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(54) **SYSTEM AND METHOD FOR DETECTING TAMPONADE**

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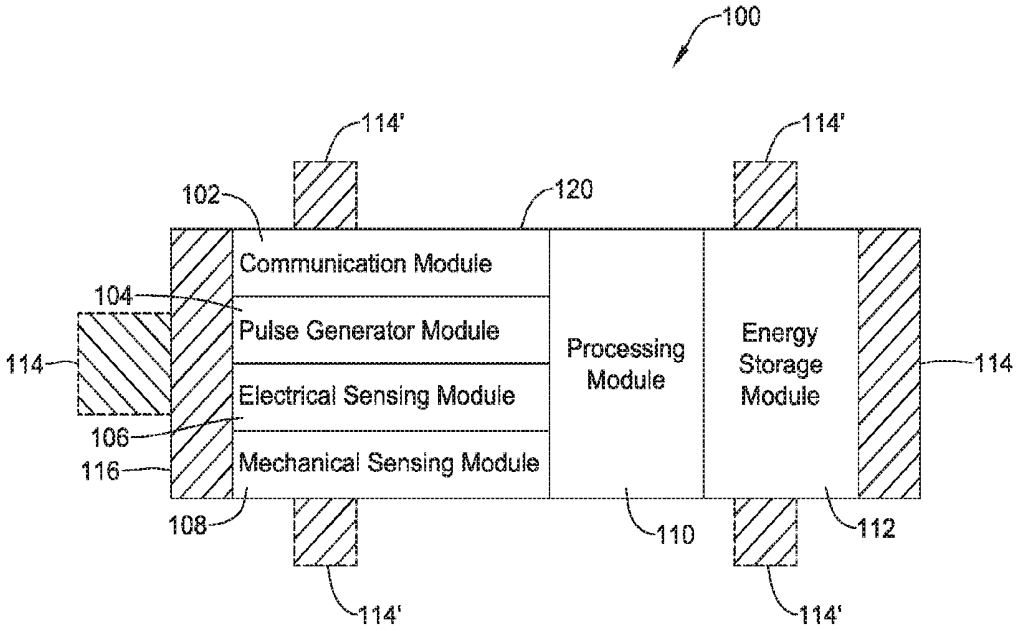
(57) **ABSTRACT**

Systems, methods, and devices for determining occurrences of a tamponade condition are disclosed. One exemplary method includes monitoring an accelerometer signal of a leadless cardiac pacemaker attached to a heart wall, determining if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal, and in response to determining that the tamponade condition is indicated, providing a notification of the tamponade condition for use by a physician to take corrective action.



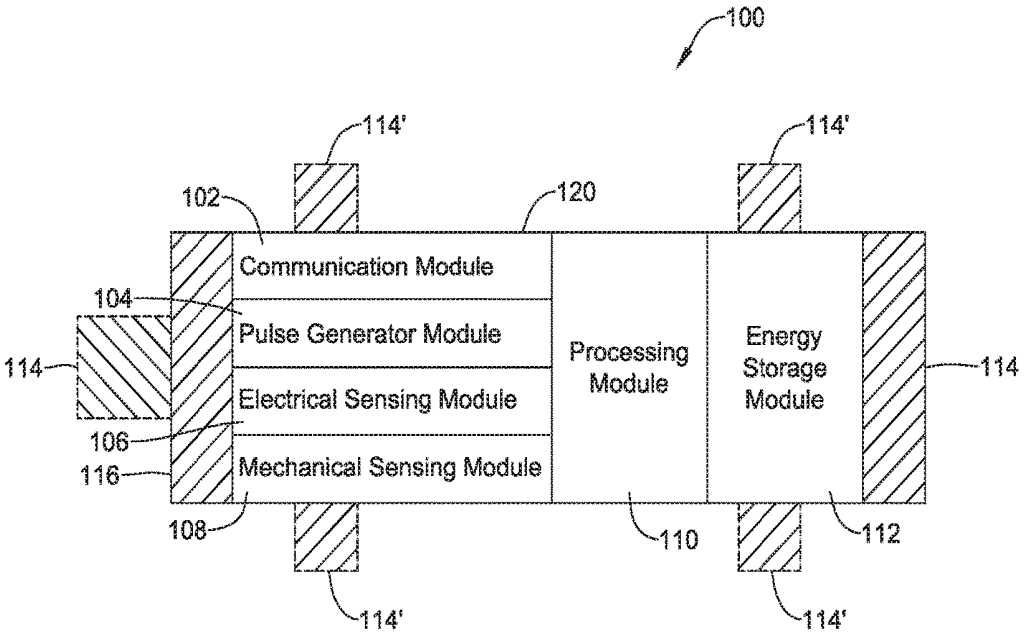

100
114'
114'
102
120
Communication Module
104
Pulse Generator Module
Processing Module
Energy Storage Module
114
114
Electrical Sensing Module
106
116
Mechanical Sensing Module
108
110
112
114'
114'

Figure 1

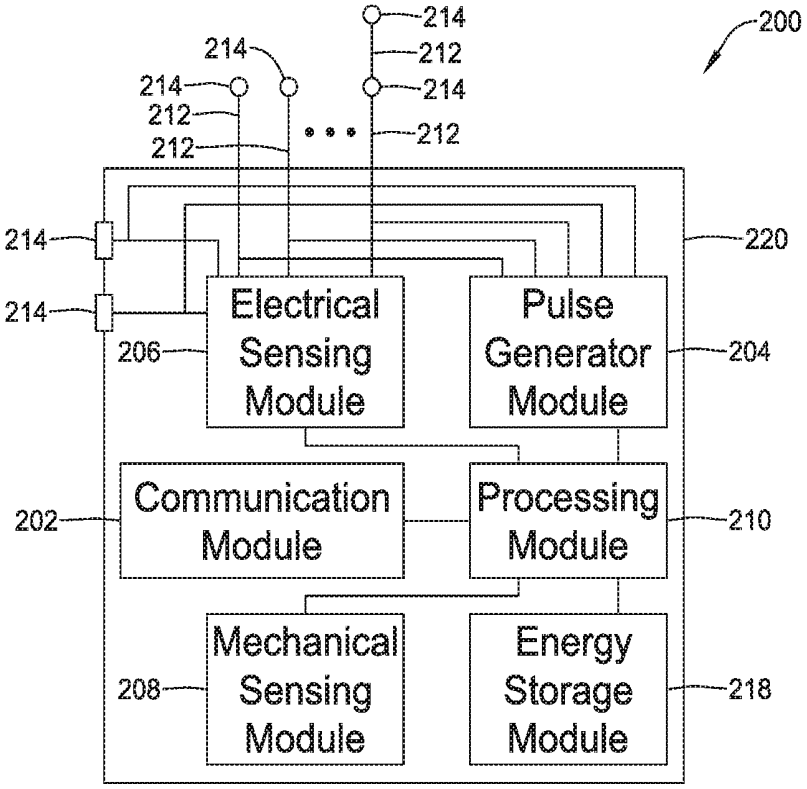

214
214
214
212
214
212
212
212
200
214
214
220
206
Electrical Sensing Module
Pulse Generator Module
204
202
Communication Module
Processing Module
210
208
Mechanical Sensing Module
Energy Storage Module
218

