc.) have been implanted in a patient's body. Such devices may monitor and provide electrical stimulation to the heart to help the heart operate in a more normal, efficient and/or safe manner. In some cases, a patient may have multiple implanted devices.

SUMMARY

The present disclosure generally relates to systems, devices, and methods for treating cardiac arrhythmias, and more particularly, to systems, devices, and methods for implementing rate adaptive pacing. In one illustrative embodiment, a medical device for delivering electrical stimulation to a heart may comprise a housing configured to be implanted on the heart or within a chamber of the heart, one or more electrodes connected to the housing, and a controller disposed within the housing. The controller may be configured to sense a first signal and determine a respiration rate based at least in part on the sensed first signal. In at least some embodiments, the controller may be configured to adjust a rate of

delivery of electrical stimulation by the medical device based at least in part on the determined respiration rate.

In some instances, the controller may include one or more sensors, such as one or more accelerometers, impedance sensors, pressure sensors, piezoelectric sensors and/or the like. In some cases, the controller may include a sense amplifier or the like connected to one or more of the electrodes of the medical device for directly sensing a signal via the one or more electrodes of the medical device.

Additionally or alternatively, in the above illustrative embodiment, the controller may be further configured to determine a relative tidal volume parameter based at least in part on the sensed first signal, and adjust the rate of delivery of electrical stimulation by the medical device based at least in part on both the determined respiration rate and the determined relative tidal volume parameter.

Additionally, or alternatively, in any of the above illustrative embodiments, the sensed first signal is an accelerometer signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the sensed first signal is a temperature signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the sensed first signal is pressure signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the sensed first signal is a strain signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the sensed first signal is an electrocardiogram (ECG).

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is configured to adjust the rate of delivery of electrical stimulation by the medical device if the determined respiration rate rises above a respiration threshold.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is configured to adjust the rate of delivery of electrical stimulation by the medical device if the determined respiration rate falls equal to or below a respiration threshold.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is further configured to sense a second signal, and adjust the rate of delivery of

electrical stimulation by the medical device based at least in part on the determined respiration rate and the second sensed signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the second sensed signal is a heart sounds signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is configured to increase the rate of delivery of electrical stimulation by the medical device if the respiration rate rises above a respiration threshold and the second sensed signal rises above a second threshold.

Additionally, or alternatively, in any of the above illustrative embodiments, to determine a respiration rate based at least in part on the sensed first signal, the controller is configured to determine an absolute value of the sensed first signal.

Additionally, or alternatively, in any of the above illustrative embodiments, to determine a respiration rate based at least in part on the sensed first signal, the controller is further configured to determine an integral of the absolute value of the sensed first signal.

Additionally, or alternatively, in any of the above illustrative embodiments, to determine a respiration rate based at least in part on the sensed first signal, the controller is further configured to filter the integrated signal with a low-pass filter.

Additionally, or alternatively, in any of the above illustrative embodiments, the low pass filter has a corner frequency of between 0.3 Hz and 0.7 Hz.

Additionally, or alternatively, in any of the above illustrative embodiments, to determine a respiration rate based at least in part on the sensed first signal, the controller is further configured to determine the zero crossings of the first derivative of the low-pass filtered signal.

Additionally, or alternatively, in any of the above illustrative embodiments, to determine a respiration rate based at least in part on the sensed first signal, the controller is further configured to determine a difference in timing between a pair of zero crossings of the first derivative of the low-pass filtered signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller may further be configured to sample the first signal at fixed points of the cardiac cycle of the heart.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller may further be configured to sample the first signal at occurrences of R-waves in a sensed electrocardiogram (ECG).

Additionally, or alternatively, in any of the above illustrative embodiments, to determine a respiration rate based at least in part on the sensed first signal, the controller may be further configured to filter the first sensed signal with a low pass filter.

In another illustrative embodiment, a method of delivering electrical stimulation to a heart may comprise delivering electrical stimulation to the heart at a first rate of delivery with a leadless cardiac pacemaker (LCP) configured to be implanted on the heart or within a chamber of the heart. The method may include sensing a first signal with the LCP and determining whether to change the rate of delivery of the electrical stimulation based at least in part on the first sensed signal. In at least some illustrative embodiments, the method may additionally include, after determining to change the rate of delivery of the electrical stimulation, delivering electrical stimulation to the heart at a second rate of delivery with the LCP.

Additionally, or alternatively, in the above illustrative embodiment, the method may further include determining a respiration rate based on the first sensed signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the first sensed signal is an accelerometer signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the second rate of delivery is determined based at least in part on a gain factor.

In still another illustrative embodiments, a medical device for delivering electrical stimulation to a heart may comprise a housing configured to be implanted on the heart or within a chamber of the heart, one or more electrodes connected to the housing, and a controller disposed within the housing. In some illustrative embodiments, the controller may be configured to sense a first signal and determine a respiration rate based at least in part on the sensed first signal. In at least some illustrative embodiments, the controller may further be configured to adjust a rate of delivery of electrical stimulation by the medical device based at least in part on the determined respiration rate.

In some instances, the controller may include one or more sensors, such as one or more accelerometers, impedance sensors, pressure sensors, piezoelectric sensors and/or the

like. In some cases, the controller may include a sense amplifier or the like connected to one or more of the electrodes of the medical device for directly sensing a signal via the one or more electrodes of the medical device.

Additionally, or alternatively, in the above illustrative embodiment, the controller may be further configured to determine a relative tidal volume parameter based at least in part on the sensed first signal, and adjust the rate of delivery of electrical stimulation by the medical device based at least in part on both the determined respiration rate and the determined relative tidal volume parameter.

Additionally, or alternatively, in any of the above illustrative embodiments, the sensed first signal is an acceleration signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the sensed first signal is an electrocardiogram (ECG).

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is configured to adjust the rate of delivery of electrical stimulation by the medical device if the determined respiration rate rises above a respiration threshold.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is configured to adjust the rate of delivery of electrical stimulation by the medical device if the determined respiration rate falls equal to or below a respiration threshold.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is further configured to sense a second signal, and adjust the rate of delivery of electrical stimulation by the medical device based at least in part on the determined respiration rate and the second sensed signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the second sensed signal is a heart sounds signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the controller is configured to increase the rate of delivery of electrical stimulation by the medical device if the respiration rate rises above a respiration threshold and the second sensed signal rises above a second threshold.

Additionally, or alternatively, in any of the above illustrative embodiments, the medical device is a leadless cardiac pacemaker.

In another illustrative embodiment, a method of delivering electrical stimulation to a heart may comprise sensing a first signal with a leadless cardiac pacemaker (LCP) configured to be implanted on the heart or within a chamber of the heart and determining an absolute value of the first sensed signal. The method may include determining an integrated signal based on the absolute value of the first sensed signal and determining a respiration rate based at least in part on the integrated signal. In at least some illustrative embodiments, the method may further include changing a rate of delivery of electrical stimulation based at least in part on changes in the respiration rate.

Additionally, or alternatively, in the above illustrative embodiment, determining a respiration rate based on the integrated signal comprises determining a difference in timing between a pair of peaks of the integrated signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the value each peak of the pair of peaks are local maximums.

Additionally, or alternatively, in any of the above illustrative embodiments, determining a respiration rate based on the integrated signal further comprises low-pass filtering the integrated signal, determining zero-crossings of the first derivative of the low-pass filtered signal, and determining a difference in timing between a pair of zero-crossings of the first derivative of the low-pass filtered signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the first sensed signal is an accelerometer signal.

Additionally, or alternatively, in any of the above illustrative embodiments, the first sensed signal is an electrocardiogram (ECG).

The above summary is not intended to describe each embodiment or every implementation of the present disclosure. Advantages and attainments, together with a more complete understanding of the disclosure, will become apparent and appreciated by referring to the following description and claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure may be more completely understood in consideration of the following description of various illustrative embodiments in connection with the accompanying drawings, in which:

Figure 1 is a schematic block diagram of an illustrative leadless cardiac pacemaker (LCP) according to one illustrative embodiment of the present disclosure;

Figure 2 is a graph of illustrative raw accelerometer data plotted over a number of cardiac cycles;

Figure 3 is a graph of the absolute value of the illustrative raw accelerometer data of Figure 2;

Figure 4 is a graph of an integrated signal based on the absolute value of the illustrative raw accelerometer data of Figure 3;

Figure 5 is a graph of a low-pass filtered signal generated by low pass-filtering the integrated signal of Figure 4;

Figure 6 is a flow diagram of an illustrative method that may be implemented by a medical device or medical device system, such as the illustrative LCP of Figure 1; and

Figure 7 is a flow diagram of an illustrative method that may be implemented by a medical device or medical device system, such as the illustrative LCP of Figure 1.

While the disclosure is amenable to various modifications and alternative forms, specifics thereof have been shown by way of embodiment in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit aspects of the disclosure to the particular illustrative embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure.

DESCRIPTION

The following description should be read with reference to the drawings in which similar elements in different drawings are numbered the same. The description and the drawings, which are not necessarily to scale, depict illustrative embodiments and are not intended to limit the scope of the disclosure.

This disclosure describes systems, devices, and methods for delivering electrical stimulation to a heart in a rate adaptive manner. Healthy people's bodies generally adjust the

rate at which their hearts beat in response to higher or lower metabolic needs, for example during exercise or in response to various external stimuli. However, some people develop diseases or conditions which affect their bodies' abilities to cause their hearts to contract in an effective manner. Accordingly, devices in accordance with the present disclosure may be implanted in such people. In some instances, the implanted devices may deliver electrical stimulation on an on-going basis and adjust the rate of delivered electrical stimulation in accordance with sensed physiological parameters indicative of increased metabolic needs.

Figure 1 is a conceptual schematic block diagram of an exemplary leadless cardiac pacemaker (LCP) that may be implanted on the heart or within a chamber of the heart and may operate to sense physiological signals and parameters and deliver one or more types of electrical stimulation therapy to the heart of the patient. Example electrical stimulation therapy may include bradycardia pacing, rate responsive pacing therapy, cardiac resynchronization therapy (CRT), anti-tachycardia pacing (ATP) therapy and/or the like. As can be seen in Figure 1, LCP 100 may be a compact device with all components housed within LCP 100 or directly on housing 120. In some instances, LCP 100 may include communication module 102, pulse generator module 104, electrical sensing module 106, mechanical sensing module 108, processing module 110, energy storage module 112, and electrodes 114.

As depicted in Figure 1, LCP 100 may include electrodes 114, which can be secured relative to housing 120 and electrically exposed to tissue and/or blood surrounding LCP 100. Electrodes 114 may generally conduct electrical signals to and from LCP 100 and the surrounding tissue and/or blood. Such electrical signals can include communication signals, electrical stimulation pulses, and intrinsic cardiac electrical signals, to name a few. Intrinsic cardiac electrical signals may include electrical signals generated by the heart and may be represented by an electrocardiogram (ECG).

