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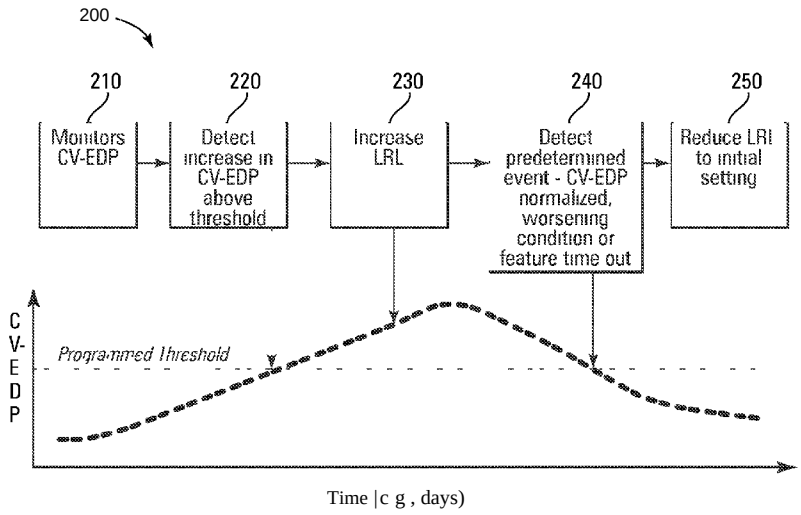

Fig-5

(57) Abstract: A system and method for detecting and treating symptoms of early decompensation utilizing a cardiac rhythm management. The system applies an electrical stimulus to the patient's heart at a first set of pacing parameters including a lower rate limit (LRL) setting, and acquires a coronary venous pressure (CVP) signal from a pressure sensor implanted in a coronary vein of the patient. An average coronary venous end diastolic pressure (CV-EDP) value is calculated from the CVP signal. The system monitors the average CV-EDP value over a predetermined interval, and dynamically adjusts the LRL setting responsive to the detection of a first or a second predetermined event based on the average CV-EDP value.

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SYSTEM AND METHOD FOR DECOMPENSATION DETECTION AND TREATMENT BASED ON PATIENT HEMODYNAMICS

TECHNICAL FIELD

[0001] The present invention relates to medical devices and methods for cardiac rhythm management. More specifically, the present invention relates to systems and methods for automatically adjusting the operating parameters of a cardiac pacemaker or cardiac resynchronization therapy system.

BACKGROUND

[0002] Implantable cardiac rhythm management (CRM) systems, including pacemakers, implantable cardioverter/defibrillators (ICDs), and cardiac resynchronization therapy (CRT, CRT-D) devices have been used to deliver effective treatment to patients with serious cardiac arrhythmias. In particular, rate adaptive pacing systems are known which utilize data obtained from various implanted sensors to adjust pacing parameters in response to increased patient demand.

SUMMARY

[0003] The present invention, in one embodiment, is a method of operating an implanted cardiac rhythm management system in a patient. The method comprises applying an electrical stimulus to the patient's heart at a first set of pacing parameters including a lower rate limit (LRL) setting. The method further comprises acquiring a coronary venous pressure (CVP) signal from a pressure sensor implanted in a coronary vein of the patient. An average coronary venous end diastolic pressure (CV-EDP) value is calculated from the CVP signal, and the average CV-EDP value is monitored over a predetermined interval. The method further comprises dynamically adjusting the LRL setting responsive to the detection of a first or a second predetermined event based on the average CV-EDP value.

[0004] In another embodiment, the present invention is a method of operating an implanted cardiac rhythm management system in a

patient, the method comprising applying an electrical stimulus to the patient's heart at a first set of pacing parameters including an LRL setting, acquiring a CVP signal from a pressure sensor implanted in a coronary vein of the patient, and calculating a baseline CV-EDP value from the CVP signal corresponding to a first interval. The average CV-EDP values are monitored over a predetermined time interval subsequent to the first interval. The method further comprises comparing each of the average CV-EDP values to the baseline CV-EDP value, and automatically increasing the LRL setting in response to a difference (ΔCV-EDP) between at least one of the average CV-EDP values and the baseline average CV-EDP value exceeding a predetermined threshold. The method further comprises subsequently automatically reducing the LRL setting upon detecting a predetermined event.

[0005] In yet another embodiment, the present invention is an implantable rate adaptive cardiac rhythm management system configured for applying a pacing stimuli to a patient's heart, the pacing stimuli defined by pacing parameters including a pacing rate and an LRL setting. The system comprises a plurality of implantable medical electrical leads and an implantable pulse generator. The leads are configured to sense cardiac electrical activity and to deliver the pacing stimuli, at least one of the leads being configured for chronic implantation within a coronary vein of the patient's heart and including a pressure sensor configured to generate a coronary venous pressure (CVP) signal indicative of fluid pressure within the coronary vein. The pulse generator is operatively coupled to the leads and is configured to generate the pacing stimuli, and includes a control system configured to acquire the CVP signal from the pressure sensor, calculate an average coronary venous end diastolic pressure (CV-EDP) value from the CVP signal, and monitor the calculated average CV-EDP value over a predetermined interval. The control system is further configured to dynamically adjust the LRL setting responsive to the detection of a

first or a second predetermined event based on the calculated average CV-EDP value.

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

BRIEF DESCRIPTION OF THE DRAWINGS

[0001] FIG. 1 is a schematic illustration of an implantable cardiac rhythm management (CRM) system according to one embodiment of the present invention in a deployed configuration.

[0007] FIG. 2 is a block diagram illustrating functional components of the implantable medical system of FIG. 1.

[0008] FIG. 3 is an illustration of coronary venous system pressure waveforms that can be obtained utilizing the CRM system of FIG. 1.

[0009] FIG. 4 is an illustration depicting a coronary venous pressure waveform and corresponding left ventricular pressure waveform.

[0010] FIG. 5 is a diagram illustrating an exemplary method of operating the CRM system of FIG. 1 to treat symptoms associated with CHF according to one embodiment of the present invention.

[0011] FIG. 6 is a flow chart illustrating a method of operating the CRM system of FIG. 1 to treat symptoms associated with CHF according to one embodiment of the present invention.

[0012] While the invention is amenable to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and are described in detail below. The intention, however, is not to limit the invention to the particular embodiments described. On the contrary, the invention is intended to

cover all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

[0013] FIG. 1 is a schematic drawing of an implantable cardiac rhythm management (CRM) system 10 according to one embodiment of the present invention, shown in a deployed state. As shown in FIG. 1, the CRM system 10 includes a pulse generator 12 coupled to a cardiac lead system 13 including a pair of medical electrical leads 14, 16 deployed in a patient's heart 18, which includes a right atrium 20 and a right ventricle 22, a left atrium 24 and a left ventricle 26, a coronary sinus ostium 28 in the right atrium 20, a coronary sinus 30, and various coronary veins including an exemplary branch vessel 32 off of the coronary sinus 30.

[0014] As discussed in detail below, the CRM system 10 is advantageously configured to treat cardiac arrhythmias in a patient suffering from CHF. More specifically, the CRM system 10 is configured to adjust pacing parameters to relieve symptoms associated with early decompensation resulting from CHF. The CRM system 10 utilizes hemodynamic performance information based on the output from implanted pressure sensors to diagnose medical conditions, such as the onset of early decompensation resulting from CHF, and to optimize the pacing system parameters to treat CHF-related symptoms. In various embodiments, the pressure sensors provide information that is indicative of or correlates closely to the patient's left ventricular pressure (LVP), which is a useful measure as an indicator of cardiac function in patients suffering from CHF.