Figure 2

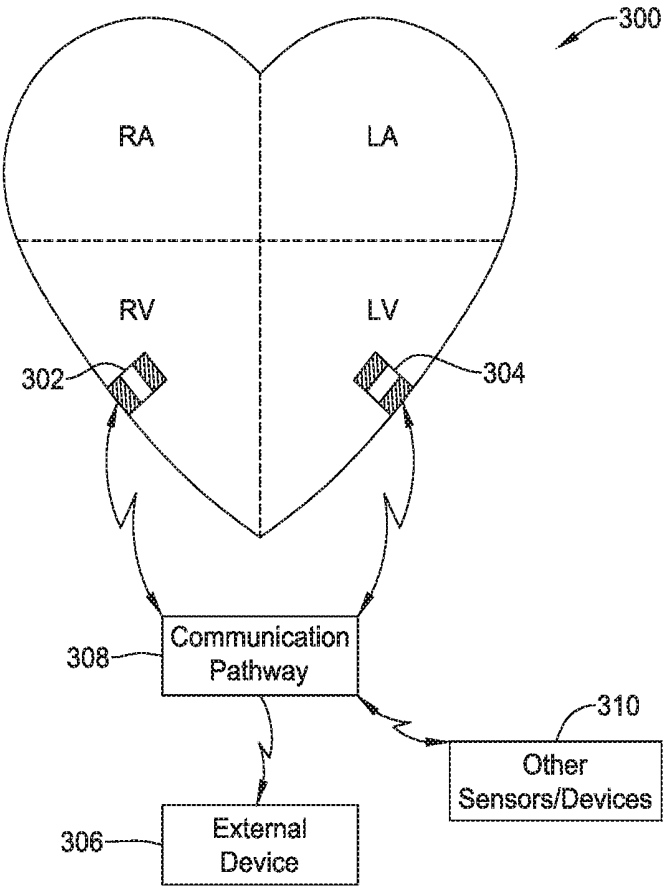

300
RA
LA
RV
LV
302
304
Communication Pathway
308
310
Other Sensors/Devices
External Device
306

Figure 3

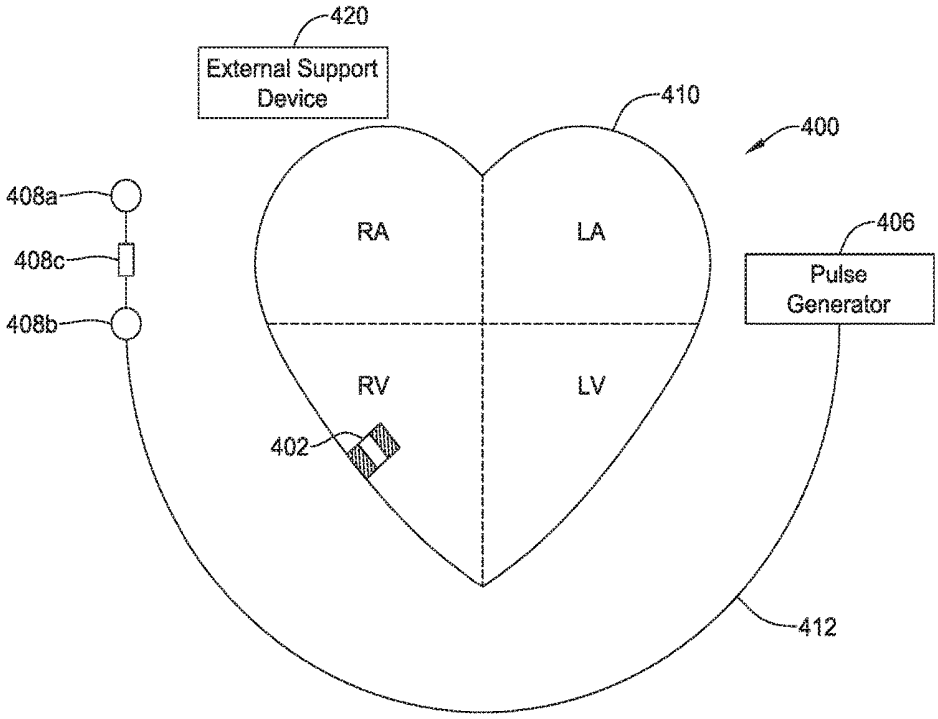

420
External Support Device
410
400
406
Pulse Generator
408a
408c
408b
RA
LA
RV
LV
402
412

Figure 4

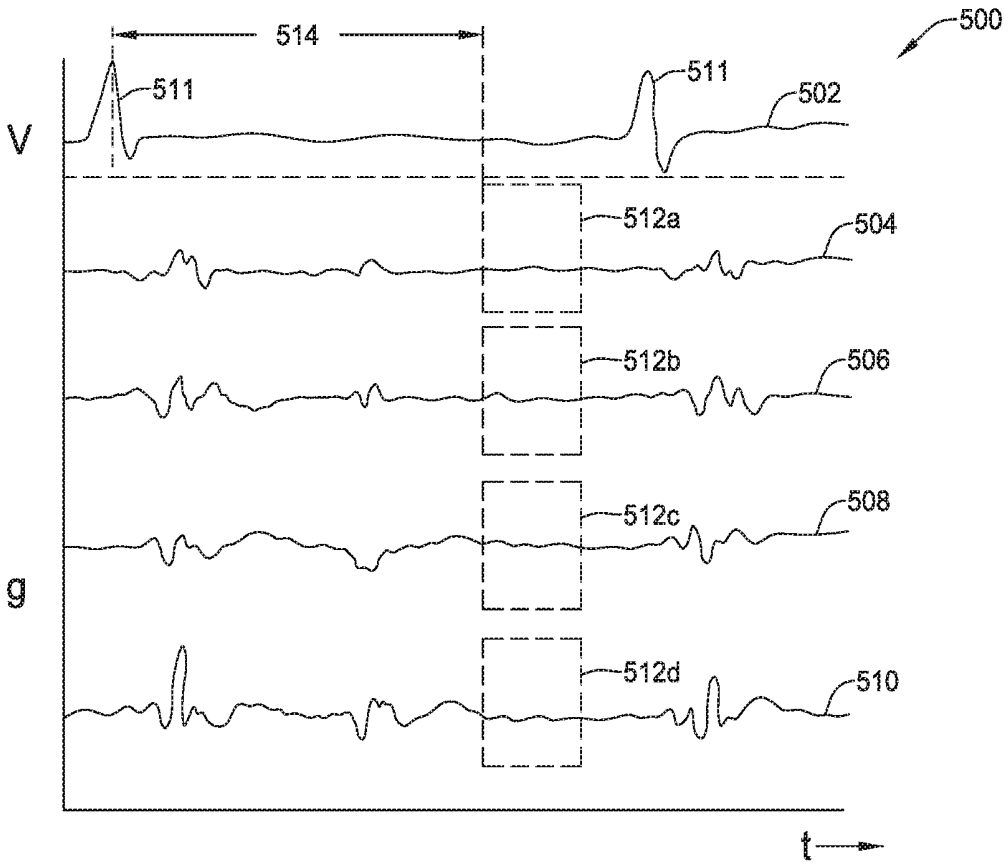


FIG. 5

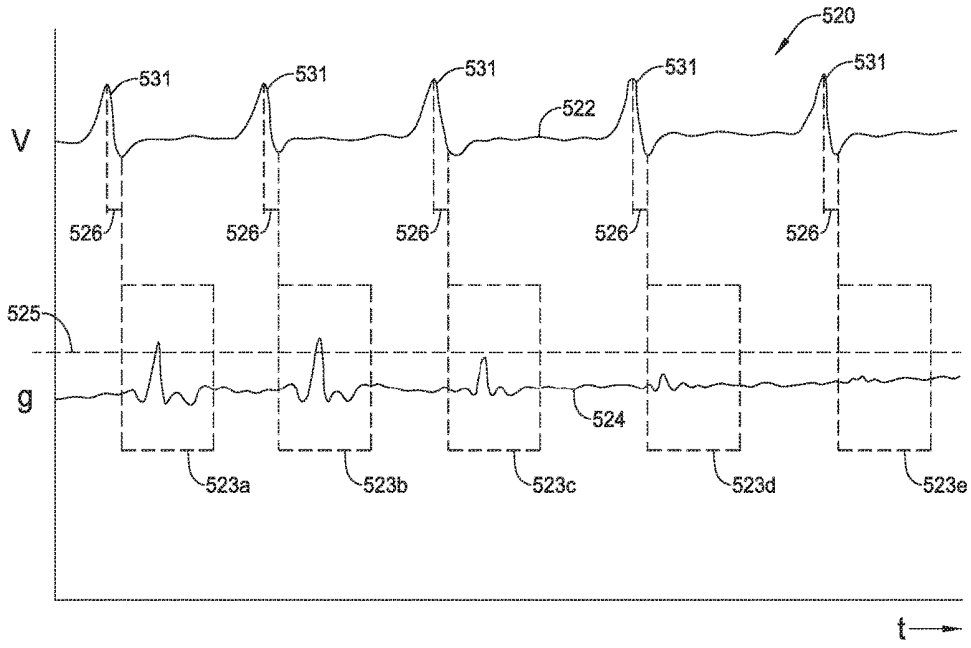

520
531
531
531
531
531
522
V
526
526
526
526
526
525
g
524
523a
523b
523c
523d
523e
t