Electrodes 114 may include one or more biocompatible conductive materials such as various metals or alloys that are known to be safe for implantation within a human body. In some instances, electrodes 114 may be generally disposed on either end of LCP 100 and may be in electrical communication with one or more of modules 102, 104, 106, 108, and 110. In embodiments where electrodes 114 are secured directly to housing 120, an insulative material may electrically isolate the electrodes 114 from adjacent electrodes, housing 120,

and/or other parts of LCP 100. In some instances, some or all of electrodes 114 may be spaced from housing 120 and connected to housing 120 and/or other components of LCP 100 through connecting wires. In such instances, the electrodes 114 may be placed on a tail (not shown) that extends out away from the housing 120. As shown in Figure 1, in some embodiments, LCP 100 may include electrodes 114'. Electrodes 114' may be in addition to electrodes 114, or may replace one or more of electrodes 114. Electrodes 114' may be similar to electrodes 114 except that electrodes 114' are disposed on the sides of LCP 100. In some cases, electrodes 114' may increase the number of electrodes by which LCP 100 may deliver communication signals and/or electrical stimulation pulses, and/or may sense intrinsic cardiac electrical signals, communication signals, and/or electrical stimulation pulses.

Electrodes 114 and/or 114' may assume any of a variety of sizes and/or shapes, and may be spaced at any of a variety of spacings. For example, electrodes 114 may have an outer diameter of two to twenty millimeters (mm). In other embodiments, electrodes 114 and/or 114' may have a diameter of two, three, five, seven millimeters (mm), or any other suitable diameter, dimension and/or shape. Example lengths for electrodes 114 and/or 114' may include, for example, one, three, five, ten millimeters (mm), or any other suitable length. As used herein, the length is a dimension of electrodes 114 and/or 114' that extends away from the outer surface of the housing 120. In some instances, at least some of electrodes 114 and/or 114' may be spaced from one another by a distance of twenty, thirty, forty, fifty millimeters (mm), or any other suitable spacing. The electrodes 114 and/or 114' of a single device may have different sizes with respect to each other, and the spacing and/or lengths of the electrodes on the device may or may not be uniform.

In the embodiment shown, communication module 102 may be electrically coupled to electrodes 114 and/or 114' and may be configured to deliver communication pulses to tissues of the patient for communicating with other devices such as sensors, programmers, other medical devices, and/or the like. Communication signals, as used herein, may be any modulated signal that conveys information to another device, either by itself or in conjunction with one or more other modulated signals. In some embodiments, communication signals may be limited to sub-threshold signals that do not result in capture of the heart yet still convey information. The communication signals may be delivered to

another device that is located either external or internal to the patient's body. In some instances, the communication may take the form of distinct communication pulses separated by various amounts of time. In some of these cases, the timing between successive pulses may convey information. Communication module 102 may additionally be configured to sense for communication signals delivered by other devices, which may be located external or internal to the patient's body.

Communication module 102 may communicate to help accomplish one or more desired functions. Some example functions include delivering sensed data, using communicated data for determining occurrences of events such as arrhythmias, coordinating delivery of electrical stimulation therapy, and/or other functions. In some cases, LCP 100 may use communication signals to communicate raw information, processed information, messages and/or commands, and/or other data. Raw information may include information such as sensed electrical signals (e.g. a sensed ECG), signals gathered from coupled sensors, and the like. In some embodiments, the processed information may include signals that have been filtered using one or more signal processing techniques. Processed information may also include parameters and/or events that are determined by the LCP 100 and/or another device, such as a determined heart rate, timing of determined heartbeats, timing of other determined events, determinations of threshold crossings, expirations of monitored time periods, activity level parameters, blood-oxygen parameters, blood pressure parameters, heart sound parameters, and the like. Messages and/or commands may include instructions or the like directing another device to take action, notifications of imminent actions of the sending device, requests for reading from the receiving device, requests for writing data to the receiving device, information messages, and/or other messages commands.

In at least some embodiments, communication module 102 (or LCP 100) may further include switching circuitry to selectively connect one or more of electrodes 114 and/or 114' to communication module 102 in order to select which electrodes 114 and/or 114' that communication module 102 delivers communication pulses. It is contemplated that communication module 102 may be communicating with other devices via conducted signals, radio frequency (RF) signals, optical signals, acoustic signals, inductive coupling, and/or any other suitable communication methodology. Where communication module 102 generates electrical communication signals, communication module 102 may include one or

more capacitor elements and/or other charge storage devices to aid in generating and delivering communication signals. In the embodiment shown, communication module 102 may use energy stored in energy storage module 112 to generate the communication signals. In at least some examples, communication module 102 may include a switching circuit that is connected to energy storage module 112 and, with the switching circuitry, may connect energy storage module 112 to one or more of electrodes 114/114' to generate the communication signals.

As shown in Figure 1, a pulse generator module 104 may be electrically connected to one or more of electrodes 114 and/or 114'. Pulse generator module 104 may be configured to generate electrical stimulation pulses and deliver the electrical stimulation pulses to tissues of a patient via one or more of the electrodes 114 and/or 114' in order to effectuate one or more electrical stimulation therapies. Electrical stimulation pulses as used herein are meant to encompass any electrical signals that may be delivered to tissue of a patient for purposes of treatment of any type of disease or abnormality. For example, when used to treat heart disease, the pulse generator module 104 may generate electrical stimulation pacing pulses for capturing the heart of the patient, i.e. causing the heart to contract in response to the delivered electrical stimulation pulse. In some of these cases, LCP 100 may vary the rate at which pulse generator 104 generates the electrical stimulation pulses, for example in rate adaptive pacing. In another embodiment, the electrical stimulation pulses may be defibrillation/cardioversion pulses for shocking the heart out of fibrillation or into a normal heart rhythm. In yet another embodiment, the electrical stimulation pulses may be anti-tachycardia pacing (ATP) pulses. These are just some examples. When used to treat other ailments, the pulse generator module 104 may generate electrical stimulation pulses suitable for neurostimulation therapy or the like. Pulse generator module 104 may include one or more capacitor elements and/or other charge storage devices to aid in generating and delivering appropriate electrical stimulation pulses. In the embodiment shown, pulse generator module 104 may use energy stored in energy storage module 112 to generate the electrical stimulation pulses. In some examples, pulse generator module 104 may include a switching circuit that is connected to energy storage module 112 and may connect energy storage module 112 to one or more of electrodes 114/114' to generate electrical stimulation pulses.

Pulse generator module 104 may include the capability to modify the electrical stimulation pulses, such as by adjusting the pulse width and/or amplitude of the electrical stimulation pulses. When pacing the heart, this may help tailor the electrical stimulation pulses to capture the heart a particular patient, sometimes with reduced battery usage. For neurostimulation therapy, adjusting the pulse width and/or amplitude may help tailor the therapy for a particular application and/or help make the therapy more effective for a particular patient.

Although depicted as separate modules, in some embodiments, LCP 550 may include a combined communication module 702/pulse generator module 704. For instance, pulse generator module 704 may be configured to also generate electrical communication signals. In such embodiments, pulse generator 704 may be configured to generate and deliver both electrical communication signals and electrical stimulation pulses.

In some embodiments, LCP 100 may include an electrical sensing module 106 and mechanical sensing module 108. Electrical sensing module 106 may be configured to sense intrinsic cardiac electrical signals conducted from electrodes 114 and/or 114' to electrical sensing module 106. For example, electrical sensing module 106 may be electrically connected to one or more electrodes 114 and/or 114' and electrical sensing module 106 may be configured to receive cardiac electrical signals conducted through electrodes 114 and/or 114' via a sensor amplifier or the like. In some embodiments, the cardiac electrical signals may represent local information from the chamber in which LCP 100 is implanted. For instance, if LCP 100 is implanted within a ventricle of the heart, cardiac electrical signals sensed by LCP 100 through electrodes 114 and/or 114' may represent ventricular cardiac electrical signals. Mechanical sensing module 108 may include, or be electrically connected to, various sensors, such as accelerometers, blood pressure sensors, heart sound sensors, piezoelectric sensors, blood-oxygen sensors, and/or other sensors which measure one or more physiological parameters of the heart and/or patient. Mechanical sensing module 108, when present, may gather signals from the sensors indicative of the various physiological parameters. Both electrical sensing module 106 and mechanical sensing module 108 may be connected to processing module 110 and may provide signals representative of the sensed cardiac electrical signals and/or physiological signals to processing module 110. Although described with respect to Figure 1 as separate sensing modules, in some embodiments,

electrical sensing module 106 and mechanical sensing module 108 may be combined into a single module. In at least some examples, LCP 100 may only include one of electrical sensing module 106 and mechanical sensing module 108. In some cases, any combination of the processing module 110, electrical sensing module 106, mechanical sensing module 108, communication module 102, pulse generator module 104 and/or energy storage module may be considered a controller of the LCP 100.

Processing module 110 may be configured to direct the operation of LCP 100. For example, processing module 110 may be configured to receive cardiac electrical signals from electrical sensing module 106 and/or physiological signals from mechanical sensing module 108. Based on the received signals, processing module 110 may determine, for example, occurrences and types of arrhythmias. Processing module 110 may further receive information from communication module 102. In some embodiments, processing module 110 may additionally use such received information to determine occurrences and types of arrhythmias. However, in other embodiments, LCP 100 may use the received information instead of the signals received from electrical sensing module 106 and/or mechanical sensing module 108 – for instance if the received information is deemed to be more accurate than the signals received from electrical sensing module 106 and/or mechanical sensing module 108 or if electrical sensing module 106 and/or mechanical sensing module 108 have been disabled or omitted from LCP 100.

After determining an occurrence of an arrhythmia, processing module 110 may control pulse generator module 104 to generate electrical stimulation pulses in accordance with one or more electrical stimulation therapies to treat the determined arrhythmia. For example, processing module 110 may control pulse generator module 104 to generate pacing pulses with varying parameters and in different sequences to effectuate one or more electrical stimulation therapies. As one example, in controlling pulse generator module 104 to deliver bradycardia pacing therapy, processing module 110 may control pulse generator module 104 to deliver pacing pulses designed to capture the heart of the patient at a regular interval to help prevent the heart of a patient from falling below a predetermined threshold. In some cases, the rate of pacing may be increased with an increased activity level of the patient (e.g. rate adaptive pacing). For instance, processing module 110 may monitor one or more physiological parameters of the patient which may indicate a need for an increased heart rate

(e.g. due to increased metabolic demand). Processing module 110 may then increase the rate at which pulse generator 104 generates electrical stimulation pulses.