[0015] As shown in FIG. 1, the lead 14 includes a proximal portion 42 and a distal portion 36, which as shown is guided through the right atrium 20, the coronary sinus ostium 28 and the coronary sinus 30, and into the branch vessel 32 of the coronary sinus 30. The distal portion 36 further includes pressure sensors 38, 39, and an electrode 40. As shown, the pressure sensor 39 and the electrode 40

are positioned on the lead 14 such that, when implanted, they are both located within the branch vessel 32. As further shown, the pressure sensor 38 is positioned on the lead 14 such that, when implanted, it is located within the right atrium 20. Alternatively, the additional pressure sensor 38 could be located in the coronary sinus 30. The illustrated position of the lead 14 may be used for delivering a pacing and/or defibrillation stimulus to the left side of the heart 18. Additionally, the lead 14 may also be partially deployed in other regions of the coronary venous system, such as in the great cardiac vein or other branch vessels for providing therapy to the left side or right side of the heart 18.

[0016] In the illustrated embodiment, the electrode 40 is a relatively small, low voltage electrode configured for sensing intrinsic cardiac electrical rhythms and/or delivering relatively low voltage pacing stimuli to the left ventricle 26 from within the branch coronary vein 32. In various embodiments, the lead 14 can include additional pace/sense electrodes for multi-polar pacing and/or for providing selective pacing site locations.

[0017] As further shown, in the illustrated embodiment, the lead 16 includes a proximal portion 34 and a distal portion 44 implanted in the right ventricle 22. In other embodiments, the CRM system 10 may include still additional leads, e.g., a lead implanted in the right atrium 20. The distal portion 44 further includes a flexible, high voltage electrode 46, a relatively low-voltage ring electrode 48, and a low voltage tip electrode 50 all implanted in the right ventricle 22 in the illustrated embodiment. The high voltage electrode 46 has a relatively large surface area compared to the ring electrode 48 and the tip electrode 50, and is thus configured for delivering relatively high voltage electrical stimulus to the cardiac tissue for defibrillation/cardioversion therapy, while the ring and tip electrodes 48, 50 are configured as relatively low voltage pace/sense electrodes. The electrodes 48, 50 provide the lead 16 with bi-polar pace/sense capabilities.

[0018] In various embodiments, the lead 16 includes additional defibrillation/cardioversion and/or additional pace/sense electrodes positioned along the lead 16 so as to provide multi-polar defibrillation/cardioversion capabilities. In one exemplary embodiment, the lead 16 includes a proximal high voltage electrode in addition to the electrode 46 positioned along the lead 16 such that it is located in the right atrium 20 (and/or superior vena cava) when implanted. Additional electrode configurations can be utilized with the lead 16. In short, any electrode configuration can be employed in the lead 16 without departing from the intended scope of the present invention.

[0019] In various embodiments, the lead 14 can be configured according to the various embodiments described in co-pending and commonly assigned U.S. Provisional Patent Application 61/088,270 titled "Implantable Lead and Coronary Venous Pressure Sensor Apparatus and Method" to Liu, et al. or commonly assigned U.S. Patent 7,409,244 titled "Method and Apparatus for Adjusting Interventricular Delay Based on Ventricular Pressure," to Salo, et al., the disclosures of which are incorporated herein by reference in their entireties. In other embodiments, the lead 14 with pressure sensor 39 and/or 38 can have other suitable configurations.

[0020] The pulse generator 12 is typically implanted subcutaneously within an implantation location or pocket in the patient's chest or abdomen. The pulse generator 12 may be any implantable medical device known in the art or later developed, for delivering an electrical therapeutic stimulus to the patient suitable for treating cardiac tachyarrhythmias. In various embodiments, the pulse generator 12 is a pacemaker, an implantable cardioverter defibrillator (ICD) or a cardiac resynchronization (CRT) device configured for bi-ventricular pacing and including defibrillation capabilities (i.e., a CRT-D device). While not shown in FIG. 1, the pulse generator 12 includes hardware, software, and circuitry operable as a detection/energy delivery system configured to receive cardiac rhythm signals from the lead electrode(s) 40, 48, 50 and pressure signals from the pressure

sensor(s) 38, 39, and also to deliver a therapeutic electrical stimulus to the electrodes 40, 48, 50.

[0021] In various embodiments, the CRM system 10 further includes an additional lead deployed in the right atrium 20, which lead may include one or more additional electrodes sensing intrinsic cardiac signals and/or delivering electrical stimuli to the cardiac tissue within the right atrium 20.

[0022] The pressure sensor 39 is operable to sense and to generate an electrical signal representative of a fluid pressure parameter within the coronary vein 32 in which it is implanted. The pressure sensor 39 can be any device, whether now known or later developed, suitable for sensing pressure parameters within the coronary venous system and generating and transmitting a signal indicative of such pressure parameters to another device, e.g., the pulse generator 12. In various embodiments, the pressure sensor 39 is configured to sense and generate a signal indicative of hydrostatic pressure within the coronary vein. In various embodiments, the pressure sensor 39 can be a micro-electrical-mechanical system (MEMS) device, which utilizes semiconductor techniques to build microscopic mechanical structures in a substrate made from silicon or similar materials. In various embodiments, the pressure sensor 39 can include a micro-machined capacitive or piezoresistive sensor exposed to the bloodstream. Other pressure sensor technologies, such as resistive strain gages, are known in the art and can also be employed as a pressure sensor 39.

[0023] In other exemplary embodiments, the pressure sensor 39 can include one or more piezoelectric elements. Such piezoelectric elements are configured to flex and/or deflect in response to changes in pressure within the coronary vein in which it is implanted, and to generate an output current or voltage proportional to the corresponding pressure change. In such embodiments, the pressure sensor 39 may advantageously be configured to sense fluid characteristics indicative of changes in coronary venous pressure parameters, e.g., coronary

venous end diastolic pressure, which in turn can be monitored over time. In addition, the pressure sensor 38 can be used to sense right atrial pressure, which can be a useful surrogate for central venous pressure and can be monitored over time to provide an indication of right side heart decompensation.

[0024] FIG. 2 is a schematic functional block diagram of an embodiment of the implantable medical system 10. As shown in FIG. 2, the system 10 is divided into functional blocks. The illustrated configuration is exemplary only, and there exist many possible configurations in which these functional blocks can be arranged. The example depicted in FIG. 2 is one possible functional arrangement. The system 10 includes circuitry for receiving cardiac electrical signals, coronary venous pressure signals, and in some embodiments, right atrial pressure signals from the heart 18 and generating and delivering electrical energy in the form of pace pulses or cardioversion/defibrillation pulses to the heart 18.

[0025] As discussed above, the cardiac lead system 13, which includes the leads 14, 16 may be implanted so that the cardiac electrodes 40, 48, 50 (see FIG. 1) contact heart tissue. The cardiac electrodes of the lead system 13 sense cardiac signals associated with electrical activity of the heart. In addition, the pressure sensors 38, 39 on the lead 14 detect and generate pressure signals indicative of blood pressure within the right atrium 20 and coronary vein 32, respectively. The sensed cardiac signals and pressure signals are transmitted to the pulse generator 12 through the lead system 13. The cardiac electrodes and lead system 13 may be used to deliver electrical stimulation generated by the pulse generator 12 to the heart to mitigate various cardiac arrhythmias. The pulse generator 12, in combination with the cardiac electrodes and the lead system 13, may detect cardiac signals and deliver therapeutic electrical stimulation to any of the left and right ventricles and left and right atria, for example.