Figure 6

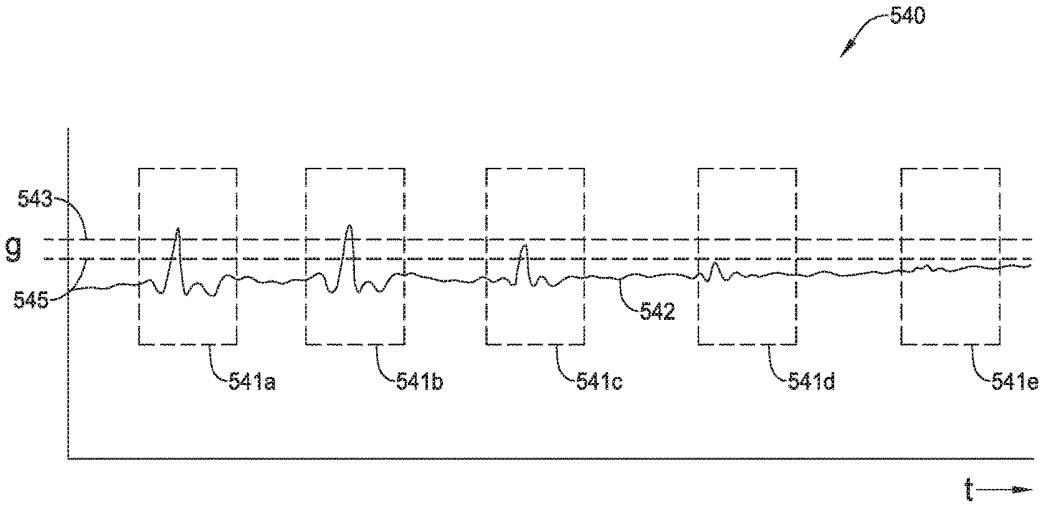


Figure 7

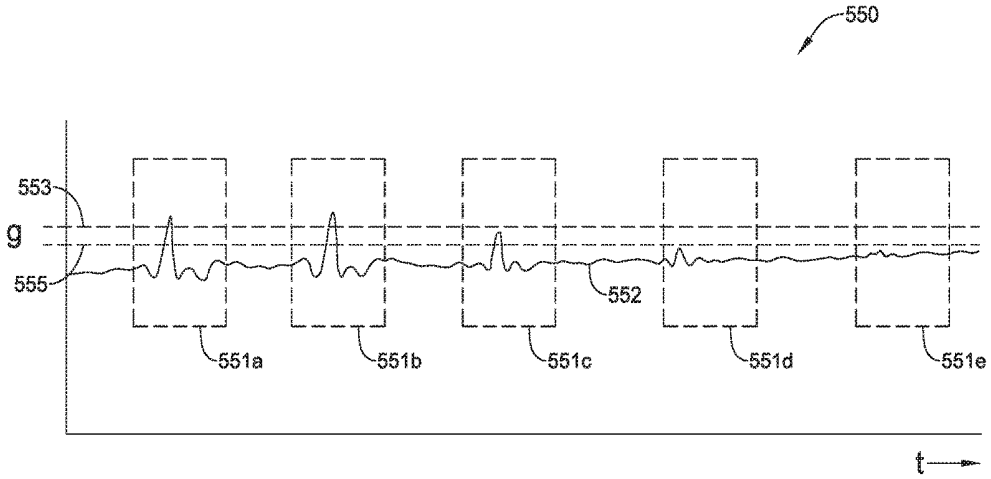


Figure 8

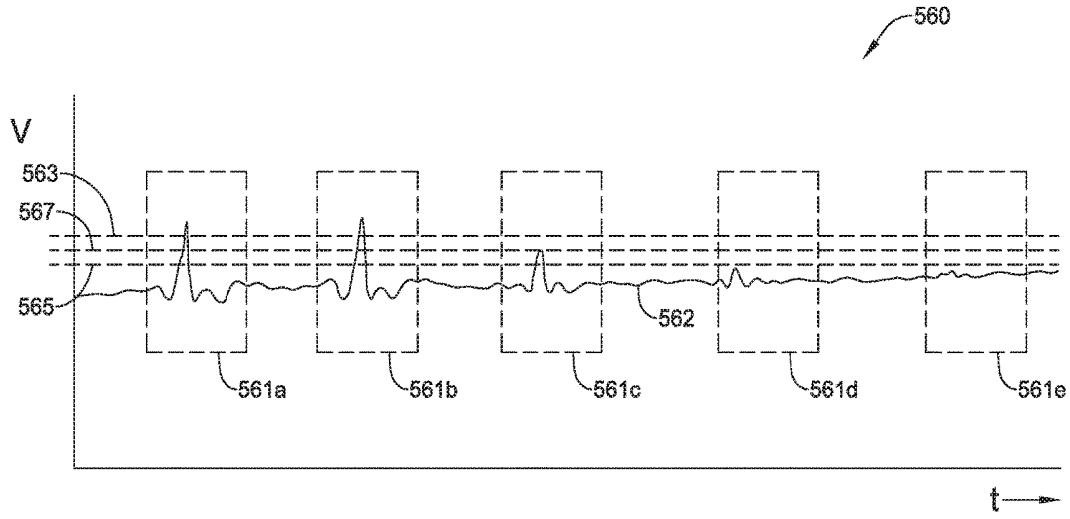


Figure 9

SYSTEM AND METHOD FOR DETECTING TAMPONADE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation of co-pending U.S. patent application Ser. No. 15/244,571 filed on Aug. 23, 2016, which claims the benefit of U.S. Provisional Patent Application Ser. No. 62/211,333 filed on Aug. 28, 2015, both of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure generally relates to systems, devices, and methods for detecting a tamponade condition, and more particularly, to systems, devices, and methods for detecting a tamponade condition using one or more signals sensed by an implanted medical device.

BACKGROUND

[0003] 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.) may be 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, such devices may be attached, at least partially, to the heart.

SUMMARY

[0004] The present disclosure generally relates to systems, devices, and methods for detecting a tamponade condition, and more particularly, to systems, devices, and methods for detecting a tamponade condition using one or more signals sensed by an implanted medical device. In a first illustrative embodiment, a leadless cardiac pacemaker for use in pacing a patient's heart may comprise a plurality of electrodes, an accelerometer for providing an accelerometer signal. The leadless cardiac pacemaker may further comprise a controller operatively coupled to the plurality of electrodes and the accelerometer. The leadless cardiac pacemaker may be implanted into a patient's heart and attached to a wall of the patient's heart using one or more fixation elements. In some instances, fixing the fixation elements to the patient's heart may cause a tamponade condition. In some instances, the controller may be configured to monitor the accelerometer signal of the leadless cardiac pacemaker and determine if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal. If the controller determines that a tamponade condition is indicated, the controller may provide a notification of the tamponade condition for use by a physician to take corrective action.

[0005] Additionally, or alternatively, in some embodiments according to the first illustrative embodiment, to determine if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal, the controller may be configured to identify a characteristic of the accelerometer signal, determine if the identified characteristic changes (e.g. diminishes) over time, and determine that the tamponade condition is indicated if the identified characteristic of the of the accelerometer signal changes (e.g. diminishes) over time.

[0006] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, the identified characteristic may comprise a peak amplitude of the accelerometer signal.

[0007] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, the identified characteristic may comprise a peak amplitude of an integral of the accelerometer signal.

[0008] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, determining if the identified characteristic diminishes over time may comprise determining if the identified characteristic falls below a predetermined threshold.

[0009] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, wherein the accelerometer signal may represent one axis of a multi-axis accelerometer.

[0010] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, the accelerometer signal may represent a summed signal of all axes of a multi-axis accelerometer.

[0011] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, to provide the notification, the controller may be configured to communicate a message to an external device programmer.

[0012] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, the notification of the tamponade condition may be communicated using two or more of the plurality of electrodes of the leadless cardiac pacemaker.

[0013] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, to determine if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal, the controller may be configured to determine if a feature of the accelerometer signal falls below a first threshold.

[0014] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, to determine if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal, the controller may be further configured to determine if the feature of the accelerometer signal rises above a second threshold within a predetermined period of time, and determine that the tamponade condition is indicated if the feature of the accelerometer signal does not rise above the second threshold within the predetermined period of time.

[0015] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, to determine if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal, the controller may be further configured to determine whether the feature of the accelerometer signal has diminished below a second threshold value before rising above a third threshold value, and determine that the tamponade condition is indicated if the feature of the accelerometer signal has diminished below the second threshold value before rising above the third threshold value.

[0016] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, the third threshold value may be less than the first threshold value.

[0017] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, the leadless cardiac pacemaker may further comprise a pressure sensor, and the controller the controller may be further configured to monitor a cardiac electrical signal sensed via the plurality of electrodes, determine if a tamponade condition of the patient's heart is indicated based at least in part on the sensed cardiac electrical signal, and in response to determining that the tamponade condition is indicated, provide a notification of the tamponade condition for use by a physician to take corrective action.

[0018] Additionally, or alternatively, in any of the above embodiments according to the first illustrative embodiment, to determine if a tamponade condition of the patient's heart is indicated based at least in part on the intracardiac signal, the controller may be configured to determine if a detected peak amplitude of the intracardiac pressure signal diminishes below a threshold value.

[0019] In a second illustrative embodiment, a method for detecting a tamponade condition of a patient's heart after attachment of a leadless cardiac pacemaker to the patient's heart, the leadless cardiac pacemaker having an accelerometer that produces an accelerometer signal, may comprise monitoring the accelerometer signal of the leadless cardiac pacemaker, determining if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal, and in response to determining that the tamponade condition is indicated, providing a notification of the tamponade condition for use by a physician to take corrective action.

[0020] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, the determining step may comprise identifying a characteristic of the accelerometer signal, determining if the identified characteristic diminishes over time, and determining that the tamponade condition is indicated if the identified characteristic of the of the accelerometer signal diminishes over time.

[0021] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, the identified characteristic may comprise a peak amplitude of the accelerometer signal.