For ATP therapy, processing module 110 may control pulse generator module 104 to deliver pacing pulses at a rate faster than an intrinsic heart rate of a patient in attempt to force the heart to beat in response to the delivered pacing pulses rather than in response to intrinsic cardiac electrical signals. Once the heart is following the pacing pulses, processing module 110 may control pulse generator module 104 to reduce the rate of delivered pacing pulses down to a safer level. In CRT, processing module 110 may control pulse generator module 104 to deliver pacing pulses in coordination with another device to cause the heart to contract more efficiently. In cases where pulse generator module 104 is capable of generating defibrillation and/or cardioversion pulses for defibrillation/cardioversion therapy, processing module 110 may control pulse generator module 104 to generate such defibrillation and/or cardioversion pulses. In some cases, processing module 110 may control pulse generator module 104 to generate electrical stimulation pulses to provide electrical stimulation therapies different than those examples described above.

Aside from controlling pulse generator module 104 to generate different types of electrical stimulation pulses and in different sequences, in some embodiments, processing module 110 may also control pulse generator module 104 to generate the various electrical stimulation pulses with varying pulse parameters. For example, each electrical stimulation pulse may have a pulse width and a pulse amplitude. Processing module 110 may control pulse generator module 104 to generate the various electrical stimulation pulses with specific pulse widths and pulse amplitudes. For example, processing module 110 may cause pulse generator module 104 to adjust the pulse width and/or the pulse amplitude of electrical stimulation pulses if the electrical stimulation pulses are not effectively capturing the heart. Such control of the specific parameters of the various electrical stimulation pulses may help LCP 100 provide more effective delivery of electrical stimulation therapy.

In some embodiments, processing module 110 may further control communication module 102 to send information to other devices. For example, processing module 110 may control communication module 102 to generate one or more communication signals for communicating with other devices of a system of devices. For instance, processing module 110 may control communication module 102 to generate communication signals in particular

pulse sequences, where the specific sequences convey different information. Communication module 102 may also receive communication signals for potential action by processing module 110.

In further embodiments, processing module 110 may control switching circuitry by which communication module 102 and pulse generator module 104 deliver communication signals and/or electrical stimulation pulses to tissue of the patient. As described above, both communication module 102 and pulse generator module 104 may include circuitry for connecting one or more electrodes 114 and/114' to communication module 102 and/or pulse generator module 104 so those modules may deliver the communication signals and electrical stimulation pulses to tissue of the patient. The specific combination of one or more electrodes by which communication module 102 and/or pulse generator module 104 deliver communication signals and electrical stimulation pulses may influence the reception of communication signals and/or the effectiveness of electrical stimulation pulses. Although it was described that each of communication module 102 and pulse generator module 104 may include switching circuitry, in some embodiments, LCP 100 may have a single switching module connected to the communication module 102, the pulse generator module 104, and electrodes 114 and/or 114'. In such embodiments, processing module 110 may control the switching module to connect modules 102/104 and electrodes 114/114' as appropriate.

In some embodiments, processing module 110 may include a pre-programmed chip, such as a very-large-scale integration (VLSI) chip or an application specific integrated circuit (ASIC). In such embodiments, the chip may be pre-programmed with control logic in order to control the operation of LCP 100. By using a pre-programmed chip, processing module 110 may use less power than other programmable circuits while able to maintain basic functionality, thereby potentially increasing the battery life of LCP 100. In other instances, processing module 110 may include a programmable microprocessor or the like. Such a programmable microprocessor may allow a user to adjust the control logic of LCP 100 after manufacture, thereby allowing for greater flexibility of LCP 100 than when using a pre-programmed chip.

Processing module 110, in additional embodiments, may include a memory circuit and processing module 110 may store information on and read information from the memory circuit. In other embodiments, LCP 100 may include a separate memory circuit (not shown)

that is in communication with processing module 110, such that processing module 110 may read and write information to and from the separate memory circuit. The memory circuit, whether part of processing module 110 or separate from processing module 110, may be volatile memory, non-volatile memory, or a combination of volatile memory and non-volatile memory.

Energy storage module 112 may provide a power source to LCP 100 for its operations. In some embodiments, energy storage module 112 may be a non-rechargeable lithium-based battery. In other embodiments, the non-rechargeable battery may be made from other suitable materials. In some embodiments, energy storage module 112 may include a rechargeable battery. In still other embodiments, energy storage module 112 may include other types of energy storage devices such as super capacitors.

To implant LCP 100 inside a patient's body, an operator (e.g., a physician, clinician, etc.), may fix LCP 100 to the cardiac tissue of the patient's heart. To facilitate fixation, LCP 100 may include one or more anchors 116. The one or more anchors 116 are shown schematically in Figure 1. The one or more anchors 116 may include any number of fixation or anchoring mechanisms. For example, one or more anchors 116 may include one or more pins, staples, threads, screws, helix, tines, and/or the like. In some embodiments, although not shown, one or more anchors 116 may include threads on its external surface that may run along at least a partial length of an anchor member. The threads may provide friction between the cardiac tissue and the anchor to help fix the anchor member within the cardiac tissue. In some cases, the one or more anchors 116 may include an anchor member that has a cork-screw shape that can be screwed into the cardiac tissue. In other embodiments, anchor 116 may include other structures such as barbs, spikes, or the like to facilitate engagement with the surrounding cardiac tissue.

In some examples, LCP 100 may be configured to be implanted on a patient's heart or within a chamber of the patient's heart. For instance, LCP 100 may be implanted within any of a left atrium, right atrium, left ventricle, or right ventricle of a patient's heart. By being implanted within a specific chamber, LCP 100 may be able to sense cardiac electrical signals originating or emanating from the specific chamber that other devices may not be able to sense with such resolution. Where LCP 100 is configured to be implanted on a patient's heart, LCP 100 may be configured to be implanted on or adjacent to one of the chambers of

the heart, or on or adjacent to a path along which intrinsically generated cardiac electrical signals generally follow. In these examples, LCP 100 may also have an enhanced ability to sense localized intrinsic cardiac electrical signals and deliver localized electrical stimulation therapy.

In some instances, LCP 100 may be configured to deliver rate-adaptive pacing therapy to a patient's heart. For instance, LCP 100 may be configured to deliver electrical stimulation pulses to the heart of the patient on an on-going basis to help ensure that the patient's heart contracts in a safe and effective manner. LCP 100 may additionally sense one or more signals, for example using electrical sensing module 106 and/or mechanical sensing module 108, and determine, based on the sensed one or more signals, whether to change the rate of delivery of the electrical stimulation pulses. For example, based on the sensed one or more signals, LCP 100 may determine that there is less of a need for cardiac output, and may decrease the rate of delivery of the electrical stimulation pulses. In other instances, based on the one or more sensed signals, LCP 100 may determine that there is a need for increased cardiac output, and may increase the rate of delivery of the electrical stimulation pulses. Adjusting the rate of delivery of the electrical stimulation pulses based on the sensed one or more signals may extend the battery life of LCP 100 by only requiring higher rates of delivery of electrical stimulation pulses when the sensed one or more signals indicate there is a need for increased cardiac output. Additionally, adjusting the rate of delivery of the electrical stimulation pulses may increase a comfort level of the patient by more closely matching the rate of delivery of electrical stimulation pulses with the cardiac output need of the patient.

Where LCP 100 adjusts the rate of delivery of electrical stimulation pulses based on the sensed one or more signals, LCP 100 may in some cases determine a respiration rate based on the sensed one or more signals. Respiration rate may be indicative of a relative cardiac output need for the patient. For example, an increased respiration rate may indicate that there is a need for increased cardiac output, and a decreased respiration rate may indicate less of a need for cardiac output. Accordingly, and when so provided, LCP 100 may adjust the rate of delivery of the electrical stimulation pulses based on the determined respiration rate.

In at least some examples, LCP 100 may include an accelerometer and may determine a measure related to the respiration rate based on the sensed accelerometer signal. Where LCP 100 is implanted on a patient's heart or within the heart, the accelerometer signal may include signals indicative of movement related to a number of different causes. For instance, the accelerometer signal may include movement related to the gross movement of the patient, such as walking, bending, or other gross body movements. Additionally, the accelerometer signal may include movement related to the contraction of the heart, particularly when LCP 100 is implanted on or within the heart. Additionally, the accelerometer signal may include movement related to the inhalation and exhalation of the patient (i.e. respiration). For instance, as a patient breathes in and out, the lungs apply different pressure to the heart and the intrathoracic pressure changes accordingly. This change in the intrathoracic pressure may cause changes in the shape and size of the various chambers of the heart, as well as the movement of the heart and the heart chambers. After inhalation, the intrathoracic pressure may be relatively higher, which may decrease the volume of blood that flows into one or more of the chambers of the heart during a cardiac cycle. Conversely, after exhalation, the intrathoracic pressure may be relatively lower, which may allow relatively more blood to enter the chambers of the heart during a cardiac cycle. These differences in the amount of blood flowing into and out of the heart and any movement of the heart or heart chambers due to the changes in intrathoracic pressure may be contained in the accelerometer signal.

Figures 2-4 depict example accelerometer data and processed accelerometer data that may facilitate LCP 100 in determining a respiration rate. Figure 2 depicts raw accelerometer data 200 taken over a period of time. In this instance, raw accelerometer data 200 represents accelerometer data captured over a number of cardiac cycles. Raw accelerometer data 200 may represent a signal output from an accelerometer of LCP 100 when LCP 100 is implanted within a patient's heart chamber.

To help determine a respiration rate, LCP 100 may process the raw accelerometer data 200 in any suitable manner. In at least some examples, LCP 100 may begin by determining an absolute value of raw accelerometer data 200, as shown in Figure 3 and represented by absolute value data 300. Thereafter, LCP 100 may determine an integrated signal 400, or integral, of the absolute value data 300. In some instances, LCP 100 may determine the integrated signal 400 of absolute value data 300 over each cardiac cycle. LCP

100 may identify each cardiac cycle based on, for example, the positioning of R-wave peaks. Integrated signal 400 depicts what such an integrated signal of absolute value data 300 may look like.

After determining integrated signal 400, LCP 100 may determine one or more respiration rates directly from integrated signal 400. As one example, LCP 100 may determine exhalation times, identified as exhalation times 403a-b. To find the exhalation times, LCP 100 may determine which of peaks 401 of integrated signal 400 represent local maximums. For instance, LCP 100 may determine that peak 401b has a greater maximum value than either of peaks 401a or 401c, which occur just prior to 401b and just subsequent to peak 401b respectively. Accordingly, LCP 100 may determine that the beginning of exhalation time 403a is in alignment with peak 401b. Using a similar methodology, LCP 100 may determine the beginning of another exhalation time at 403b. LCP 100 may divide sixty seconds by the difference in time between two successive exhalation times, such as exhalation times 403a and 403b, to determine a respiration rate. For instance, if exhalation times 403a and 403b are two seconds apart, LCP 100 may determine the respiration rate to be 30 breaths per minute. Of course, in other examples, LCP 100 may determine a respiration rate based on identified local minimums. LCP 100 may determine times of local minimums in a similar manner to how LCP 100 may determine local maximums, except LCP 100 may identify peaks that have lower values than other nearby peaks.