[0026] As shown, the pulse generator 12 includes circuitry encased in a hermetically sealed housing 70 suitable for implanting in a

human body. Power is supplied by a battery 72 that is housed within the housing 70. In one embodiment, the pulse generator circuitry is a programmable microprocessor-based system, including a control system 74, sensing circuitry 76, therapy circuitry 78, communications circuitry 80, and memory 82. The memory 82 may be used, for example, to store programmed instructions for various pacing and defibrillation therapy and sensing modes, and also data associated with sensed cardiac signals or other physiologic data, e.g., blood pressure. The parameters and data stored in the memory 82 may be used on-board for various purposes and/or transmitted via telemetry to an external programmer unit 84 or other patient-external device, as desired. In various embodiments, the stored data can be uploaded by a clinician and/or transmitted over an advanced patient management (APM) system, such as the LATITUDE® system marketed by Boston Scientific Corporation.

[0027] The communications circuitry 80 allows the pulse generator 12 to communicate with the external programmer unit 84 and/or other patient-external system(s). In one embodiment, the communications circuitry 80 and the programmer unit 84 use a wire loop antenna and a radio frequency telemetric link to receive and transmit signals and data between the programmer 84 and communications circuitry 80. In this manner, programming commands may be transferred to the pulse generator 12 from the programmer 84 during and after implantation. In addition, stored cardiac data may be transferred to the programmer unit 84 from the pulse generator 12, for example.

[0028] The sensing circuitry 76 detects cardiac signals sensed at the cardiac electrodes 40, 48, 50, as well as blood pressure signals generated by the pressure sensors 38, 39, and signals from other implanted sensors (e.g., activity sensors providing information relating to the patient's physical activity and associated metabolic demand). The sensing circuitry 76 may include, for example, amplifiers, filters, A/D converters and other signal processing circuitry. Cardiac signals

and pressure signals processed by the sensing circuitry may be communicated to the control system 74.

[0029] The therapy circuitry 78 is controlled by the control system 74 and may be used to deliver therapeutic stimulation pulses to the heart through one or more of the cardiac electrodes, according to a pre-established pacing regimen under appropriate conditions. Thus, in various embodiments, the therapy circuitry 78 is configured to deliver pacing stimuli to the right side and, in the case of a CRT or CRT-D system such as the CRM system 10, also to the left side of the heart 18. In various embodiments, the therapy circuitry 78 is also configured to deliver anti-tachycardia therapy stimuli to the ventricles and/or the atria. Such therapies may include, without limitation, relatively low-energy anti-tachycardia pacing pulses as well as high-energy shocks to treat and disrupt ventricular fibrillation episodes.

[0030] The control system 74 is used to control various subsystems of the pulse generator 12, including the therapy circuitry 78 and the sensing circuitry 76. The control system 74 performs various functions, including, for example, arrhythmia analysis and therapy selection. An arrhythmia analysis section of the control system 74 may compare signals detected through the sensing circuitry 76 to detect or predict various cardiac arrhythmias, and to assist selection of appropriate therapies for the patient. In general, the control system 74 controls therapy delivery according to pacing parameters programmed by the clinician either at implantation or thereafter.

[0031] As discussed above, the CRM system 10 utilizes hemodynamic performance information based on the output from the implanted pressure sensors, e.g., pressure sensors 39 and/or 38, to diagnose medical conditions including the onset of early decompensation resulting from CHF, and optimizes the pacing system parameters to treat CHF-related symptoms.

[0032] In particular, as discussed in detail below, one pacing parameter that is dynamically adjusted by the CRM system 10 to treat symptoms of early decompensation is the lower rate limit (LRL). The

LRL is a programmed parameter defining the pacing rate (e.g., number of pulses per minute) at which the pulse generator 12 will deliver pacing stimuli in the absence of sensed intrinsic cardiac activity. In other words, unless the CRM system 10 senses cardiac activity or metabolic demand dictating stimulating at a different rate, the pulse generator 12 will deliver pacing stimuli at the LRL. According to various embodiments of the present invention, the LRL can be automatically adjusted by the control system 74 upon detecting the onset of decompensation so as to cause the CRM system 10 to pace the heart at an increased rate, thereby facilitating removal of fluid accumulated in the patient's heart and/or lungs.

[0033] As further discussed above, LVP is a useful indicator of hemodynamic performance in patients with CHF, and can provide an indication as to worsening hemodynamic conditions, including the onset of early decompensation in CHF patients. In particular, the left ventricular end diastolic pressure (LV-EDP) is an especially important measure used to evaluate hemodynamic state. That is, an increase in LV-EDP over time can be a reliable indicator of symptoms associated with early decompensation caused by CHF, e.g., accumulation of blood or other fluid in the heart chambers or the lungs as a result of the reduced hemodynamic performance of the heart 18 caused by CHF.

[0034] Notwithstanding the usefulness of LVP in early decompensation detection and treatment, obtaining direct LV pressure information chronically is both technically and clinically challenging. As discussed in detail below, however, LV-EDP (or other LVP-derived parameters such as LV systolic pressure (LV-SP), mean LVP, and LV dp/dt) can be estimated utilizing pressure data obtained from within a coronary vein without requiring direct pressure readings from the left ventricle or left atrium. That is, in various embodiments, coronary venous pressure (CVP) is chronically sensed using implanted pressure sensors and is utilized as a surrogate for direct LVP measurement.

[0035] Referring back to FIG. 1, the pressure sensors 38, 39 are configured to detect and generate pressure signals representative of

fluid pressure within the right atrium 20 and the coronary vein 36, respectively. From these pressure signals, pressure waveforms can be derived and evaluated by the sensing circuitry 76 and the control system of the pulse generator 12. FIG. 3 illustrates pressure waveforms obtained from the right atrium (RA), left ventricle (LV), coronary sinus (CS) and various locations in a coronary vein (CV) in an exemplary animal study. As shown, the coronary venous pressure (CVP) waveform takes on the same general shape as the LV waveform, particularly where the CVP is taken from a location lower in the coronary vein, i.e., as indicated by the "Wedged" (apical two-thirds) CV pressure graph.

[0036] FIG. 4 is an illustration depicting a CVP waveform and a corresponding LVP waveform also obtained in an exemplary animal study. As can be seen in FIG. 4, the CVP and LVP waveforms correlate closely to one another. Thus, in view of the close correlation between coronary venous pressure and LV pressure, CVP can function as a surrogate for LVP in the CRM system 10, which can then derive one or more CVP indexes that closely correlate to corresponding LVP indexes, and can thus be utilized in the same manner as the LVP indexes to adaptively adjust pacing parameters, e.g., pacing rate limits such as the lower rate limit (LRL), in response to changes in the patient's hemodynamic status.

[0037] Thus, from FIG. 4, it can be seen that LV-EDP can be estimated based on CVP signals obtained from the pressure sensor 39 implanted in the coronary vein 32, and optionally, the pressure sensor 38 implanted in the right atrium (or the coronary sinus). Additionally, changes in CV end diastolic pressure (CV-EDP) over time will correlate with changes in LV-EDP. Thus, hemodynamic performance information that can be derived from changes in LV-EDP over time can also be derived by monitoring changes in CV-EDP, which as discussed above, can be directly calculated based on CVP signals from the implanted pressure sensors. As further discussed above, one important diagnostic application of LV-EDP changes (and thus, CV-

EDP changes as well) is to detect the onset of early decompensation in CHF patients, which can be detected based on increased LV-EDP caused by the accumulation of fluid in the patient's heart and lungs.

[0038] FIG. 5 is a diagram graphically illustrating an exemplary method 200 of treating symptoms associated with CHF using the CRM system 10 according to one embodiment of the present invention. As shown in FIG. 5, the control system 74 of the CRM system 10 monitors CV-EDP calculated from the output based on the output of the implanted pressure sensor 39 (block 210). The control system 74 then detects changes in the CV-EDP, and in particular, increases in the CV-EDP above a programmed threshold value indicative of early decompensation (block 220).