[0022] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, the identified characteristic may comprise a peak amplitude of an integral of the accelerometer signal.

[0023] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, the accelerometer signal may represent one axis of a multi-axis accelerometer.

[0024] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, the accelerometer signal may represent a summed signal of all axes of a multi-axis accelerometer.

[0025] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, determining if the identified characteristic diminishes over time may comprise determining if the identified characteristic falls below a predetermined threshold.

[0026] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, the leadless cardiac pacemaker may perform the monitoring, determining and providing steps.

[0027] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, the leadless cardiac pacemaker may perform the monitoring step.

[0028] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, an external device programmer may perform one or more of the monitoring, determining and providing steps.

[0029] Additionally, or alternatively, in any of the above embodiments according to the second illustrative embodiment, providing the notification may comprise communicating a message from the leadless cardiac pacemaker for reception by an external device programmer.

[0030] In a third illustrative embodiment, a leadless cardiac pacemaker for use in pacing a patient's heart may comprise a plurality of electrodes, an accelerometer for providing an accelerometer signal, and a controller operatively coupled to the plurality of electrodes and the accelerometer. In at least some embodiments, the controller may be configured to monitor the accelerometer signal of the accelerometer over time, determine if a tamponade condition of the patient's heart is indicated based at least in part on the monitored accelerometer signal, and, in response to determining that the tamponade condition is indicated, communicate a notification of the tamponade condition for use by a physician to take corrective action.

[0031] Additionally, or alternatively, in any of the above embodiments according to the third illustrative embodiment, the notification of the tamponade condition may be communicated using two or more of the plurality of electrodes of the leadless cardiac pacemaker.

[0032] Additionally, or alternatively, in any of the above embodiments according to the third illustrative embodiment, to determine if the tamponade condition of the patient's heart is indicated, the controller may be configured to identify a characteristic of the accelerometer signal, determine if the identified characteristic diminishes over time, and determine that the tamponade condition is indicated if the identified characteristic of the of the accelerometer signal diminishes over time.

[0033] Additionally, or alternatively, in any of the above embodiments according to the third illustrative embodiment, the identified characteristic may comprise a peak amplitude of the accelerometer signal.

[0034] Additionally, or alternatively, in any of the above embodiments according to the third illustrative embodiment, the identified characteristic may comprise a peak amplitude of an integral of the accelerometer signal.

[0035] In a fourth illustrative embodiment, a leadless cardiac pacemaker may comprise a plurality of electrodes, an accelerometer for providing an accelerometer signal, a controller operatively coupled to the plurality of electrodes and the accelerometer. In at least some embodiments, the controller may be configured to monitor an indication of a range of physical motion of a patient's heart over time using the accelerometer signal, determine if the indication of the range of physical motion of the patient's heart reduces over time by at least a predefined amount, and, if it is determined that the indication of the range of physical motion of the patient's heart has reduced over time by at least the pre-

defined amount, communicate a notification of a possible tamponade condition for reception by a remote device that is remote from the leadless cardiac pacemaker.

[0036] Additionally, or alternatively, in any of the above embodiments according to the fourth illustrative embodiment, the controller may be further configured to monitor a heart rate of the patient's heart over time and to determine if the heart rate increases over time by at least a predetermined heart rate amount.

[0037] Additionally, or alternatively, in any of the above embodiments according to the fourth illustrative embodiment, the controller may only communicate a notification of the possible tamponade condition if it is determined that the indication of the range of physical motion of the patient's heart has reduced over time by at least the predefined amount and the heart rate of the patient's heart has increased over time by at least the predetermined heart rate amount.

[0038] Additionally, or alternatively, in any of the above embodiments according to the fourth illustrative embodiment, the notification of the possible tamponade condition may be communicated using two or more of the plurality of electrodes of the leadless cardiac pacemaker.

[0039] 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

[0040] 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:

[0041] FIG. **1** is a schematic block diagram of an illustrative leadless cardiac pacemaker (LCP) according to one embodiment of the present disclosure;

[0042] FIG. **2** is a schematic block diagram of another illustrative medical device that may be used in conjunction with the LCP of FIG. **1**;

[0043] FIG. **3** is a schematic diagram of an exemplary medical system that includes multiple LCPs and/or other devices in communication with one another;

[0044] FIG. **4** is a schematic diagram of a system including an LCP and another medical device, in accordance with another embodiment of the present disclosure;

[0045] FIG. **5** is a graph showing an illustrative cardiac electrical signal and illustrative accelerometer signals detected by an LCP;

[0046] FIG. **6** is a graph showing an illustrative cardiac electrical signal and an illustrative accelerometer signal detected by an LCP;

[0047] FIG. **7** is a graph showing an illustrative accelerometer signal detected by an LCP showing multiple thresholds, in accordance with techniques of the present disclosure;

[0048] FIG. **8** is a graph showing an illustrative accelerometer signal detected by an LCP showing multiple thresholds, in accordance with techniques of the present disclosure; and

[0049] FIG. **9** is a graph showing an illustrative accelerometer signal detected by an LCP showing multiple thresholds, in accordance with techniques of the present disclosure.

[0050] 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

[0051] 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.

[0052] This disclosure describes systems, devices, and methods for detecting a tamponade condition. Cardiac tamponade is a medical condition characterized by compression of the heart due to an accumulation of fluid in the pericardial sac. When a patient is experiencing cardiac tamponade, the electrical system of the heart may be functioning normally. The heart may still be generating intrinsic electrical signals in a normal rhythm, and the generated signals may propagate throughout the heart in a normal fashion. However, since the heart is being compressed by fluid in the pericardial sac, the heart muscle may not be able to relax from a contracted state, thereby limiting the ability of the heart to sufficiently pump blood.

[0053] Specifically in relation to medical devices, tamponade may be caused by attaching a medical device or leads of the medical device to the heart. Generally, a medical device or lead may have a fixation element to securely place the device or lead at a location on or within the heart. During implantation, the fixation element may end up puncturing through the heart wall or an artery or other vessel on the outside of the heart, resulting in a leak of blood between the heart muscle and the pericardial sac. As the leak continues, more blood may seep between the heart muscle and the pericardial sac, resulting in continually decreasing pumping action, potentially resulting in a dangerous situation for the patient. The present disclosure describes devices, systems, and techniques for monitoring one or more signals to determine whether a tamponade condition is occurring.

[0054] FIG. **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 FIG. **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.

[0055] As depicted in FIG. 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).

[0056] 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 FIG. 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.

[0057] 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.

[0058] 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.

[0059] 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, accelerometer signals, 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.

[0060] 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.

[0061] As shown in FIG. **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 other embodiments, the electrical stimulation pulses may include defibrillation/cardioversion pulses for shocking the heart out of fibrillation or into a normal heart rhythm. In yet other embodiments, the electrical stimulation pulses may include anti-tachycardia pacing (ATP) pulses. It should be understood that 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 at least some embodiments, pulse generator module **104** may use energy stored in energy storage module **112** to generate the electrical stimulation pulses. In some particular embodiments, 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.

[0062] LCP **100** may further 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, including multi-axis accelerometers such as two- or three-axis accelerometers, gyroscopes, including multi-axis gyroscopes such as two- or three-axis gyroscopes, 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 FIG. **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**.

[0063] Processing module **110** may be configured to direct the operation of LCP **100** and may, in some embodiments, be termed a controller. 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 and other determinations such as whether LCP **100** has become dislodged. 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 and/or and other determinations such as whether LCP **100** has become dislodged. In still some additional 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**.

[0064] 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.

[0065] 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.

[0066] 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.

[0067] 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**.

[0068] 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.

[0069] 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. In still other embodiments, processing module **110** may not be a single component. For example, processing module **110** may include multiple components positioned at disparate locations within LCP **100** in order to perform the various described functions. For example, certain functions may be performed in one component of processing module **110**, while other functions are performed in a separate component of processing module **110**.

[0070] 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.

[0071] 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 capacitors or super capacitors.

[0072] 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 FIG. **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.

[0073] 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.

[0074] FIG. **2** depicts an embodiment of another device, medical device (MD) **200**, which may operate to sense physiological signals and parameters and deliver one or more types of electrical stimulation therapy to tissues of the patient. In the embodiment shown, MD **200** may include a communication module **202**, a pulse generator module **204**, an electrical sensing module **206**, a mechanical sensing module **208**, a processing module **210**, and an energy storage module **218**. Each of modules **202**, **204**, **206**, **208**, and **210** may be similar to modules **102**, **104**, **106**, **108**, and **110** of LCP **100**. Additionally, energy storage module **218** may be similar to energy storage module **112** of LCP **100**. However, in some embodiments, MD **200** may have a larger volume within housing **220**. In such embodiments, MD **200** may include a larger energy storage module **218** and/or a larger processing module **210** capable of handling more complex operations than processing module **110** of LCP **100**.