In some instances, LCP 100 may employ one or more enhancements to the method described above. For instance, LCP 100 may only determine one of peaks 401 that correspond to a local maximum corresponds to the beginning of an exhalation time if the identified peak 401 is not within a threshold time of the previous peak determined to be a local maximum. For instance, looking at integrated signal 400, although peak 401d is a local maximum, peak 401d occurs within blanking period 402 of local maximum peak 401e. Accordingly, LCP 100 may not consider peak 401d as corresponding to the beginning of an exhalation time. LCP 100 may reset blanking period 402 after each determination of the beginning of an exhalation time. Blanking period 402 may help smooth out the determined respiration and help ensure that the respiration rate is not significantly affected by artifacts that affect the accelerometer signal from sources other than inhalation and exhalation. In some cases, blanking period 402 may range anywhere from one-quarter of a second to one

second or more. In some instances, LCP 100 402 may adjust blanking period 402 based on the last known good respiration rate or an expected respiration rate. Additionally, in some instances, LCP 100 402 may adjust blanking period 402, for example based on one or more other sensed signals. The blanking period 402 may be adjusted down as the respiration rate increases, and visa-versa.

Another example of an enhancement includes not determining local maximums as corresponding to a beginning of an exhalation time if the identified local maximums have maximum values outside of a maximum value range. For instance, if a local maximum has a value that is greater than the maximum value range, LCP 100 may not determine the local maximum as corresponding to a beginning of an exhalation time. In some instances, the maximum value range may be an average of the values of the previous three, five, ten, or any other suitable number of peaks. In other instances, the maximum value range may be the mean of the maximum peak values over the last minute. In some additional instances, the maximum value range may be the mean of the maximum peak values over the last minute plus or minus a standard deviation. Alternatively, instead of the maximum value range corresponding to the maximum value of the peaks, the maximum value range could correspond to an amplitude, with the amplitude being measured by the distance between the identified peak and the previous, or subsequent, valley.

In some examples, LCP 100 may determine an overall respiration rate that is a rolling average of five respiration rates determined by the difference in timings of five successive pairs of exhalation times. However, the exact number of respiration rates used to determine the overall respiration rate may differ in other examples. In alternative cases, the overall respiration rate may be the most recent determined respiration rate. These are just some examples of how LCP 100 may determine an overall respiration rate based on integrated signal 400.

Once LCP 100 has determined an overall respiration rate, LCP 100 may determine whether to adjust the rate at which LCP 100 is delivering electrical stimulation pulses. In some instances, LCP 100 may use thresholding to determine an appropriate rate of electrical stimulation delivery. As one example, LCP 100 may have a number of respiration rate thresholds stored in memory, and each respiration rate threshold may be associated with a different rate of electrical stimulation delivery. As the respiration rate rises above each

respiration rate threshold, or falls equal to or below each respiration rate threshold, LCP 100 may adjust the rate of delivery of electrical stimulation pulses based on the rate associated with the appropriate threshold. As one example, LCP 100 may have respiration rate thresholds of ten breathes per minute, twenty breaths per minute, and thirty breaths per minute, and the respiration rate threshold of twenty breaths per minute is associated with a rate of delivery of electrical stimulation of seventy stimulation pulses per minute (e.g. 70 beats/minute). In such an example, while the overall respiration rate is greater than twenty breaths per minute and less than or equal to thirty breaths per minute, LCP 100 may deliver electrical stimulation pulses at a rate of seventy pulses per minute. Once LCP 100 determines that the overall respiration rate has risen above the thirty breaths per minute respiration rate threshold, LCP 100 may increase the rate of delivery of electrical stimulation pulses to the rate associated with the thirty breaths per minute respiration rate threshold, for example ninety beats per minute (e.g. 90 beats/minute). In this manner, LCP 100 may adjust the rate of delivery of electrical stimulation pulses based on the overall respiration rate.

In some alternative embodiments, LCP 100 may adjust the rate of delivery of electrical stimulation pulses based on a gain factor related to the overall respiration rate. For instance, the gain factor may be a factor multiplied by the percentage change in the respiration rate from a baseline respiration rate. As one example, the baseline respiration rate may be ten breathes per minute. While the overall respiration rate is ten breathes per minute, LCP 100 may deliver electrical stimulation pulses, for example, at a rate of sixty pulses per minute (e.g. 60 beats/minute). If the overall respiration rate rises to twenty breathes per minute, the change in the overall respiration rate is one-hundred percent. If the gain factor is set to 0.5, LCP 100 may then increase the rate of delivery of electrical stimulation pulses by 50%, to ninety pulses per minute (e.g. 90 beats/minute). It should be understood that a gain factor of 0.5 is only used as an example. The gain factor may be any suitable number, which may vary between patients. In other instances, the gain factor may be related to the relative change in the overall respiration rate, for instance between the most recent overall respiration rate and a newly determined and different overall respiration rate. In at least some embodiments, LCP 100 may have a minimum threshold of change in the overall respiration rate that must be reached before LCP 100 adjusts the rate of electrical stimulation delivery.

Regardless of the specific method that LCP 100 employs to adjust the rate of delivery of electrical stimulation pulses, LCP 100 may have programmed maximum and minimum rates. For instance, even if the method used to adjust the rate of delivery of the electrical stimulation pulses would cause LCP 100 to adjust the rate of delivery of the electrical stimulation pulses above the maximum threshold, LCP 100 may only deliver the electrical stimulation pulses at the maximum rate. Additionally, even if the method used to adjust the rate of delivery of electrical stimulation pulses would cause LCP 100 to adjust the rate of delivery of the electrical stimulation pulses below the minimum threshold, LCP 100 may only deliver the electrical stimulation pulses at the minimum rate.

In some alternative or additional embodiments, LCP 100 may process integrated signal 400 before determining a respiration rate. For instance, LCP 100 may pass integrated signal 400 through a low pass filter. An illustrative filtered signal 500, shown in Figure 5, represents an output after low-pass filtering integrated signal 400. The peaks and valleys, for examples peaks 501 and 503 and valley 505, of filtered signal 500 may represent the inhalations and exhalations of the patient, respectively. In on example, LCP 100 may determine timings of the inflections of filtered signal 500 by taking the first derivative of filtered signal 500 and finding the zero-crossings. Then, the differences in timings between two peaks (or two valleys) may be used to determine a respiration rate. For examples, LCP 100 may take the difference in timing between time 502a and time 502c, and divide sixty by the resulting difference to determine a respiration rate in breaths per minute.

Alternative embodiments may process raw accelerometer data 200 in a different manner than described with respect to Figures 2-5. For instance, LCP 100 may apply a low pass filter directly to raw accelerometer data 200. LCP 100 may use a filter that has a corner frequency of, for example, between 0.3 Hz and 0.7 Hz, and in some examples, LCP 100 may use a filter with a corner frequency of 0.5 Hz. In such embodiments, the resulting filtered signal may look similar to filtered signal 500. In these instances, and as one example, LCP 100 may find zero-crossing of the first derivative of the filtered signal to find inflection points, and may use the timings of those inflection points to determine a respiration rate.

In alternative embodiments, instead of determining a respiration rate, LCP 100 may adjust the rate of delivery of the electrical stimulation pulses based on a frequency of a signal, such as filtered signal 500. For instance, as the patient's respiration rate increases, the

relative power of the frequency components of filtered signal 500 may skew towards higher frequencies. Accordingly, after determining changes in the relative power of the frequency components of filtered signal 500, LCP 100 may adjust the rate of delivery of the electrical stimulation pulses based on those determined changes. In some cases, this may be less computationally intensive, and/or may yield more accurate data about the current respiration of the patient.

In still other additional or alternative embodiments, LCP 100 may sample the accelerometer signal at a fixed rate, for instance at a fixed point in the cardiac cycle. In some examples, LCP 100 may sample the accelerometer signal at times corresponding to sensed R-waves. For instance, LCP 100 may use a peak detector, or one or more other techniques, to determine occurrences of R-waves in sensed cardiac electrical signals. LCP 100 may then sample the accelerometer signal when LCP 100 determines an occurrence of an R-wave. Although, in other embodiments, LCP 100 may sample the accelerometer signal at other fixed points in the cardiac cycle. This sampled accelerometer signal may be used by LCP 100 in a similar manner to that described with respect to filtered signal 500, for example in determining respiration rates and/or relative tidal volumes, as described herein.

It should be understood that although the above description revolved around determining a respiration rate based on accelerometer data, other signals can be used to determine a respiration rate. For instance, LCP 100 may use ECG data to determine a respiration rate. When LCP 100 is implanted within a chamber of the heart, LCP 100 may sense intracardiac electrical signals, for example represented by an ECG, via a sense amplifier or the like. The relative magnitude of the R-wave of the ECG signal may fluctuate with changes in the volume of the heart chamber, and the volume of the heart chamber may fluctuate as a function of intrathoracic pressure – such as due to changes in lung volume of the patient. In some instances, such changes in intracardiac pressure may be used to determine respiration rate.

In some instances, LCP 100 may use a parameter other than respiration rate to adjust the rate of delivery of the electrical stimulation pulses. For instance, LCP 100 may use heart sounds to adjust the rate of delivery of the electrical stimulation pulses. Increased heart sounds, and specifically increased S1 heart sounds, may be an indication of increased contractility of the heart. Examples of increased heart sounds may include an increase in the

amplitude of the heart sounds signal, or an increase in the duration of the signal peaks. Increased contractility of the heart may indicate a need for increased cardiac output. Accordingly, as the heart sounds increase, LCP 100 may increase the rate of delivery of the electrical stimulation pulses, for example in a manner similar to that described with respect to respiration rate. In some cases, LCP 100 may use temperature to adjust the rate of delivery of the electrical stimulation pulses. For instance, increased blood temperature may indicate increased metabolic activity of the body, and accordingly, a need for increased cardiac output.

In some instances, LCP 100 may use a relative tidal volume parameter to adjust the rate of delivery of the electrical stimulation pulses. For example, LCP 100 may determine a relative tidal volume parameter from integrated signal 400, or in other examples, filtered signal 500. As can be seen in Figure 4, where LCP 100 determines a relative tidal volume parameter, LCP 100 may determine peaks 401 that are local minimums, for example, peak 401f. LCP 100 may determine peaks 401 that are local minimums in a similar manner to how LCP 100 may determine peaks 401 that are local maximums. For instance, LCP 100 may identify peaks whose value is lower than the immediately preceding and following peaks. LCP 100 may then determine a difference in values between peak 401f, having value 407b, and the preceding local maximum peak, such as peak 401b in Figure 4, having value 407a. LCP 100 may use this difference in values between values 407a and 407b to provide a measure related to the relative tidal volume parameter. Increases in the relative tidal volume, or increases in the variability of the relative tidal volume, may indicate an increased need for cardiac output. Accordingly, LCP 100 may track how the relative tidal volume changes over time and may adjust the rate of delivery of the electrical stimulation pulses based on the changes in relative tidal volume, for instance possibly in a similar manner to respiration rate. Where LCP 100 further low-pass filters integrated signal 400, or directly low-pass filters raw accelerometer data 200 to produce filtered signal 500, LCP 100 may determine a relative tidal volume parameter from filtered signal 500. For instance, LCP 100 may determine a difference in values 507a and 507b between peak 501 and valley 505. LCP 100 may use this determined difference as a measure related to the relative tidal volume parameter value.