[0039] Upon detecting a CV-EDP increase above the programmed threshold, the control system 74 then increases the LRL above the previously programmed value, thereby increasing the rate at which the heart 18 will be paced in the absence of sensed intrinsic events (block 230). Accordingly, by pacing at the corresponding elevated rate, the CRM system 10 facilitates removal of blood and other fluid accumulated in the patient's heart and/or lungs, thus relieving the symptoms associated with this fluid accumulation.

[0040] As further shown in FIG. 5, the control system 74 of the CRM system 10 will continue to monitor CV-EDP during the period of elevated pacing/heart rate resulting from the increase in LRL until one or more predetermined events is detected (block 240). In the illustrated embodiment, upon detection of one of the predetermined events, the control system 74 will return the LRL to its original settings (block 250). Exemplary predetermined events that will trigger this step include the CV-EDP returning back to a pre-established value, or alternatively, to a value equal to or below the programmed threshold value for triggering the LRL increase. Another event that may trigger the reduction in the LRL is the passage of a prescribed time limit for pacing at the elevated rate where the CV-EDP has not fully returned to a value below the programmed threshold. In still another embodiment,

the LRL may be reduced upon a detection by the CRM system 10, based on the CV-EDP trend, of worsening hemodynamic conditions.

[0041] In various embodiments, feedback in the form of alerts or other information regarding sensed events and/or CRM system 10 operating parameters may be transmitted over an APM system to a physician or other caregiver.

[0042] The particular CVP parameters calculated and monitored can be any parameters useful for providing an indication of the patient's hemodynamic state, and in particular, for identifying the onset of symptoms associated with early decompensation. As discussed above, increases in CV-EDP provides one such useful indicator of symptoms of early decompensation. In various embodiments, the CRM system 10 is configured to calculate average CV-EDP values over predetermined intervals, e.g., a predetermined time period or a predetermined number of beats or cardiac cycles. For example, in one embodiment, the CRM system 10 generates a CVP waveform based on the CVP signal and calculates an average CV-EDP value over a predetermined interval based on the CVP waveform. In one embodiment, the CV-EDP value monitored is a rolling average CV-EDP value, which can be monitored by the CRM system 10 over time. Thus, as shown in FIG. 5, a trend in the average CV-EDP over time is monitored by the control system 74, and this trend provides the input for triggering the LRL increase by the control system 74. In still other embodiments, other CVP parameters may be monitored by the CRM system 10.

[0043] FIG. 6 is a flow chart illustrating a method 300 of operating the CRM system 10 to treat symptoms associated with CHF according to one embodiment of the present invention. The method 300 of FIG. 6 contemplates that the CRM system 10 is implanted and programmed to pace at an initial set of pacing parameters including an initial LRL. As shown in FIG. 6, the method 300 includes acquiring a CVP signal from the implanted pressure sensors, e.g., the pressure sensor 39 of FIG. 1 (block 310). From the pressure signal, the control

system 74 of the CRM system 10 calculates a baseline CV-EDP value (block 320). In one embodiment, this baseline CV-EDP value may be based on a single measurement at a predetermined time. Alternatively, the baseline CV-EDP value may be an average CV-EDP value over a predetermined sampling interval.

[0044] As further shown in FIG. 6, the control system 74 subsequently monitors average CV-EDP values (block 330), and compares the average CV-EDP values to the baseline CV-EDP value (block 340). Here again, the average CV-EDP values may constitute a series of rolling average CV-EDP values each calculated for a predetermined time period or number of beats/cycles.

[0045] As shown, in comparing the average CV-EDP values to the baseline CV-EDP value, the control system 74 determines whether the difference (ΔCV-EDP) between at least one of the average CV-EDP values and the baseline average CV-EDP value exceeds a predetermined threshold amount (block 350). If not, the control system 74 will continue to monitor the average CV-EDP values and compare them to the baseline CV-EDP value. If, however, the ΔCV-EDP does exceed the predetermined threshold amount, the control system 74 increases the LRL and monitors the average CV-EDP values at the elevated heart/pacing rates associated with the increased LRL (block 360). In one embodiment, the CRM system 10 maintains the LRL at the increased setting for a prescribed time period, and then determines whether a predetermined event has occurred (block 370).

[0046] The threshold ΔCV-EDP values for triggering the LRL increase can be determined by the clinician at implantation or thereafter through programming changes based on the patient's history and clinical needs. Additionally, the ΔCV-EDP can be based on any useful measure of CVP changes. For example, in one embodiment, the ΔCV-EDP will be evaluated as a change average CV-EDP value measured as a percentage of the baseline value. Thus, in this example, the control system 74 may be programmed to initiate the LRL increase when the ΔCV-EDP value reaches a predetermined

percentage increase over the baseline CV-EDP value, in which case this percentage would represent the programmed threshold value described above. In another embodiment, the ΔCV-EDP may be expressed as an absolute rise, e.g., as measured in mm/Hg, in the average CV-EDP over the baseline CV-EDP. In short, the CRM system 10 provides for broad flexibility in defining the specific operating parameters/thresholds.

[0047] Similar to the method 200 discussed above, exemplary predetermined events include the ΔCV-EDP returning to a value equal to or below the programmed threshold value for triggering the LRL increase. Another event that may trigger the reduction in the LRL is the passage of a prescribed time limit for pacing at the elevated rate where the CV-EDP has not fully returned to a value below the programmed threshold. In still another embodiment, the LRL may be reduced upon a detection by the CRM system 10, based on the CV-EDP trend, of worsening hemodynamic conditions.

[0048] As shown, if one or more of the predetermined events has occurred, the control system 74 returns the LRL back to its initial setting (block 380). If one or more of the predetermined events has not occurred, in the illustrated embodiment, the control system 74 further increases the LRL and continue to monitor the CV-EDP for a prescribed time period, as indicated by the return arrow to from block 370 to block 360 in FIG. 6. In another embodiment, the control system 74 will maintain the LRL at the initial elevated rate, but will not initiate further increases in the LRL setting (i.e., the return arrow from block 370 to block 360 in FIG. 6 is omitted).

[0049] In still other embodiments, other operating parameters may be programmed into the control system 74 of the CRM system 10. In one exemplary embodiment, the control system 74 may be programmed to initiate a predetermined number of LRL increases while not to exceeding a maximum pacing rate limit, e.g., the maximum sensor rate (MSR) or maximum tracking rate (MTR). Thus, for example, the control system 74 may be programmed to increase the

LRL up to a rate setting a predetermined margin, e.g., expressed as a percentage of or a number of beats/minute below the MSR/MTR. In short, a range of operating scenarios can be implemented according to the various embodiments of the present invention.

[0050] While not shown in FIG. 6, the method 300 further contemplates recalculating the baseline CV-EDP value(s) after completion of the therapy cycle described above (i.e., upon returning the LRL to its initial programmed value). Thus, the method 300 can then be repeated as appropriate.

[0051] Thus, the CRM system 10 utilizes hemodynamic performance information based on the output from implanted CVP sensors to diagnose medical conditions, such as the onset of early decompensation resulting from CHF, and to adjust the LRL settings so as to pace the heart at an elevated rate to facilitate removal of fluid accumulated in the patient's cardiopulmonary system as a result of CHF. The CRM system 10 thus advantageously provides a means for diagnosing and treating CHF-related symptoms based on actual patient hemodynamic state information.

[0052] Various modifications and additions can be made to the exemplary embodiments discussed without departing from the scope of the present invention. For example, while the embodiments described above refer to particular features, the scope of this invention also includes embodiments having different combinations of features and embodiments that do not include all of the described features. Accordingly, the scope of the present invention is intended to embrace all such alternatives, modifications, and variations as fall within the scope of the claims, together with all equivalents thereof.