[0075] While MD **200** may be another leadless device such as shown in FIG. **1**, in some instances MD **200** may include leads, such as leads **212**. Leads **212** may include electrical wires that conduct electrical signals between electrodes **214** and one or more modules located within housing **220**. In some cases, leads **212** may be connected to and extend away from housing **220** of MD **200**. In some embodiments, leads **212** are implanted on, within, or adjacent to a heart of a patient. Leads **212** may contain one or more electrodes **214** positioned at various locations on leads **212** and various distances from housing **220**. Some leads **212** may only include a single electrode **214**, while other leads **212** may include multiple electrodes **214**. Generally, electrodes **214** are positioned on leads **212** such that when leads **212** are implanted within the patient, one or more of the electrodes **214** are positioned to perform a desired function. In some cases, the one or more of the electrodes **214** may be in contact with the patient's cardiac tissue. In other cases, the one or more of the electrodes **214** may be positioned subcutaneously but adjacent the patient's heart. The electrodes **214** may conduct intrinsically generated electrical cardiac signals to leads **212**. Leads **212** may, in turn, conduct the received electrical cardiac signals to one or more of the modules **202**, **204**, **206**, and **208** of MD **200**. In some cases, MD **200** may generate electrical stimulation signals, and leads **212** may conduct the generated electrical stimulation signals to electrodes **214**. Electrodes **214** may then conduct the electrical stimulation signals to the cardiac tissue of the patient (either directly or indirectly). MD **200** may also include one or more electrodes **214** not disposed on a lead **212**. For example, one or more electrodes **214** may be connected directly to housing **220**.

[0076] Leads **212**, in some embodiments, may additionally contain one or more sensors, such as accelerometers, blood pressure sensors, heart sound sensors, blood-oxygen sensors, and/or other sensors which are configured to measure one or more physiological parameters of the heart and/or patient. In such embodiments, mechanical sensing module **208** may be in electrical communication with leads **212** and may receive signals generated from such sensors.

[0077] While not required, in some embodiments MD **200** may be an implantable medical device. In such embodiments, housing **220** of MD **200** may be implanted in, for example, a transthoracic region of the patient. Housing **220** may generally include any of a number of known materials that are safe for implantation in a human body and may, when implanted, hermetically seal the various components of MD **200** from fluids and tissues of the patient's body. In such embodiments, leads **212** may be implanted at one or more various locations within the patient, such as within the heart of the patient, adjacent to the heart of the patient, adjacent to the spine of the patient, or any other desired location.

[0078] In some embodiments, MD **200** may be an implantable cardiac pacemaker (ICP). In these embodiments, MD **200** may have one or more leads, for example leads **212**, which are implanted on or within the patient's heart. The one or more leads **212** may include one or more electrodes **214** that are in contact with cardiac tissue and/or blood of the patient's heart. MD **200** may be configured to sense intrinsically generated cardiac electrical signals and determine, for example, one or more cardiac arrhythmias based on analysis of the sensed signals. MD **200** may be configured to deliver CRT, ATP therapy, bradycardia therapy, and/or other therapy types via leads **212** implanted within the heart. In some embodiments, MD **200** may additionally be configured to provide defibrillation/cardioversion therapy.

[0079] In some instances, MD **200** may be an implantable cardioverter-defibrillator (ICD). In such embodiments, MD **200** may include one or more leads implanted within a patient's heart. MD **200** may also be configured to sense electrical cardiac signals, determine occurrences of tachyarrhythmias based on the sensed electrical cardiac signals, and deliver defibrillation and/or cardioversion therapy in response to determining an occurrence of a tachyarrhythmia (for example by delivering defibrillation and/or cardioversion pulses to the heart of the patient). In other embodiments, MD **200** may be a subcutaneous implantable cardioverter-defibrillator (SICD). In embodiments where MD **200** is an SICD, one of leads **212** may be a subcutaneously implanted lead. In at least some embodiments where MD **200** is an SICD, MD **200** may include only a single lead which is implanted subcutaneously but outside of the chest cavity, however this is not required.

[0080] In some embodiments, MD **200** may not be an implantable medical device. Rather, MD **200** may be a device external to the patient's body, and electrodes **214** may be skin-electrodes that are placed on a patient's body. In such embodiments, MD **200** may be able to sense surface electrical signals (e.g. electrical cardiac signals that are

generated by the heart or electrical signals generated by a device implanted within a patient's body and conducted through the body to the skin). MD **200** may further be configured to deliver various types of electrical stimulation therapy, including, for example, defibrillation therapy via skin-electrodes **214**.

[0081] FIG. **3** illustrates an embodiment of a medical device system and a communication pathway through which multiple medical devices **302**, **304**, **306**, and/or **310** of the medical device system may communicate. In the embodiment shown, medical device system **300** may include LCPs **302** and **304**, external medical device **306**, and other sensors/devices **310**. External device **306** may be a device disposed external to a patient's body, as described previously with respect to MD **200**. In at least some examples, external device **306** may represent an external support device such as a device programmer, as will be described in more detail below. Other sensors/devices **310** may be any of the devices described previously with respect to MD **200**, such as ICPs, ICDs, and SICDs. Other sensors/devices **310** may also include various diagnostic sensors that gather information about the patient, such as accelerometers, blood pressure sensors, or the like. In some cases, other sensors/devices **310** may include an external programmer device that may be used to program one or more devices of system **300**.

[0082] Various devices of system **300** may communicate via communication pathway **308**. For example, LCPs **302** and/or **304** may sense intrinsic cardiac electrical signals and may communicate such signals to one or more other devices **302/304**, **306**, and **310** of system **300** via communication pathway **308**. In one embodiment, one or more of devices **302/304** may receive such signals and, based on the received signals, determine an occurrence of an arrhythmia. In some cases, device or devices **302/304** may communicate such determinations to one or more other devices **306** and **310** of system **300**. In some cases, one or more of devices **302/304**, **306**, and **310** of system **300** may take action based on the communicated determination of an arrhythmia, such as by delivering a suitable electrical stimulation to the heart of the patient. One or more of devices **302/304**, **306**, and **310** of system **300** may additionally communicate command or response messages via communication pathway **308**. The command messages may cause a receiving device to take a particular action whereas response messages may include requested information or a confirmation that a receiving device did, in fact, receive a communicated message or data.

[0083] It is contemplated that the various devices of system **300** may communicate via pathway **308** using RF signals, inductive coupling, optical signals, acoustic signals, or any other signals suitable for communication. Additionally, in at least some embodiments, the various devices of system **300** may communicate via pathway **308** using multiple signal types. For instance, other sensors/device **310** may communicate with external device **306** using a first signal type (e.g. RF communication) but communicate with LCPs **302/304** using a second signal type (e.g. conducted communication). Further, in some embodiments, communication between devices may be limited. For instance, as described above, in some embodiments, LCPs **302/304** may communicate with external device **306** only through other sensors/devices **310**, where LCPs **302/304** send signals to other sensors/devices **310**, and other sensors/devices **310** relay the received signals to external device **306**.

[0084] In some cases, the various devices of system **300** may communicate via pathway **308** using conducted communication signals. Accordingly, devices of system **300** may have components that allow for such conducted communication. For instance, the devices of system **300** may be configured to transmit conducted communication signals (e.g. a voltage and/or current waveform punctuated with current and/or voltage pulses, referred herein as electrical communication pulses) into the patient's body via one or more electrodes of a transmitting device, and may receive the conducted communication signals via one or more electrodes of a receiving device. The patient's body may "conduct" the conducted communication signals from the one or more electrodes of the transmitting device to the electrodes of the receiving device in the system **300**. In such embodiments, the delivered conducted communication signals may differ from pacing pulses, defibrillation and/or cardioversion pulses, or other electrical stimulation therapy signals. For example, the devices of system **300** may deliver electrical communication pulses at an amplitude/pulse width that is sub-threshold. That is, the communication pulses have an amplitude/pulse width designed to not capture the heart. In some cases, the amplitude/pulse width of the delivered electrical communication pulses may be above the capture threshold of the heart, but may be delivered during a refractory period of the heart and/or may be incorporated in or modulated onto a pacing pulse, if desired.

[0085] Additionally, unlike normal electrical stimulation therapy pulses, the electrical communication pulses may be delivered in specific sequences which convey information to receiving devices. For instance, delivered electrical communication pulses may be modulated in any suitable manner to encode communicated information. In some cases, the communication pulses may be pulse width modulated and/or amplitude modulated. Alternatively, or in addition, the time between pulses may be modulated to encode desired information. In some cases, a predefined sequence of communication pulses may represent a corresponding symbol (e.g. a logic "1" symbol, a logic "0" symbol, an ATP therapy trigger symbol, etc.). In some cases, conducted communication pulses may be voltage pulses, current pulses, biphasic voltage pulses, biphasic current pulses, or any other suitable electrical pulse as desired.