Figure 6 depicts a general method 600 for how a device, such as LCP 100, may adjust the rate of delivery of the electrical stimulation pulses. Illustrative method 600 begins with

delivering electrical stimulation to a heart at a first rate of delivery with a leadless cardiac pacemaker (LCP) configured to be implanted on the heart or within a chamber of the heart, as indicated at 601. The LCP may be an LCP such as LCP 100 described with respect to Figure 100. Next, method 600 may sense a first signal with the LCP, as at 603. As described above, the signal may be a signal such as an accelerometer signal, an ECG, a heart sounds signal, a pressure signal, or a temperature signal or the like. Next, method 600 may determine whether to change the rate of delivery of the electrical stimulation based at least in part on the first sensed signal, as at 605. As mentioned, in some instances, the LCP may determine a parameter based on the first sensed signal, such as a respiration rate, and may adjust the rate of delivery of the electrical stimulation pulses based on the determined parameter. In some cases, the LCP may determine a relative tidal volume parameter, a heart sounds parameter, and/or an intracardiac pressure parameter. Where the LCP determines a parameter based on the first sensed signal, the LCP may further determine whether to change the rate of electrical stimulation based at least in part on the determined parameter instead of or in addition to the first sensed signal. For instance, the LCP may determine to change the rate of delivery of electrical stimulation in response to the determined parameter rising above or falling below, as appropriate, a threshold. As one illustrative example, the LCP may determine to increase the rate of delivery of electrical stimulation in response to determining the respiration rate parameter rises above a threshold, thereby indicating an increased need for cardiac output. After determining to change the rate of delivery of the electrical stimulation, method 600 may continue with delivering electrical stimulation to the heart at a second rate of delivery with the LCP, as at 607. For instance, if the first sensed signal, or determined parameter, indicates a need for increased cardiac output, the LCP may increase the rate of delivery of the electrical stimulation. Conversely, if the first sensed signal, or determined parameter, does not indicate a need for the current cardiac output, the LCP may decrease the rate of delivery of the electrical stimulation.

In some cases, LCP 100 may adjust the rate of delivery of the electrical stimulation based on a combination of sensed signals. For instance, LCP 100 may sense a first signal and, based on the sensed first signal, determine a respiration rate. LCP 100 may further determine a second parameter in addition to respiration rate. In some examples, LCP 100 may determine the second parameter also from the acceleration signal, for instance a relative

tidal volume parameter. In other examples, LCP 100 may sense a second signal, for instance a heart sounds signal, an intracardiac pressure signal, a temperature signal, and/or the like, and may determine a second parameter from the sensed second signal. LCP 100 may determine a heart sounds parameter, an intracardiac pressure parameter, and/or a temperature parameter. In some alternative examples, LCP 100 may determine a second respiration rate based on the sensed second signal.

After determining the second parameter, LCP 100 may use a combination of the determined respiration rate and the determined second parameter to adjust the rate of delivery of the electrical stimulation. For instance, LCP 100 may follow a method according to Figure 7. Figure 7 depicts a flow diagram of method 700 that LCP 100 may follow in order to adjust the rate of delivery of the electrical stimulation pulses. Method 700 begins with LCP 100 determining if a first one of the determined respiration rate or a second determined parameter indicates a need for increased cardiac output, as at 701. For example, and in some cases, the determined respiration rate or the determined second parameter may rise above a corresponding threshold, or may fall below a corresponding threshold where appropriate. The determined respiration rate or the second determined parameter rising above a threshold or falling below a threshold may indicate a need for increased cardiac output. If neither of the respiration rate nor the second determined parameter indicates a need for increased cardiac output, LCP 100 may follow the NO branch of step 701, maintain the current rate of delivery of the electrical stimulation pulses as shown at 707, and continue to monitor the respiration rate and the determined second parameter until one of the parameters does indicate a need for increased cardiac output at 701.

Where LCP 100 determines that the determine respiration rate or the determined second parameter do indicate a need for increased cardiac output, LCP 100 may follow the YES branch of step 701. LCP 100 may then determine whether the second one of the determined respiration rate and the second determined parameter indicate a need for increased cardiac output, as at 703. If LCP 100 determines that the second one of the determined respiration rate and the second determined parameter does not indicate a need for increased cardiac output, LCP 100 may follow the NO branch of step 703, maintain the current rate of delivery of the electrical stimulation pulses as shown at 707, and continue to monitor the respiration rate and the determined second parameter until one of the parameters

does indicate a need for increased cardiac output at 701. However, if LCP 100 determines that the second one of the determined respiration rate and the second determined parameter indicates a need for increased cardiac output, i.e. both the determined respiration rate and the second determined parameter indicate a need for increased cardiac output, LCP 100 may adjust the rate of delivery of electrical stimulation pulses, as at 705. For instance, LCP 100 may increase the rate of delivery of the electrical stimulation pulses.

While the example method of Figure 7 references a determined respiration rate and a second determined parameter, it is contemplated that any two (or more) parameters may be used. For example, a heart sounds parameter and a relative tidal volume parameter may be used. In some case, the rate of delivery of electrical stimulation pulses may not be adjusted unless three or more parameters indicates a need for increased cardiac output, or two out of three parameters indicates a need for increased cardiac output. These are just some examples.

In some cases, LCP 100 may determine and monitor two parameters, such as respiration rate and the second determined parameter as above, but still adjust the rate of delivery of the electrical stimulation pulses based on only the determined respiration rate. In some cases, if LCP 100 determines that both the determined respiration rate and the second determined parameter indicate a need for increased cardiac output, LCP 100 may adjust the rate of delivery of the electrical stimulation pulses even further. For instance, if one of the determined respiration rate and the second determined parameter indicate a need for increased cardiac output, LCP 100 may increase the rate of delivery of the electrical stimulation pulses. If LCP 100 determines that both the determined respiration rate and the second determined parameter indicates a need for increased cardiac output, LCP 100 may increase the rate of delivery of the electrical stimulation pulses even further. In some cases, LCP 100 may have two gain factors stored in memory and may apply the first gain factor to adjusting the rate of delivery of the electrical stimulation pulses after determining that only one of the determined respiration rate and the second determined parameter indicate a need for increased cardiac output. The LCP 100 may apply the second gain factor to adjusting the rate of delivery of the electrical stimulation pulses after determining that both the determined respiration rate and the second determined parameter indicate a need for increased cardiac output, where the second gain factor is greater than the first gain factor. Of course, in such

examples, LCP 100 may still further adjust the rate of delivery of the electrical stimulation pulses if LCP 100 determines further changes to the first one of the determined respiration rate and/or the second determined parameter.

In yet another example, LCP 100 may use multiple parameters in sequence to determine whether to adjust the rate of delivery of the electrical stimulation pulses. For instance, LCP 100 may first determine whether a respiration rate parameter changes. Once LCP 100 has determined that the respiration rate parameter has changed, for example increased above a threshold, LCP 100 may then increase the rate of delivery of the electrical stimulation pulses to a first increased rate. Once LCP 100 is delivering the electrical stimulation pulses at the first increased rate, LCP 100 may monitor a second parameter for changes to further adjust the rate of delivery of the electrical stimulation pulses. For instance, LCP 100 may monitor the relative tidal volume for changes in determining whether to further adjust the rate of delivery of the electrical stimulation pulses. If LCP 100 determines changes in the relative tidal volume parameter, for example increases in the relative tidal volume parameter above a threshold, LCP 100 may further increase the rate of delivery of the electrical stimulation pulses to a second increased rate. Of course, in other examples, the order of the sequence of the monitored parameters may be different. Generally, this disclosure contemplates embodiments including any number and any combination of parameters arranged in any order.

Although the above methods for adjusting the rate were described with respect to increasing the rate of delivery of the electrical stimulation pulses when one or more parameters indicate a need for increased cardiac output, in a similar manner LCP 100 may decrease the rate of delivery of the electrical stimulation pulses when the one or more parameters do not indicate a need for the current level of cardiac output. For instance, when one or more of the parameters fall below a threshold, or rise above a threshold where appropriate, which indicates less need that is provided by the current cardiac output, and hence the current rate of delivery of the electrical stimulation pulses. Accordingly, LCP 100 may be configured to decrease the rate of delivery of the electrical stimulation pulses to reduce the cardiac output. In some embodiments, LCP 100 may use multiple determined parameters to aid in determining whether to decease the rate of delivery of the electrical

stimulation pulses, for example in a similar manner described with respect to Figure 6 for increasing the rate of delivery of the electrical stimulation pulses.

Additionally, although the above methods for adjusting the rate of delivery of the electrical stimulation pulses were described with respect to respiration rate and another parameter, in alternative embodiments, LCP 100 may use two parameters that do not include respiration rate to determine whether to adjust the rate of delivery of the electrical stimulation pulses. For instance, LCP 100 may use a heart sounds parameter and a relative tidal volume parameter. In other instance, LCP 100 may use an intracardiac pressure parameter and a temperature parameter. In general, LCP 100 may use any combination of parameters described herein in determining whether to adjust the rate of delivery of the electrical stimulation pulses. In still some examples, both parameters may be respiration rate parameters. However, both respiration rate parameters may be determined using different signal sources or using different signal processing algorithms. For example, LCP 100 may determine a first respiration rate parameter based on an accelerometer signal and a second respiration rate parameter based on an ECG signal, or an intracardiac signal, or another sensed signal as desired. In such examples, the LCP 100 may consider two respiration rates based on two different signals when adjusting the rate of delivery of the electrical stimulation pulses.

Although not explicitly mentioned previously, where LCP 100 includes an accelerometer, the accelerometer may be a three-axis accelerometer. Where LCP 100 includes a three-axis accelerometer, raw accelerometer data 200 may be a summation from all three channels of the three-axis accelerometer, a summation from two of the three channels, or may be only one of the three channels. LCP 100 may then proceed to process raw accelerometer data 200 as described herein. In some cases, LCP 100 may be configured to low-pass filter each channel of the three-axis accelerometer separately. LCP 100 may then use the resulting filtered signal of the three filtered signals that most closely correlates with a template signal. In some instances, the template signal may be similar to filtered signal 500. In still other examples, a user may view each of the three filtered signals and program LCP 100 to use a specific one of the filtered signals.