CLAIMS

We claim:

1. An implantable medical device comprising an implantable pulse generator configured to generate an electrical stimulus to be delivered to a patient's heart according to a first set of pacing parameters including a lower rate limit (LRL) setting, the pulse generator including a control system configured to:

acquire a coronary venous pressure (CVP) signal from a pressure sensor implanted in a coronary vein of the patient;

calculate an average coronary venous end diastolic pressure (CV-EDP) value from the CVP signal;

monitor the average CV-EDP value over a predetermined interval; and

dynamically adjust the LRL setting responsive to the detection of a first or a second predetermined event based on the average CV-EDP value.

2. The device of claim 1 wherein the control system is configured to increase the LRL setting in response to detecting the first predetermined event.

3. The device of either of claims 1 or 2 wherein the control system is configured to reduce the LRL setting upon detecting the second predetermined event.

4. The device of any of claims 1 through 3 wherein the first predetermined event is an increase in the average CV-EDP value indicative of an onset of early decompensation symptoms.

5. The device of any of claims 1 through 4 wherein the second predetermined event is a reduction in the average CV-EDP value indicating the termination of early decompensation symptoms.

6. The device of any of claims 1 through 4 wherein the second predetermined event is an expiration of a predetermined time period for applying the electrical stimulus at the increased LRL setting.

7. The device of any of claims 1 through 6 wherein the control system is configured to generate a CVP waveform based on the CVP signal, and to calculate an average CV-EDP value over a predetermined interval based on the CVP waveform.

8. The device of any of claims 1 through 7 wherein the first predetermined event is an increase in the average CV-EDP value over a selected interval exceeding a predetermined threshold.

9. The device of claim 1 wherein the control system is further configured to:

calculate a baseline CV-EDP value from the CVP signal corresponding to a first interval; and

compare each of average CV-EDP values to the baseline CV-EDP value.

10. The device of claim 9 wherein the first predetermined event is a difference (ΔCV-EDP) between at least one of the average CV-EDP values and the baseline average CV-EDP value exceeding a predetermined threshold, and wherein the control system is configured to automatically increase the LRL setting in response to the first predetermined event, and to subsequently automatically reduce the LRL setting upon detecting the second predetermined event.

11. The device of claim 10 wherein the second predetermined event includes the ΔCV-EDP returning to below the predetermined threshold.

12. The device of either of claims 10 or 11 wherein the second predetermined event is an expiration of a predetermined time period for applying the electrical stimulus at the increased LRL setting.

13. The device of any of claims 10 through 12 wherein the baseline CV-EDP value is a rolling average CV-EDP value over a plurality of cardiac cycles or a predetermined time interval.

14. The device of any of claims 10 through 13 wherein the control system is further configured to recalculate the baseline CV-EDP value after reducing the LRL setting upon detecting the second predetermined event.

15. The device of any of claims 10 through 14 wherein the predetermined threshold is a programmed percentage change in any of the plurality of average CV-EDP values relative to the baseline CV-EDP value.

16. The device of any of claims 10 through 15 the control system is configured to maintain the LRL setting at the increased setting for a prescribed time interval.

17. The device of claim 16 wherein the control system is further configured to increase the LRL if the second predetermined event is not detected after the prescribed time interval.

18. The device of claim 17 wherein the control system is further configured to increase the LRL up to a prescribed maximum LRL if the second predetermined event is not detected after the prescribed time interval.

19. An implantable rate adaptive cardiac rhythm management system configured for applying pacing stimuli to a patient's heart, the pacing stimuli defined by pacing parameters including a pacing rate and an LRL setting, the system comprising:

the implantable medical device of any of claims 1 through 18; and

a plurality of implantable medical electrical leads configured to sense cardiac electrical activity and to deliver the pacing stimuli, at least one of the leads being configured for chronic implantation within a coronary vein of the patient's heart and including a pressure sensor configured to generate a coronary venous pressure (CVP) signal indicative of fluid pressure within the coronary vein.

20. The system of claim 19 wherein the control system is further configured to estimate and monitor average left ventricular end diastolic pressure (LV-EDP) values based on the CVP signal.

21. A method of operating an implanted cardiac rhythm management system in a patient, the method comprising:

applying an electrical stimulus to the patient's heart at a first set of pacing parameters including a lower rate limit (LRL) setting;

acquiring a coronary venous pressure (CVP) signal from a pressure sensor implanted in a coronary vein of the patient;

calculating an average coronary venous end diastolic pressure (CV-EDP) value from the CVP signal;

monitoring the average CV-EDP value over a predetermined interval; and

dynamically adjusting the LRL setting responsive to the detection of a first or a second predetermined event based on the average CV-EDP value.

22. The method of claim 21 wherein dynamically adjusting the LRL setting includes increasing the LRL setting in response to detecting the first predetermined event.

23. The method of either of claims 21 or 22 wherein dynamically adjusting the LRL setting includes reducing the LRL setting upon detecting the second predetermined event.

24. The method of any of claims 21 through 23 wherein the first predetermined event is an increase in the average CV-EDP value indicative of an onset of early decompensation symptoms.

25. The method of any of claims 21 through 24 wherein the second predetermined event is a reduction in the average CV-EDP value indicating the termination of early decompensation symptoms.

26. The method of any of claims 21 through 24 wherein the second predetermined event is an expiration of a predetermined time period for applying the electrical stimulus at the increased LRL setting.

27. The method of any of claims 21 through 26 wherein calculating the average CV-EDP value includes generating a CVP waveform based on the CVP signal and calculating an average CV-EDP value over a predetermined interval based on the CVP waveform.

28. The method of any of claims 21 through 27 wherein the first predetermined event is an increase in the average CV-EDP value over a selected interval exceeding a predetermined threshold.

29. The method of claim 21 further comprising:

calculating a baseline CV-EDP value from the CVP signal corresponding to a first interval; and

comparing each of average CV-EDP values to the baseline CV-EDP value.

30. The method of claim 29 wherein the first predetermined event is a difference (ΔCV-EDP) between at least one of the average CV-EDP values and the baseline average CV-EDP value exceeding a predetermined threshold, and further comprising:

automatically increasing the LRL setting in response to the first predetermined event; and

subsequently automatically reducing the LRL setting upon detecting the second predetermined event.

31. The method of claim 30 wherein the second predetermined event includes the ΔCV-EDP returning to below the predetermined threshold.

32. The method of claim 30 wherein the second predetermined event is an expiration of a predetermined time period for applying the electrical stimulus at the increased LRL setting.

33. The method of claim any of claims 29 through 32 wherein the baseline CV-EDP value is a rolling average CV-EDP value over a plurality of cardiac cycles or a predetermined time interval.

34. The method of any of claims 29 through 33 further comprising recalculating the baseline CV-EDP value after reducing the LRL setting upon detecting the second predetermined event.

35. The method of any of claims 29 through 34 wherein the predetermined threshold is a programmed percentage change in any of the plurality of average CV-EDP values relative to the baseline CV-EDP value.

36. The method of any of claims 29 through 35 wherein automatically increasing the LRL setting includes maintaining the LRL setting at the increased setting for a prescribed time interval.

37. The method of claim 36 further comprising increasing the LRL if the second predetermined event is not detected after the prescribed time interval.

38. The method of claim 37 further comprising increasing the LRL up to a prescribed maximum LRL if the second predetermined event is not detected after the prescribed time interval.