[0086] FIG. **4** depicts an illustrative medical device system **400** that may be configured to operate together. For example, system **400** may include multiple devices that are implanted within a patient and are configured to sense physiological signals, determine occurrences of cardiac arrhythmias, and deliver electrical stimulation to treat detected cardiac arrhythmias. In some embodiments, the devices of system **400** may be configured to determine occurrences of dislodgment of one or more devices of system **400**. In FIG. **4**, an LCP **402** is shown fixed to the interior of the right ventricle of the heart **410**, and a pulse generator **406** is shown coupled to a lead **412** having one or more electrodes **408***a*-**408***c*. In some cases, pulse generator **406** may be part of a subcutaneous implantable cardioverter-defibrillator (SICD), and the one or more electrodes **408***a*-**408***c* may be positioned subcutaneously adjacent the heart. LCP **402** may communicate with the SICD, such as via communication pathway **308**. The locations of LCP **402**, pulse generator **406**, lead **412**, and electrodes **408***a-c* depicted in FIG. **4** are just exemplary. In other embodiments of system **400**, LCP **402** may be positioned in the left

ventricle, right atrium, or left atrium of the heart, as desired. In still other embodiments, LCP **402** may be implanted externally adjacent to heart **410** or even remote from heart **410**.

[0087] Medical device system **400** may also include external support device **420**. External support device **420** can be used to perform functions such as device identification, device programming and/or transfer of real-time and/or stored data between devices using one or more of the communication techniques described herein, or other functions involving communication with one or more devices of system **400**. As one example, communication between external support device **420** and pulse generator **406** can be performed via a wireless mode, and communication between pulse generator **406** and LCP **402** can be performed via a conducted communication mode. In some embodiments, communication between LCP **402** and external support device **420** is accomplished by sending communication information through pulse generator **406**. However, in other embodiments, communication between the LCP **402** and external support device **420** may be via a communication module.

[0088] FIG. **4** only illustrates one example embodiment of a medical device system that may be configured to operate according to techniques disclosed herein. Other example medical device systems may include additional or different medical devices and/or configurations. For instance, other medical device systems that are suitable to operate according to techniques disclosed herein may include additional LCPs implanted within the heart. Another example medical device system may include a plurality of LCPs with or without other devices such as pulse generator **406**, with at least one LCP capable of delivering defibrillation therapy. Still another example may include one or more LCPs implanted along with a transvenous pacemaker and with or without an implanted SICD. In yet other embodiments, the configuration or placement of the medical devices, leads, and/or electrodes may be different from those depicted in FIG. **4**. Accordingly, it should be recognized that numerous other medical device systems, different from system **400** depicted in FIG. **4**, may be operated in accordance with techniques disclosed herein. As such, the embodiment shown in FIG. **4** should not be viewed as limiting in any way.

[0089] In some embodiments, LCP **100** may be configured to determine whether a tamponade condition is occurring. For instance, LCP **100** may be configured to monitor one or more signals and determine, based on the one or more monitored signals, whether a tamponade condition is occurring within the heart. Additionally, or alternatively, LCP **100** may use one or more determined features or characteristics of the monitored signal or signals and determine whether tamponade is occurring based on the one or more determined features. In some embodiments, to determine whether a tamponade condition is occurring, LCP **100** may monitor a signal or a feature of the signal and determine whether the signal or the feature changes (e.g. diminishes) over time. Generally, diminishment of a signal or feature over time, such as diminishing below a threshold, may indicate that a tamponade condition is occurring. The below described techniques illustrate various signals and features that LCP **100** may monitor in order to determine whether a tamponade condition is occurring. In some cases, the LCP **100** may monitor one or more signals or features, and communicate information related to the one or more signals or features to a separate device. In some cases, the actual determination of whether a tamponade condition is occurring may be performed by the separate device.

[0090] In some embodiments, LCP **100** may be triggered to enter or exit a tamponade mode, where LCP **100** monitors for whether a tamponade condition is occurring. In some cases, the LCP may enter or exit the tamponade mode based on a communicated trigger signal. LCP **100** may receive such a trigger signal from a device external to LCP **100**, such as support device **420**, or may be internally generated. Generally, a user may trigger LCP **100**, e.g. via external support device **420**, to enter the tamponade mode at the time of implant and maintain LCP **100** in the tamponade mode throughout the implantation procedure and for a short time thereafter. A user may additionally trigger LCP **100** to enter the tamponade mode during follow-up procedures or appointments where the physician may be concerned that tamponade is a risk. Outside of these times, the physician may trigger tamponade detection off to save energy in the LCP.

[0091] FIG. **5** is a graph **500** showing an illustrative cardiac electrical signal **502** (e.g. ECG) along with corresponding accelerometer signals **504**, **506**, **508** and **510** of a three axis accelerometer along a common time axis. The signal tracings of graph **500** may represent signals sensed or generated by an LCP **100** when LCP **100** is attached to a wall of a patients' heart. For example, signal **502** may represent a cardiac electrical signal **502** sensed by LCP **100**. Signals **504**, **506**, and **508** may represent signals from different axes generated by a three-axis accelerometer of LCP **100**. Signal **510** may represent an accelerometer magnitude signal, which may be determined by summing signals **504**, **506**, and **508** or summing the absolute values of signals **504**, **506**, and **508**. In other embodiments, signal **510** may represent a different signal generated by other combinations of signals **504**, **506**, and **508**, such as a root-mean-square or root-sum-square of signals **504**, **506**, and **508**, or any other derivation of signals **504**, **506**, and **508**.

[0092] LCP **100** may be configured to sense one or more of signals **504**, **506**, **508** and/or **510** during certain time periods. For instance, to "sense" one or more of the signals, it is contemplated that the LCP **100** may be configured to receive and process signals **504**, **506**, **508** and/or **510** at processing module **110**. Whereas when the one or more of the signals are not being "sensed", processing module **110** of LCP **100** may not receive and/or process the signals **504**, **506**, **508** and/or **510**. In some embodiments, to "sense" signals **504**, **506**, **508** and/or **510**, LCP **100** may connect an output of the accelerometer to processing module **110** via a switch, multiplexer of the like. In other embodiments, the accelerometer may be configured to only output valid signals **504**, **506**, **508** and/or **510** when the accelerometer is to be sensed (e.g. the accelerometer may be enabled by processing module **110** when sensing is desired). In some cases, LCP **100** may control the generation of signals **504**, **506**, **508** and/or **510** by the accelerometer. For instance, LCP **100** may control when power is provided to the accelerometer, and the accelerometer may only generate signals **504**, **506**, **508** and/or **510** when power is provided to the accelerometer. In some cases, LCP **100** may switch the accelerometer from a lower-power state (e.g. a sleep mode) to a higher-power state (e.g. awake or active mode) during time periods where LCP **100** is to sense the accelerometer signal(s). During the lower-power state, the accelerometer may not provide an

appreciable signal for LCP **100** to sense and/or sample. In some cases, and where processing module **110** is a digital device, an A/D converter may sample signals **504**, **506**, **508** and/or **510** when sensing is desired. These are just some examples of how signals **504**, **506**, **508** and/or **510** may be "sensed" during certain time periods.

[0093] LCP **100** may be configured to sense one or more signals during predetermined time periods. Such predetermined time periods may be represented by sensing periods **512***a*-**512***d* in FIG. **5**. Sensing periods **512***a*-**512***d* may occur at regular intervals, such as every five seconds, every second, every eight hundred milliseconds, every seven hundred milliseconds, or any other suitable value. Alternatively, LCP **100** may initiate sensing periods **512***a*-**512***d* after every beat, once every other beat, once every five beats, or at any other suitable frequency and/or duration. In at least some cases, LCP **100** may adjust the interval according to a heart rate of the patient such that successive sensing periods **512***a*-**512***d* occur during the same portion of the cardiac cycle (e.g. when the heart is quiet such as between heart beats).

[0094] In some instances, LCP **100** may implement sensing periods **512***a*-**512***d* based on one or more detected features of cardiac electrical signal **502**. For instance, LCP **100** may detect one or more features of cardiac electrical signal **502**, such as cardiac electrical events **511**. Cardiac electrical events **511** may represent R-waves or other morphological features detected by LCP **100**. Upon detection of cardiac electrical event **511**, LCP **100** may initiate a time delay, such as time delay **514**. Upon expiration of time delay **514**, LCP **100** may initiate sensing periods **512***a*-**512***d*, during which LCP **100** may "sense" one or more signals, such as signals **504**, **506**, **508** and/or **510**. In at least some cases, LCP **100** may adjust time delay **514** based on the heart rate of the patient. For instance, when the heart rate is at a relatively higher heart rate, LCP **100** may shorten time delay **514**, and when the heart rate is at a relatively lower heart rate, LCP **100** may lengthen time delay **514**. This may help the LCP **100** consistently initiate sensing periods **512***a*-**512***d* during the same or similar portion of the cardiac cycle (e.g. during the quit period between polarization/repolarizations of the heart).