Aside from differences in how LCP 100 may operate with respect to how LCP 100 processes the accelerometer data where LCP 100 includes a three-axis accelerometer, in

some embodiments, LCP 100 may change one or more ways in which LCP 100 determines parameters or one or more of the steps LCP 100 uses to adjust the rate of delivery of the electrical stimulation pulses. For instance, based on the three-axis accelerometer signals, LCP 100 may be able to determine whether the patient has a supine or erect posture. Based on the determination, LCP 100 may enable or disable rate-adaptive pacing. For instance, if the patient is in a supine position, LCP 100 may disable rate-adaptive pacing. In other instances, LCP 100 may change the specific method by which LCP 100 adjusts the rate of delivery of the electrical stimulation pulses, or even the gain factor used in determining by how much to adjust the rate of delivery of the electrical stimulation pulses, based on whether the patient is in a supine or erect position.

It is contemplated that LCP 100 may include one or more pre-programmed parameters. For instance, LCP 100 may include pre-programmed respiration rate thresholds, or thresholds associated with other parameters. Additionally, the various thresholds may be associated with one or more rates of delivery of the electrical stimulation pulses. In examples where LCP 100 may adjust the rate of delivery of the electrical stimulation pulses based on one or more gain factors, LCP 100 may be pre-programmed with the one or more gain factors. In some instances, some or all of these pre-programmed values may be programmable and changeable. For instance, LCP 100 may be able to communicate with a programming device located external to the patient. A user of the programming device, such as a physician, may enter changes to the one or more programmable values into the programming device. The programming device may then communicate the changed values to LCP 100 where the changed values overwrite the previous pre-programmed values. In addition, in some examples, LCP 100 may be pre-programmed with multiple methods for determining whether to adjust the rate of delivery of the electrical stimulation pulses. LCP 100 may operate according to one of the methods at a time, whichever method is the active method. In some examples, the programming device may be able to communicate with the LCP 100 to change the active method, or even to communicate a new method for storage into a memory of LCP 100.

In some instances, LCP 100 may be calibrated from time to time. For example, LCP 100 may be calibrated following implantation in a patient, or during subsequent follow-up clinic visits. To calibrate LCP 100, a patient may be hooked up to an external respiration

sensor, such as a spirometer, or a respiratory inductance plethysmography machine, or the like. Signals collected from these respiration instruments may be compared to the determined respiration rate of LCP 100. Where there are differences between the respiration rate determined by LCP 100 and the output of the respiration instrument or instruments, a user, such as a physician, may calibrate the specific algorithm used by LCP 100 to determine the respiration rate. For instance, the user may alter the specific algorithm by which LCP 100 determines the respiration rate – for example the user may switch LCP 100 from using one of the methods described herein to another one of the methods described herein. Alternatively, the user may alter specific parameters of the current method by which LCP 100 is operating. For instance, where LCP 100 employs one or more filters, the user may adjust the corner frequencies of the filters. Alternatively, where LCP 100 includes multiple electrodes, the user may adjust the specific electrodes via which LCP 100 senses cardiac electrical signals. In still other embodiments, the user may alter other aspect of LCP 100 or the particular method by which LCP 100 determines a respiration rate.

In some examples where LCP 100 is calibrated, a user may employ a two-point calibration process. For instance, a user may calibrate LCP 100 while the patient is in a resting state. The user may then further calibrate LCP 100 while the patient is undergoing physical exertion, such as while the patient is walking or running, or climbing stairs, or the like.

Those skilled in the art will recognize that the present disclosure may be manifested in a variety of forms other than the specific embodiments described and contemplated herein. For instance, as described herein, various embodiments include one or more modules described as performing various functions. However, other embodiments may include additional modules that split the described functions up over more modules than that described herein. Additionally, other embodiments may consolidate the described functions into fewer modules.

Although various features may have been described with respect to less than all embodiments, this disclosure contemplates that those features may be included on any embodiment. Further, although the embodiments described herein may have omitted some combinations of the various described features, this disclosure contemplates embodiments that include any combination of each described feature. Accordingly, departure in form and

detail may be made without departing from the scope and spirit of the present disclosure as described in the appended claims.

WHAT IS CLAIMED IS:

1. A medical device for delivering electrical stimulation to a heart, the device comprising:

a housing configured to be implanted on the heart or within a chamber of the heart;

one or more electrodes connected to the housing; and

a controller disposed within the housing, the controller configured to:

sense a first signal,

determine a respiration rate based at least in part on the sensed first signal, and

adjust a rate of delivery of electrical stimulation by the medical device based at least in part on the determined respiration rate.

2. The medical device of claim 1, wherein the controller is further configured to:

determine a relative tidal volume parameter based at least in part on the sensed first signal; and

adjust the rate of delivery of electrical stimulation by the medical device based at least in part on both the determined respiration rate and the determined relative tidal volume parameter.

3. The medical device of any of claims 1-2, wherein the sensed first signal is an accelerometer signal.

4. The medical device of any of claims 1-3, wherein the controller is further configured to sample the first signal at fixed points of the cardiac cycle of the heart.

5. The medical device of any of claims 1-4, wherein the controller is configured to adjust the rate of delivery of electrical stimulation by the medical device if the determined respiration rate rises above a respiration threshold.

6. The medical device of any of claims 1-5, wherein the controller is configured to adjust the rate of delivery of electrical stimulation by the medical device if the determined respiration rate falls equal to or below a respiration threshold.

7. The medical device of any of claims 1-6, wherein the controller is further configured to:

sense a second signal; and

adjust the rate of delivery of electrical stimulation by the medical device based at least in part on the determined respiration rate and the second sensed signal.

8. The medical device of claim 7, wherein the second sensed signal is a heart sounds signal.

9. The medical device of any of claims 7-8, wherein the controller is configured to increase the rate of delivery of electrical stimulation by the medical device if the respiration rate rises above a respiration threshold and the second sensed signal rises above a second threshold.

10. The medical device of any of claims 1-9, wherein to determine a respiration rate based at least in part on the sensed first signal, the controller is configured to determine an absolute value of the sensed first signal.

11. The medical device of claim 10, wherein to determine a respiration rate based at least in part on the sensed first signal, the controller is further configured to determine an integral of the absolute value of the sensed first signal.

12. The medical device of claim 11, wherein to determine a respiration rate based at least in part on the sensed first signal, the controller is further configured to filter the integrated signal with a low-pass filter.

13. The medical device of claim 12, wherein the low pass filter has a corner frequency of between 0.3 Hz and 0.7 Hz.

14. The medical device of claim 13, wherein to determine a respiration rate based at least in part on the sensed first signal, the controller is further configured to determine the zero crossings of the first derivative of the low-pass filtered signal.

15. The medical device of any of claims 1-9, wherein to determine a respiration rate based at least in part on the sensed first signal, the controller is configured to filter the first sensed signal with a low pass filter.

16. A method of delivering electrical stimulation to a heart, the method comprising:

delivering electrical stimulation to the heart at a first rate of delivery with a leadless cardiac pacemaker (LCP) configured to be implanted on the heart or within a chamber of the heart;

sensing a first signal with the LCP;

determining whether to change the rate of delivery of the electrical stimulation based at least in part on the first sensed signal; and

after determining to change the rate of delivery of the electrical stimulation, delivering electrical stimulation to the heart at a second rate of delivery with the LCP.

17. The method of claim 16, further comprising determining a respiration rate based on the first sensed signal.

18. The method of claim 16, wherein the first sensed signal is an accelerometer signal.

19. The method of claim 16, wherein the second rate of delivery is determined based at least in part on a gain factor.

20. A medical device for delivering electrical stimulation to a heart, the device comprising:

a housing configured to be implanted on the heart or within a chamber of the heart;

one or more electrodes connected to the housing; and

a controller disposed within the housing, the controller configured to:

sense a first signal,

determine a respiration rate based at least in part on the sensed first signal, and

adjust a rate of delivery of electrical stimulation by the medical device based at least in part on the determined respiration rate.

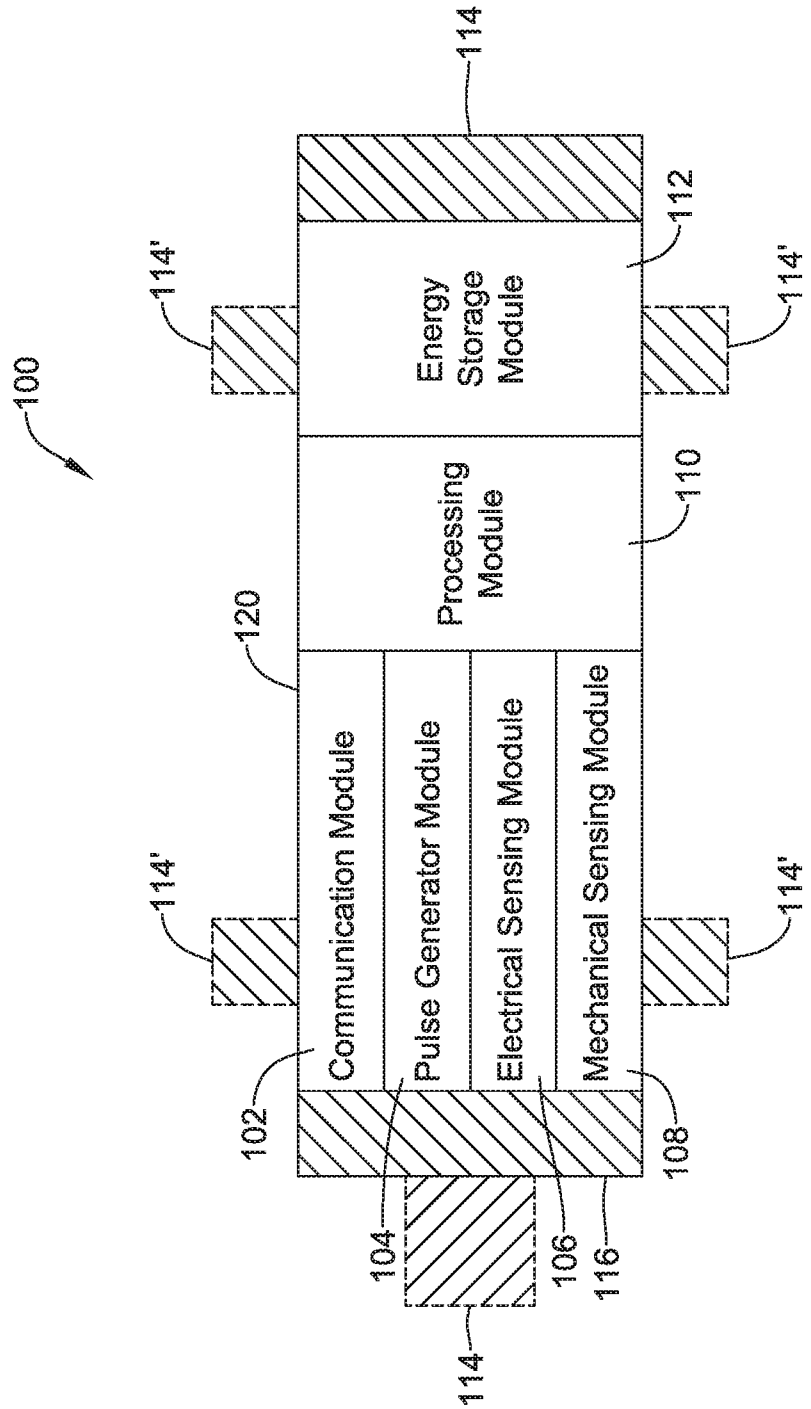

100
114
114'
112
Energy Storage Module
114'
110
Processing Module
120
114'
Communication Module
Pulse Generator Module
Electrical Sensing Module
Mechanical Sensing Module
114'
102
104
106
108
116
114