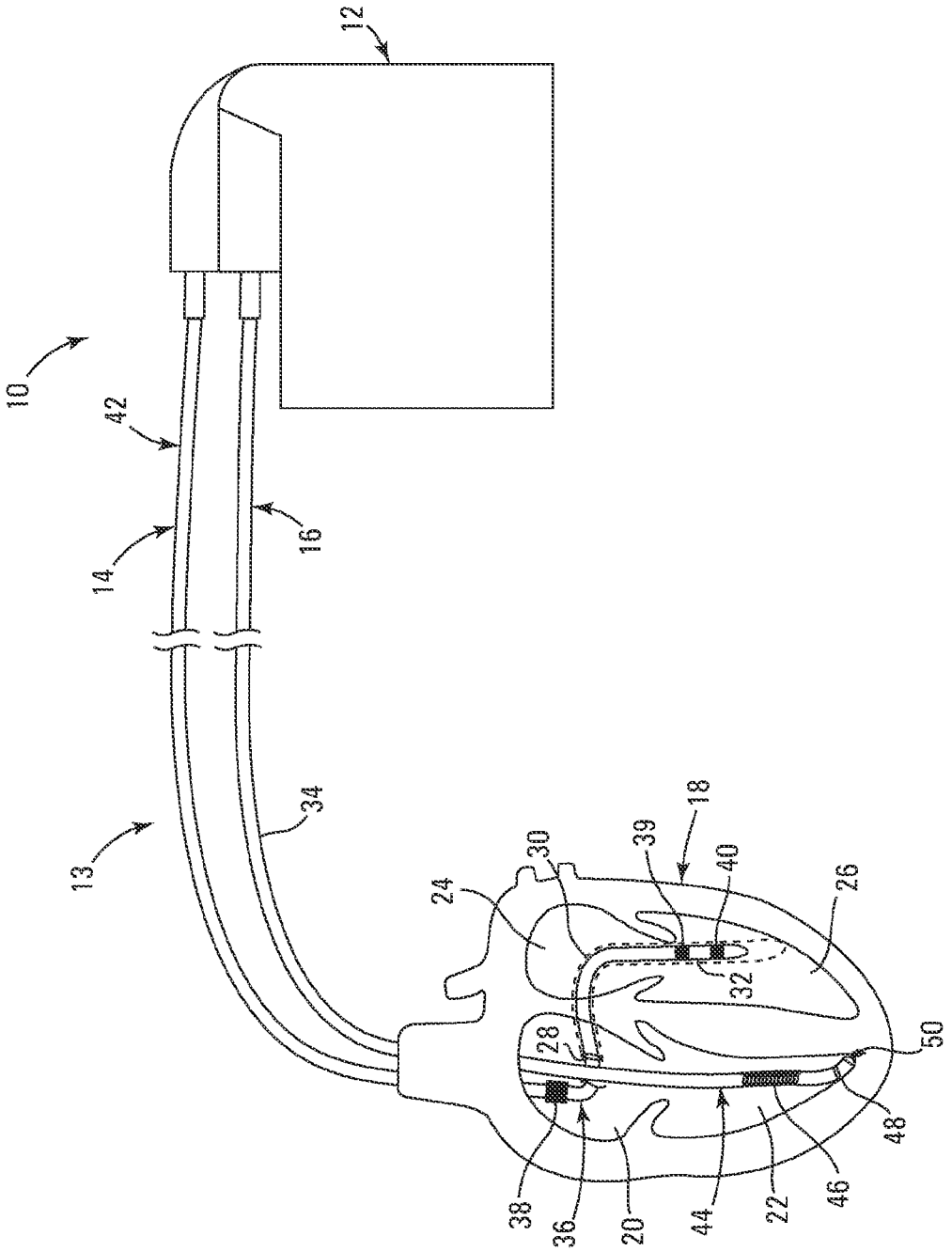

Fig. 1

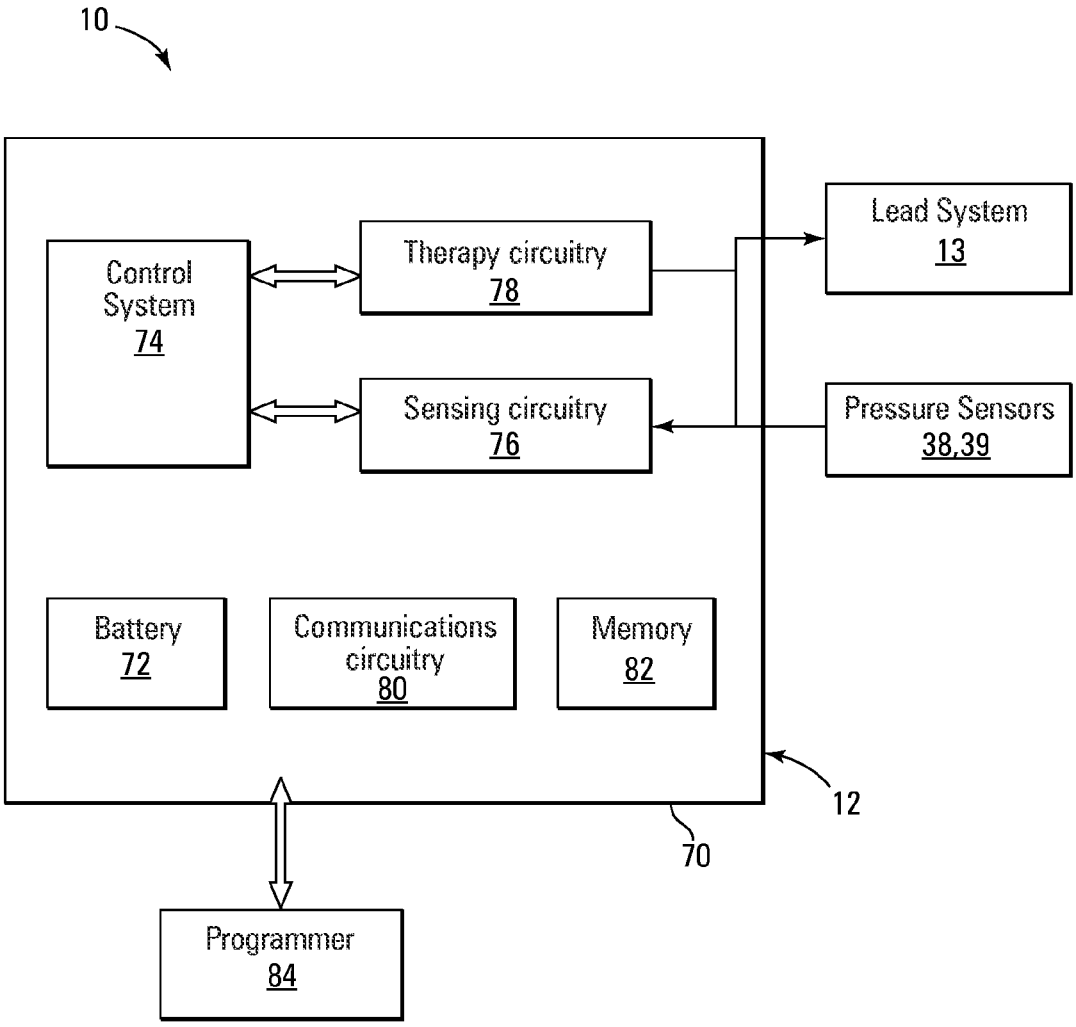
10
Control System 74
Therapy circuitry 78
Sensing circuitry 76
Lead System 13
Pressure Sensors 38,39
Battery 72
Communications circuitry 80
Memory 82
12
70
Programmer 84