[0095] In some instances, the length of time delay **514** may be chosen to align with a portion of the cardiac cycle where the heart is relatively mechanically inactive, such as shown in FIG. **5**. For instance, time delay **514** may be chosen so that it expires between about fifty milliseconds to about one-hundred fifty milliseconds before the beginning of the next heartbeat. During this portion of the cardiac cycle, the heart muscle may be in a relatively relaxed state while filling with blood. Accordingly, during this portion of the cardiac cycle, the orientation of LCP **100** may be at a relatively consistent position. This may allow LCP **100** to more easily detect a current posture of the patient, as explained in more detail below. In other embodiments, an accelerometer or other sensor may be implanted in the patient outside of the heart, and may transmit an indication of posture to the LCP **100**.

[0096] The signals depicted in FIG. **5** may represent signals acquired during normal cardiac function, e.g. when no tamponade condition is occurring. Notice that each of the accelerometer signals following each cardiac electrical event **511** are similar in shape and magnitude.

[0097] FIG. **6** depicts graph **520** including an example cardiac electrical signal **522**, including cardiac electrical events **531**, and accelerometer signal **524** which represents a magnitude of the accelerometer of LCP **100**, similar to signal **510** of FIG. **5**. Graph **520** depicts signals **522** and **524** over multiple cardiac cycles where the patient is suffering from a tamponade condition. As can be seen in FIG. **6**, the maximum amplitude of signal **524** diminishes over time throughout successive cardiac cycles. However, the maximum amplitude of the illustrative cardiac electrical signal **522** remains relatively constant over the same cardiac cycles. Accordingly, detecting a tamponade condition may be difficult using only the cardiac electrical signal.

[0098] While FIG. **6** shows the maximum amplitude of signal **524** diminish rapidly over only five (5) cardiac cycles, this has been intentionally compressed in time for ease of description only. In most cases, the maximum amplitude of signal **524** will diminish much more slowly, such as over minutes, hours or even days. FIGS. **7**-**9** have been similarly compressed in time for ease of description.

[0099] When LCP **100** is in the tamponade mode, LCP **100** may adjust how LCP **100** senses the accelerometer signal(s). As can be seen, time delay **526** of FIG. **6** is relatively shorter than time delay **514** of FIG. **5**. The length of time delay **526** may be chosen to generally align with the contraction of the heart. This may help LCP **100** sense the accelerometer signals during sensing periods **523***a-e* that correspond to when the heart is actually contracting.

[0100] In some instances, time delay **526** may be about ten milliseconds, about fifteen milliseconds, about twenty milliseconds, about twenty-five milliseconds, about thirty milliseconds, about thirty-five milliseconds, or any other suitable period of time following a detected R-wave. In general, time delay **526** may have a value that is less than an electromechanical delay of the heart, which is the delay between when LCP **100** detects a cardiac electrical event **531** (e.g. R-wave) and an onset of cardiac wall motion or a threshold amount of cardiac wall motion. Sensing periods **523***a-e* may have a duration of about twenty-five milliseconds, about thirty milliseconds, about forty milliseconds, or about fifty milliseconds. However, in other embodiments, sensing periods **523***a-e* may be substantially longer, for instance, about half of a cardiac cycle of the patient, about three quarters of the cardiac cycle of the patient, or may span an entire cardiac cycle of the patient. In some additional or alternative embodiments, time delay **526** and/or sensing periods **523***a-e* may have lengths that change along with the heart rate of the patient. As one example, for relatively higher heart rates, time delay **526** and/or sensing periods **523***a-e* may be shorter than for relatively lower heart rates.

[0101] In general, LCP **100** may be able to use accelerometer signals sensed during a portion of the cardiac cycle that corresponds to sensing periods **523***a-e* to determine whether a tamponade condition is occurring. As mentioned previously, when tamponade is occurring, blood or other fluid may be pooling in the pericardial sac, preventing full relaxation of the heart between contractions. The pooled blood may then prevent the heart from contracting to as great of an extent as under normal conditions. This difference in the motion of the heart may be seen through the sensed accelerometer signals.

[0102] To determine whether a tamponade condition is occurring, in some instances, LCP **100** may compare a maximum amplitude of signal **524** within a sensing window

to a threshold, such as threshold **525**. If LCP **100** determines that the maximum amplitude of signal **524** is less than threshold **525**, LCP **100** may determine that a tamponade condition is occurring. In other embodiments, after determining that the maximum amplitude of signal **524** is less than threshold **525** in a first sensing window, such as sensing window **523***c*, LCP **100** may continue to monitor signal **524** during subsequent sensing windows, for example sensing windows **523***d* and **523***e*, and comparing signal **524** to threshold **525** during those subsequent sensing windows. In these embodiments, LCP **100** may only determine that a tamponade condition is occurring if the maximum amplitude of signal **524** in a second, subsequent sensing window is also less than threshold **525**. In still further embodiments, LCP **100** may require the maximum amplitude of signal **524** to be less than threshold **525** in three (or more) consecutive sensing windows before determining that a tamponade condition is occurring.

[0103] In still other embodiments, LCP **100** may require the maximum amplitude of signal **524** to be less than threshold **525** in four, five, ten, or twenty consecutive sensing windows, or any other suitable number of sensing windows, before determining that a tamponade condition is occurring. Other options further include LCP **100** requiring that the maximum amplitude of signal **524** to be less than threshold **525** in three out of five consecutive sensing windows, five out of ten consecutive sensing windows, or any other suitable combinations before determining that a tamponade condition is occurring.

[0104] In even more additional or alternative embodiments, after LCP **100** determines the maximum amplitude of signal **524** is less than threshold **525**, LCP **100** may track a period of time. LCP **100** may then determine that a tamponade condition is occurring if the maximum amplitude of signal **524** does not cross back above threshold **525** within the predefined period of time. In some instances, LCP **100** may switch to continuously or substantially continuously sensing signal **524** (e.g. turn on and/or sample accelerometer signal continuously or substantially continuously). In other embodiments, however, LCP **100** may maintain sensing signal **524** only in sensing windows. Accordingly, rather than counting a number of sensing windows, LCP **100** may simply monitor signal **524** within any number of subsequent sensing windows which fall within the tracked period of time

[0105] In other alternative embodiments, LCP **100** may track a moving average of the maximum amplitude of signal **524** over about three, about five, about ten, about fifteen, or about twenty cardiac cycles, or any other suitable number of cardiac cycles, and may store the determined moving averages in a memory. During a tamponade condition, this moving average will steadily decrease over time as the heart loses its ability to expand and pump blood due to blood pooling in the pericardial sac. Accordingly, in some embodiments, LCP **100** may compare the moving average to a threshold to determine whether a tamponade condition is occurring. In other or additional embodiments, LCP **100** may determine whether the stored moving averages decrease in a monotonic fashion. If LCP **100** determines that about five, about ten, about fifteen, or any other suitable number of consecutive determined moving averages decrease in a monotonic fashion, LCP **100** may determine that a tamponade condition is occurring.

[0106] Alternatively, LCP **100** may determine the slopes between consecutive determined moving averages. If LCP **100** determines that a threshold number, such as three, five, ten, fifteen, or twenty, of consecutive slopes are negative, LCP **100** may determine that a tamponade condition is occurring. Also, the magnitude of the slope(s) may be taken into consideration. A larger slope may indicate a more severe tamponade condition, and thus the LCP **100** may determine that a tamponade condition is occurring sooner.

[0107] Although the above tamponade detection techniques included monitoring for tamponade over a relatively short time period, e.g. a number of cardiac cycles, in some additional or alternative embodiments, LCP **100** may be configured to monitor for a tamponade condition over longer periods of time. For instance, LCP **100** may be configured to monitor for tamponade once an hour, once every few hours, twice a day, or once a day. In these embodiments, LCP **100** may monitor, for example, the maximum amplitude of signal **524** during one or more sensing periods during each chosen time interval. LCP **100** may then compare the sensed maximum amplitude of signal **524** during each of these chosen time intervals to determine if there is a trend. For example, LCP **100** may compare these determined differences to one or more thresholds, as above, to determine if a tamponade condition is occurring. This may facilitate detection of slow-onset tamponade conditions.