FIG. 1

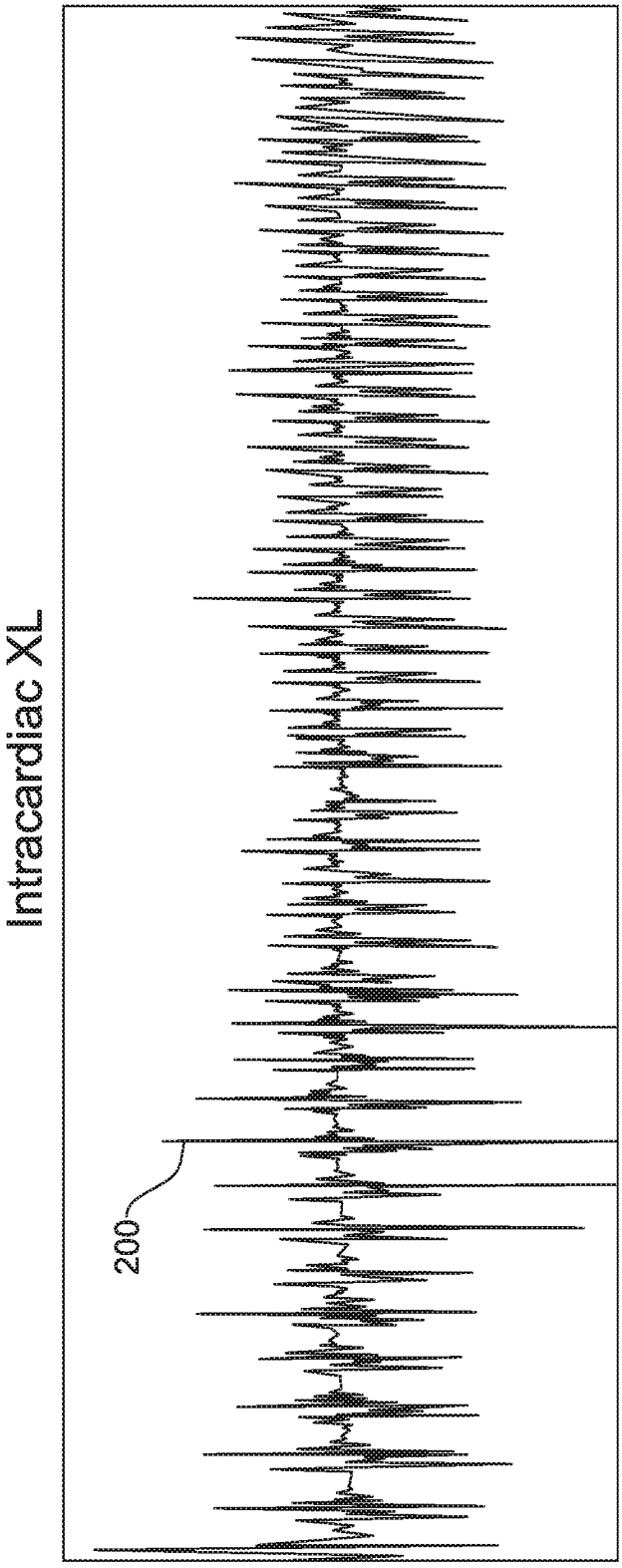


FIG. 2

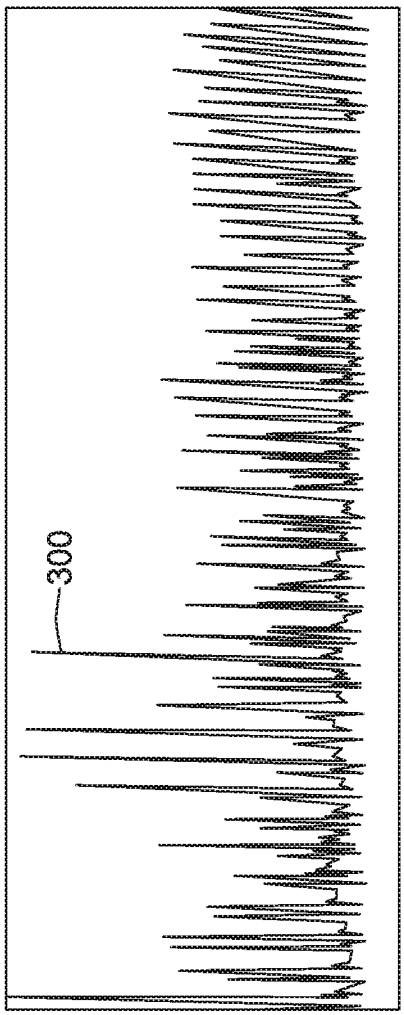


FIG. 3

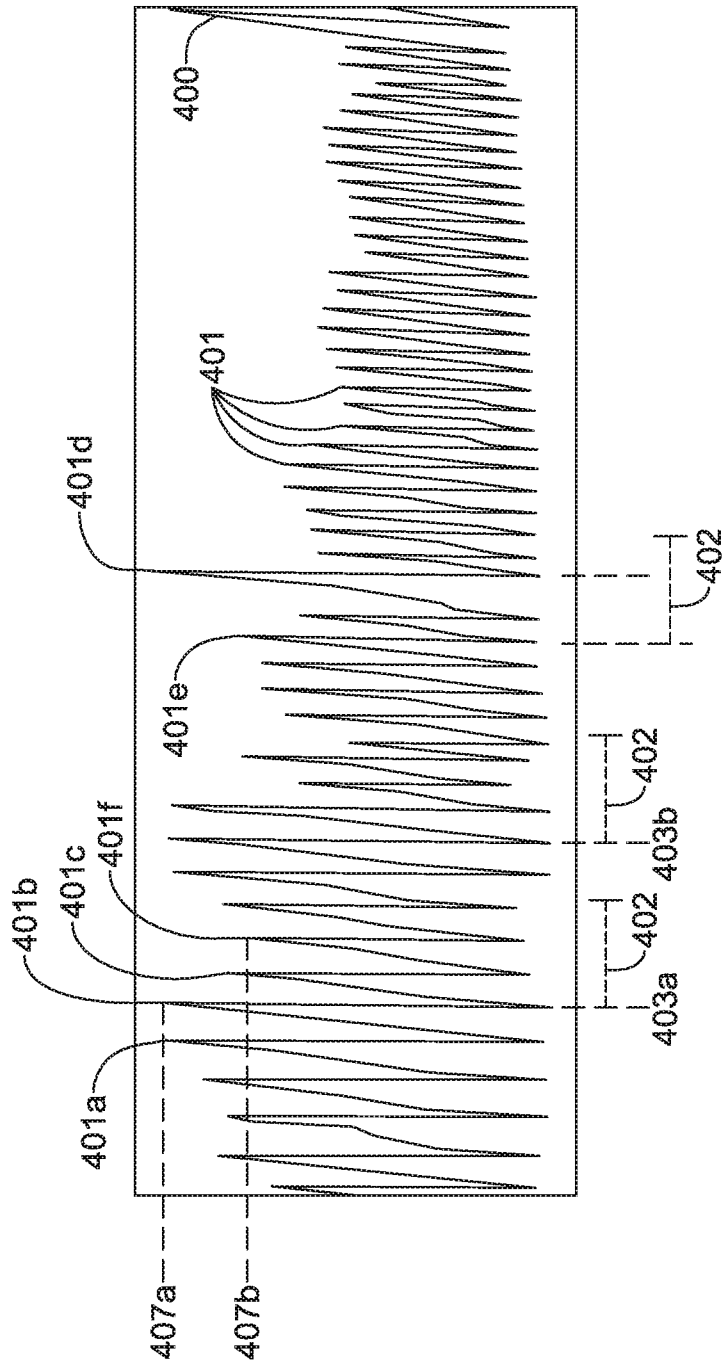

400
401
401d
401e
401f
401c
401b
401a
402
402
402
403b
403a
407a
407b

FIG. 4

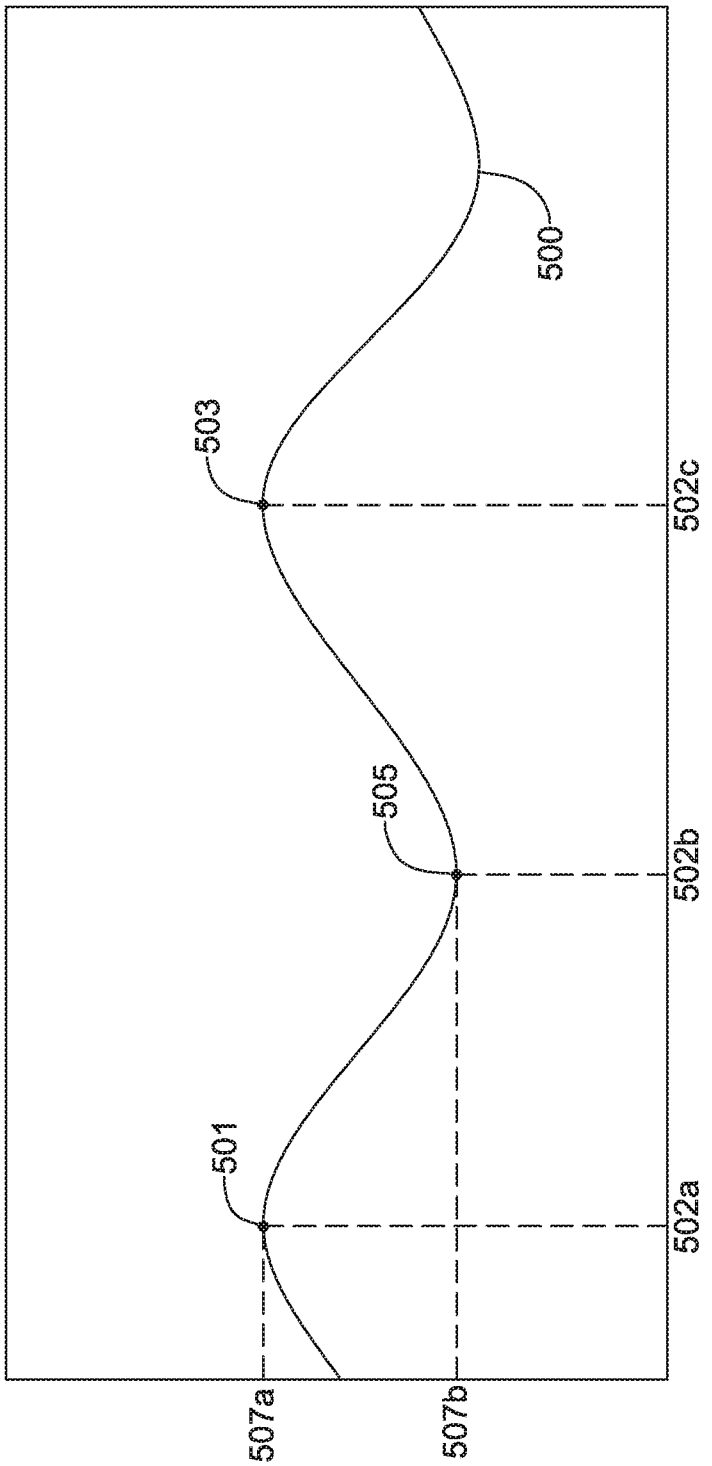


FIG. 5

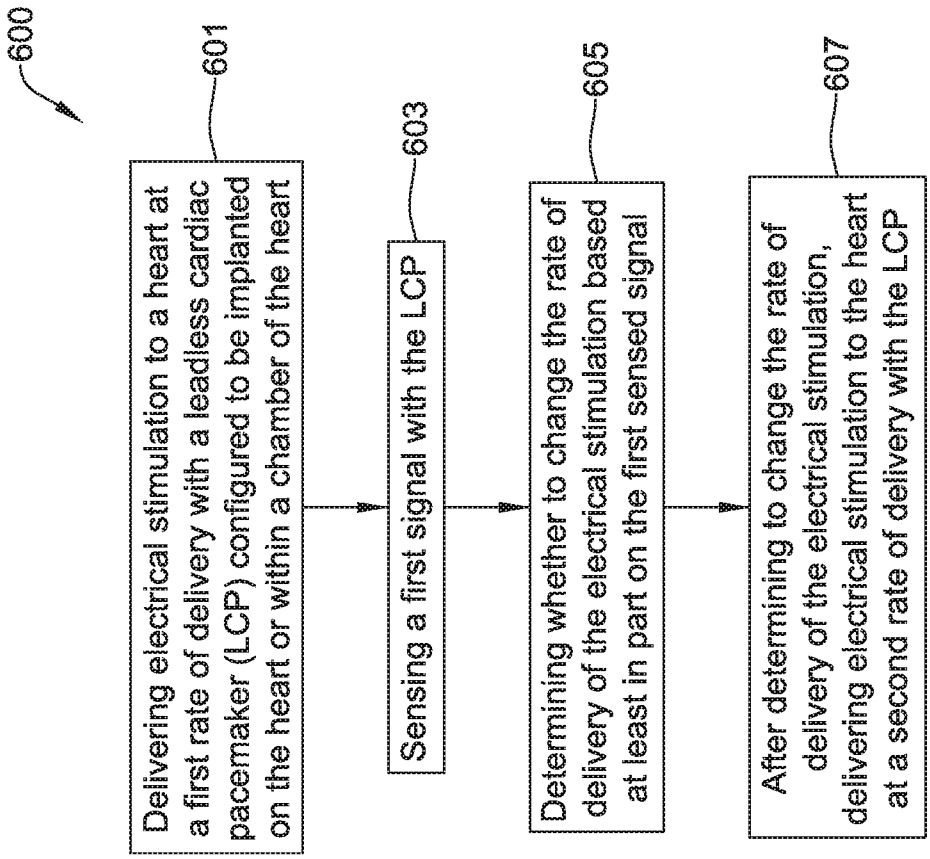

600
601
Delivering electrical stimulation to a heart at a first rate of delivery with a leadless cardiac pacemaker (LCP) configured to be implanted on the heart or within a chamber of the heart
603
Sensing a first signal with the LCP
605
Determining whether to change the rate of delivery of the electrical stimulation based at least in part on the first sensed signal
607
After determining to change the rate of delivery of the electrical stimulation, delivering electrical stimulation to the heart at a second rate of delivery with the LCP

FIG. 6

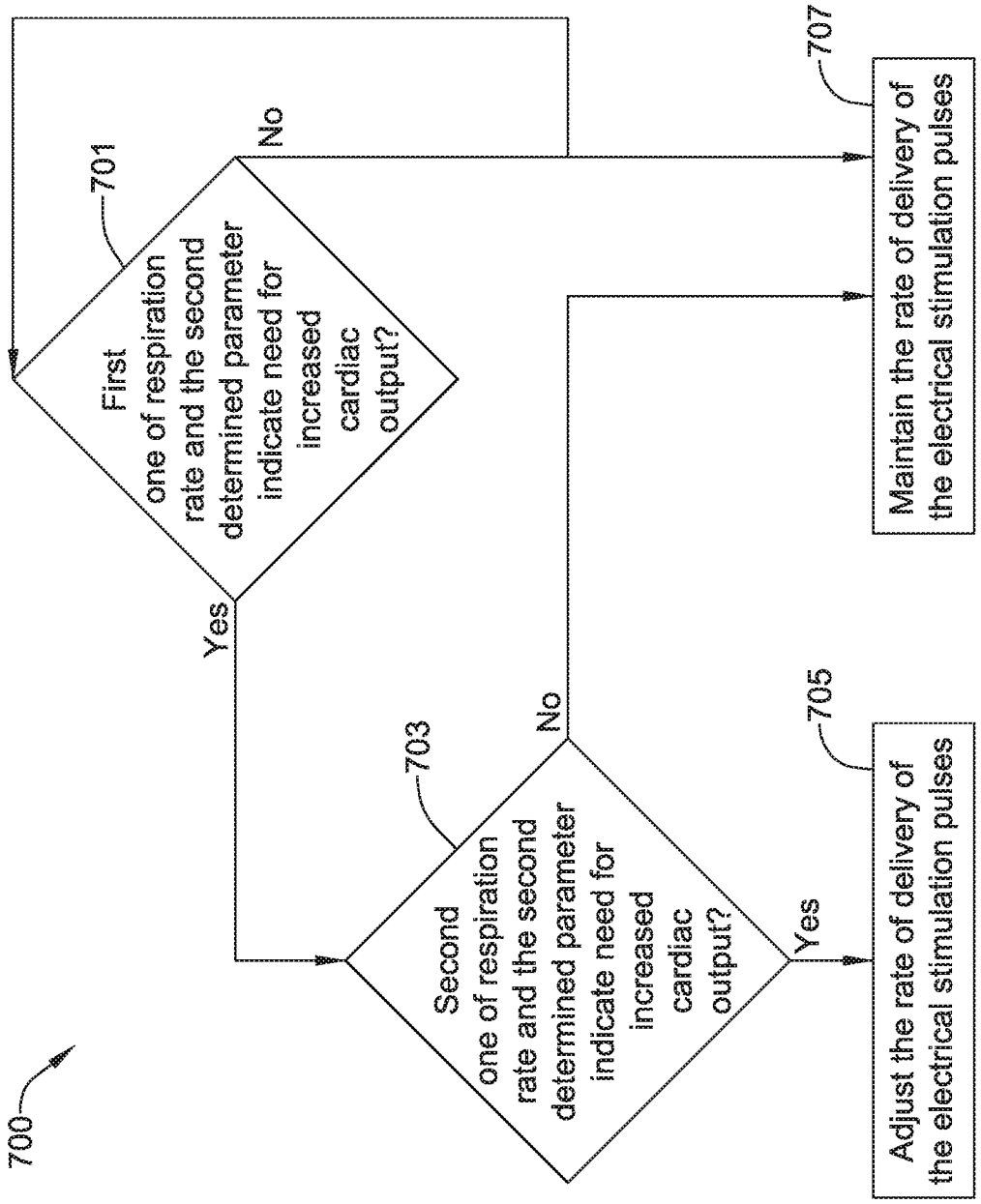

700
First one of respiration rate and the second determined parameter indicate need for increased cardiac output?
701
No
Yes
Second one of respiration rate and the second determined parameter indicate need for increased cardiac output?
703
No
Yes
Maintain the rate of delivery of the electrical stimulation pulses
707
Adjust the rate of delivery of the electrical stimulation pulses
705

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/020432

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

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

1. [X] Claims Nos.: 16-19
because they relate to subject matter not required to be searched by this Authority, namely:

The subject-matter of claims 16-19 has not been searched since it relates to a method for treatment of the human or animal body by therapy (Rule 39.1(iv) PCT). The method of claim 16 comprises the therapeutical step of delivering electrical stimulation to the living human body.

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

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

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

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

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

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

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

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