Fig. 2

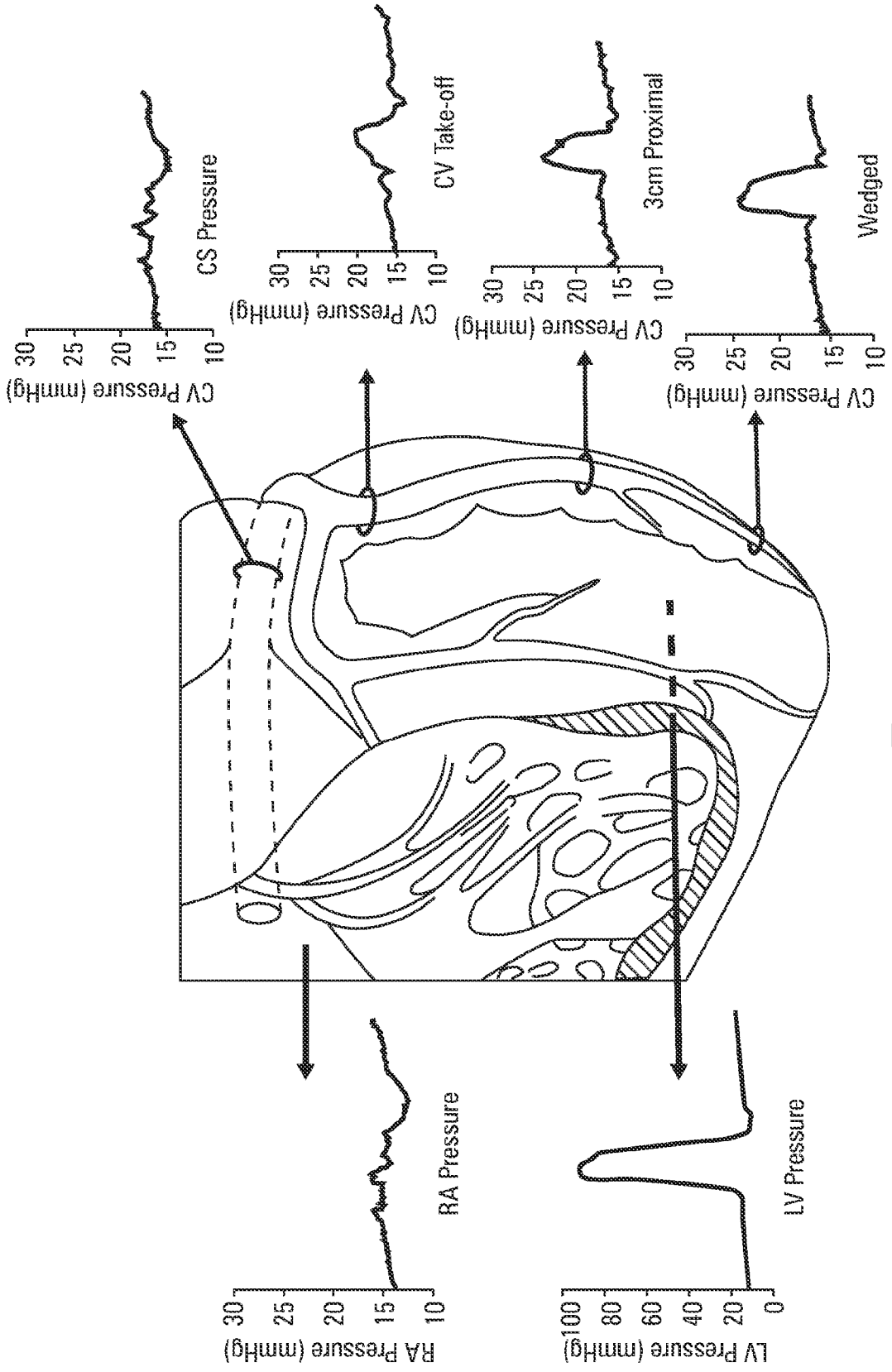
CS Pressure
CV Pressure (mmHg)
CV Take-off
CV Pressure (mmHg)
3cm Proximal
CV Pressure (mmHg)
Wedged
CV Pressure (mmHg)
RA Pressure
RA Pressure (mmHg)
LV Pressure
LV Pressure (mmHg)

Fig. 3

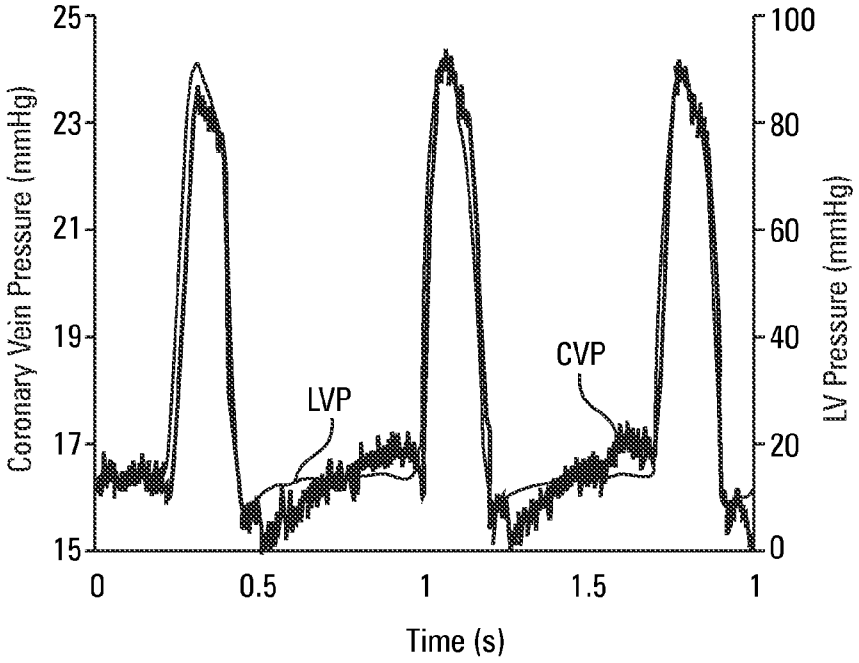
25
23
21
19
17
15
Coronary Vein Pressure (mmHg)
100
80
60
40
20
0
LV Pressure (mmHg)
LVP
CVP
0
0.5
1
1.5
1
Time (s)