Remark on Protest

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

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

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/020432

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/375 A61N1/365 A61N1/372
ADD. A61N1/05 A61B5/08 A61B5/091 A61B5/113 A61B5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61N A61B

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.
X Y	US 2013/325081 A1 (KARST EDWARD [US] ET AL) 5 December 2013 (2013-12-05) paragraphs [0042] - [0048], [0066] - [0070], [0084] - [0086], [0114] - [0119], [0135] - [0137]; figures 1-5, 7, 13	1,2,4-6, 9,20 3,7,8, 10-15
X Y	US 2014/172034 A1 (BORNZIN GENE A [US] ET AL) 19 June 2014 (2014-06-19) paragraphs [0036] - [0039], [0083] - [0088], [0098]; figures 1, 11	1,2,4-6, 9,20 3,7,8, 10-15

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[X] Further documents are listed in the continuation of Box C.

[X] 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
14 July 2016	22/07/2016

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	Fischer, Olivier

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/020432

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 8 634 919 B1 (HOU WENBO [US] ET AL) 21 January 2014 (2014-01-21) column 5, lines 30-65 column 7, lines 13-67 column 12, lines 6-67 column 14, lines 32-50 figures 1, 2A, 7	1,2,4-6, 9,20 3,7,8, 10-15
Y	US 2008/161657 A1 (BULLENS ROLAND W M [NL] ET AL) 3 July 2008 (2008-07-03) paragraphs [0010], [0020], [0031]	3
Y	US 2008/154139 A1 (SHUROS ALLAN C [US] ET AL) 26 June 2008 (2008-06-26) paragraphs [0038] - [0040], [0044]; figure 5	3,7,8, 10-15
Y	US 2012/197323 A1 (ELFERRI EFDAL [US] ET AL) 2 August 2012 (2012-08-02) paragraph [0041]	3,15
Y	US 2010/298732 A1 (ZHANG YI [US] ET AL) 25 November 2010 (2010-11-25) paragraph [0084]	3,7,8
Y	US 5 974 340 A (KADHIRESAN V A [US]) 26 October 1999 (1999-10-26) column 4, lines 15-45; figure 3	3,15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2016/020432

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		JP 5246960 B2	24-07-2013
		JP 2010514469 A	06-05-2010
		US 2008154139 A1	26-06-2008
		US 2013184776 A1	18-07-2013
		WO 2008079840 A2	03-07-2008
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