Fig. 4

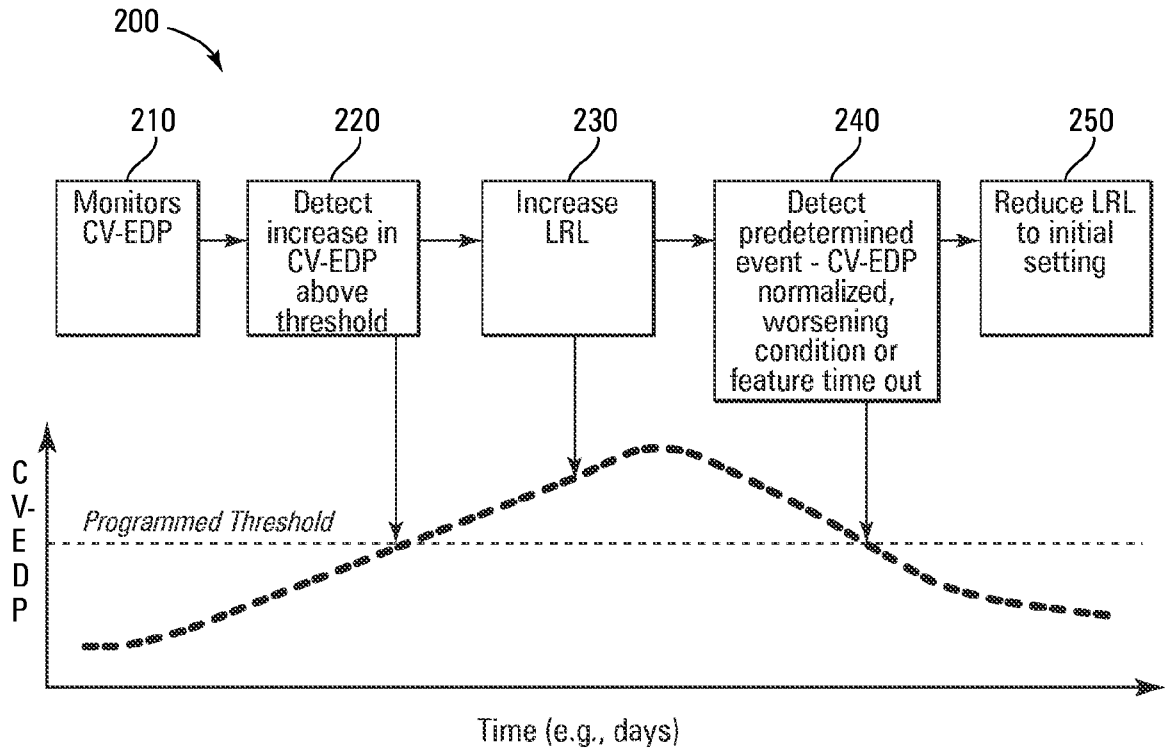
200
210
220
230
240
250
Monitors CV-EDP
Detect increase in CV-EDP above threshold
Increase LRL
Detect predetermined event - CV-EDP normalized, worsening condition or feature time out
Reduce LRL to initial setting
CV-EDP
Programmed Threshold
Time (e.g., days)

Fig. 5

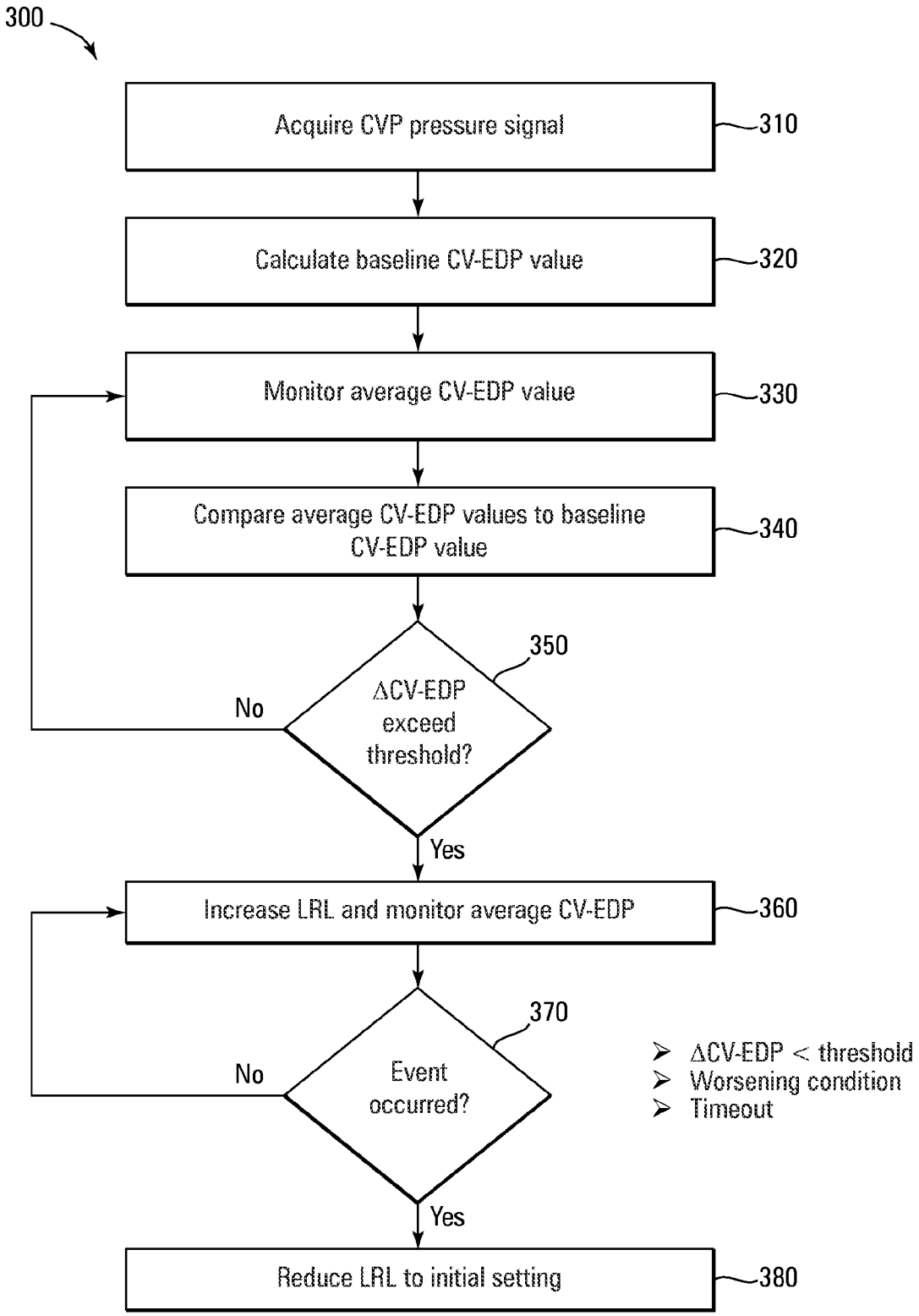
300
Acquire CVP pressure signal
310
Calculate baseline CV-EDP value
320
Monitor average CV-EDP value
330
Compare average CV-EDP values to baseline CV-EDP value
340
350
ΔCV-EDP exceed threshold?
No
Yes
Increase LRL and monitor average CV-EDP
360
370
Event occurred?
No
Yes
ΔCV-EDP < threshold
Worsening condition
Timeout
Reduce LRL to initial setting
380

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/036137

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/365
ADD.

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

B. FIELDS SEARCHED

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

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

Electronic data base consulted during the international search (name of data base and, where practical, 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 2007/239219 A1 (SALO RODNEY W [US] ET AL) 11 October 2007 (2007-10-11) paragraph [0018]; figures 1A-3 paragraph [0017] paragraph [0031] paragraph [0020]	1,9, 15-18 10-12
X Y	US 2002/188329 A1 (STRUBLE CHESTER [NL]) 12 December 2002 (2002-12-12) paragraph [0081] - paragraph [0082]; figures 4,6,7,9-11 paragraph [0074] paragraph [0099] - paragraph [0102] paragraph [0106] - paragraph [0110] paragraph [0056] - paragraph [0058]	1-8,13, 14,19,20 10-12

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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 document but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 October 2010	28/10/2010

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/036137

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
A	EP 0 498 533 A1 (CARDIAC PACEMAKERS INC [US]) 12 August 1992 (1992-08-12) the whole document	1-20
A	US 2008/082135 A1 (ARCOT-KRISHNAMURTHY SHANTHA [US] ET AL) 3 April 2008 (2008-04-03) paragraph [0027]	1-20
A	US 5 626 623 A (KIEVAL ROBERT S [US] ET AL) 6 May 1997 (1997-05-06) the whole document	1-20

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/036137

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 [Xj Claims Nos 21-38
because they relate to subject matter not required to be searched by this Authority, namely

Rule 39.1(iv) PCT - Method for treatment of the human or animal body **by therapy**

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

3 [ ] Claims Nos
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6 4(a)

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

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

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

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

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

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

Remark on Protest

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

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

[ ] No protest accompanied the payment of additional search fees

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2010/036137

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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