[0108] FIG. **7** depicts another embodiment where LCP **100** may be configured to determine that a tamponade condition is occurring. FIG. **7** depicts a graph **540** showing an accelerometer signal **542**, which may represent a magnitude of acceleration from an accelerometer of LCP **100**. In the example of FIG. **7**, LCP **100** may employ multiple thresholds in determining whether a tamponade condition is occurring. For example, LCP **100** may initially monitor accelerometer signal **542** during sensing windows **541***a*-**541***e* to determine when a maximum amplitude of signal **542** within a sensing window falls below first threshold **543**. Once LCP **100** determines that signal **542** has fallen below first threshold **543**, LCP **100** may monitor accelerometer signal **542** to determine if, or when, accelerometer signal **542** falls below second threshold **545**. In the example of FIG. **7**, LCP **100** would determine that accelerometer signal **542** falls below second threshold **545** in the next sensing window **541***d*. At this point, after accelerometer signal **542** has fallen below the first threshold **543** and then subsequently fallen below the second threshold **545**, LCP **100** may determine that a tamponade condition is occurring, as this trend may indicate declining mechanical motion of the heart. Of course, in additional embodiments, LCP **100** may only determine that a tamponade condition is occurring after determining that a maximum amplitude of accelerometer signal **542** in multiple subsequent sensing windows is still below second threshold **545**, for instance in any manner that was described with respect to FIG. **6**.

[0109] Of course, in some cases, the maximum amplitude of accelerometer signal **542** may be above both first threshold **543** and second threshold **545** in a first sensing window and may be less than both first threshold **543** and second threshold **545** in a next sensing window. In such embodiments, LCP **100** may monitor subsequent sensing windows and determine whether the maximum amplitude of accelerometer signal **542** stays below second threshold **545**. If LCP **100** determines the maximum amplitude of accelerometer signal **542** stays below second threshold **545** for one or more

subsequent sensing windows, LCP **100** may then determine that a tamponade condition is occurring. In such embodiments, the tamponade condition may worsen too quickly for LCP **100** to sense the decline in mechanical motion of the heart, and LCP **100** may instead rely simply on a consistent indication of low cardiac motion to determine that a tamponade condition is occurring.

[0110] In some embodiments, first threshold **543** may be set as a certain percentage of a maximum value of sensed signal **542** in a sensing window when signal **542** is sensed under conditions where it is known that tamponade is not occurring. For instance, first threshold **543** may be set at about seventy-five percent of the maximum value of sensed signal **542** in a sensing window. However, in other embodiments, first threshold **543** may be set at different percentages of the maximum value of sensed signal **542** in a sensing window, such as about fifty percent, about sixty-percent, about seventy percent, about eighty percent, about eighty-five percent, about ninety percent, or any other suitable value. In some embodiments, the value of second threshold **543** may be programmable.

[0111] Second threshold **545** may be set at a certain percentage of first threshold **543**. For instance, second threshold **545** may be set at about seventy-five percent of first threshold **543**. However, in other embodiments, second threshold **545** may be set at different percentages of first threshold **543**, such as about fifty percent, about sixty-percent, about seventy percent, about eighty percent, about eighty-five percent, about ninety percent, or any other suitable value. In some embodiments, the value of second threshold **545** may be programmable.

[0112] FIG. **8** depicts still another embodiment where LCP **100** may be configured to determine that a tamponade condition is occurring. FIG. **8** depicts a graph **550** showing an accelerometer signal **552**, which may represent a magnitude of acceleration from an accelerometer of LCP **100**. In the example of FIG. **8**, LCP **100** may employ multiple thresholds in determining whether a tamponade condition is occurring. For example, LCP **100** may initially monitor accelerometer signal **552** during sensing windows **551***a*-**551***e* to determine when a maximum amplitude of accelerometer signal **552** within a sensing window falls below first threshold **553**.

[0113] Once LCP **100** determines that the maximum amplitude of signal **552** has fallen below first threshold **553**, such as in sensing window **551***c*, LCP **100** may monitor accelerometer signal **552** to determine if, or when, accelerometer signal **552** rises above second threshold **555**. For example, LCP **100** may monitor accelerometer signal **552** for a number of subsequent sensing windows, or for a predefined period of time, after detecting that the maximum amplitude of accelerometer signal **552** is less than first threshold **553**. If LCP **100** determines that the maximum amplitude of accelerometer signal **552** did not rise above second threshold **555** within the predetermined number of subsequent sensing windows, or within the predefined period of time, LCP **100** may determine that a tamponade condition is occurring. If LCP **100** determines that accelerometer signal **552** did rise above second threshold **555** within the predetermined number of subsequent sensing windows, or within the predefined period of time, LCP **100** may then switch back to monitoring whether the maximum amplitude of accelerometer signal **552** is below first threshold **553**.

[0114] In some embodiments, first threshold **553** may be set as a certain percentage of a maximum value of sensed signal **552** in a sensing window when signal **552** is sensed under conditions where it is known that tamponade is not occurring. For instance, first threshold **553** may be set at about seventy-five percent of the maximum value of sensed signal **552** in a sensing window. However, in other embodiments, first threshold **553** may be set at different percentages of the maximum value of sensed signal **552** in a sensing window, such as about fifty percent, about sixty-percent, about seventy percent, about eighty percent, about eighty-five percent, about ninety percent, or any other suitable value. In some embodiments, the value of second threshold **553** may be programmable.

[0115] Second threshold **555** may be may be set at a certain percentage of first threshold **543**. For instance, second threshold **545** may be set at about seventy-five percent of first threshold **543**. However, in other embodiments, second threshold **545** may be set at different percentages of first threshold **543**, such as about fifty percent, about sixty-percent, about seventy percent, about eighty percent, about eighty-five percent, about ninety percent, or any other suitable value. In some embodiments, the value of second threshold **555** may be programmable.

[0116] FIG. **9** depicts still another embodiment where LCP **100** may be configured to determine that a tamponade condition is occurring. FIG. **9** depicts a graph **560** showing an accelerometer signal **562**, which may represent a magnitude of acceleration from an accelerometer of LCP **100**. In the example of FIG. **9**, LCP **100** may employ multiple thresholds in determining whether a tamponade condition is occurring. For example, LCP **100** may initially monitor accelerometer signal **562** during sensing windows **561***a*-**561***e* to determine when a maximum amplitude of accelerometer signal **562** within a sensing window falls below first threshold **563**.

[0117] Once LCP **100** determines that the maximum amplitude of accelerometer signal **562** has fallen below first threshold **563**, such as in sensing window **561***c*, LCP **100** may monitor accelerometer signal **562** to determine whether accelerometer signal **562** falls below second threshold **565** or rises above third threshold **567**. For example, LCP **100** may monitor accelerometer signal **562** for a number of subsequent sensing windows, or for a predefined period of time, after detecting that the maximum amplitude of accelerometer signal **562** is less than first threshold **563**. If LCP **100** determines that the maximum amplitude of accelerometer signal **562** rises above third threshold **567** before falling below second threshold **565**, LCP **100** may go back to determining whether the maximum amplitude of accelerometer signal **562** is below first threshold **563**. However, if LCP **100** determine that the maximum amplitude of accelerometer signal **562** does not rise above third threshold **567** within the predetermined number of subsequent sensing windows, or for the predefined period of time, LCP **100** may determine that a tamponade condition is occurring. Additionally, if LCP **100** determines that the maximum amplitude of accelerometer signal **562** falls below second threshold **565** at any point, LCP **100** may determine a tamponade condition is occurring, even if the predetermined number of subsequent sensing windows have not occurred, or the predefined period of time ran out.

[0118] In some embodiments, first threshold **563** may be set as a certain percentage of a maximum value of sensed

signal **562** in a sensing window when signal **562** is sensed under conditions where it is known that tamponade is not occurring. For instance, first threshold **563** may be set at about seventy-five percent of the maximum value of sensed signal **562** in a sensing window. However, in other embodiments, first threshold **563** may be set at different percentages of the maximum value of sensed signal **562** in a sensing window, such as about fifty percent, about sixty-percent, about seventy percent, about eighty percent, about eighty-five percent, about ninety percent, or any other suitable value. In some embodiments, the value of second threshold **563** may be programmable.

[0119] Second threshold **565** and/or third threshold **567** may be set at a certain percentage of first threshold **563**. For instance, third threshold **567** may be set at about seventy-five percent of first threshold **563**. However, in other embodiments, third threshold **567** may be set at different percentages of first threshold **563**, such as about fifty percent, about sixty-percent, about seventy percent, about eighty percent, about eighty-five percent, about ninety percent, or any other suitable value. In some embodiments, second threshold **565** may be set at about fifty percent of first threshold **563**. However, in other embodiments, second threshold **565** may be set at different percentages of first threshold **563**, such as about twenty-five percent, about thirty percent, about thirty-five percent, about forty percent, about forty-five percent, or any other suitable value. In some embodiments, the value of second and/or third threshold **565**, **567** may be programmable.

[0120] Although the embodiments of FIGS. **6-9** all use the magnitude of the accelerometer signal, it should be understood that this is for illustrative purposes only. In other embodiments, LCP **100** may use other signals to determine whether a tamponade condition is occurring. For example, LCP **100** may use any signal received from the accelerometer, such as the different signals representing different axes of the accelerometer, to determine whether a tamponade condition is occurring. LCP **100** may further process the accelerometer signal to derive one or more other signals for use in determining whether a tamponade condition is occurring. As one example, LCP **100** may double integrate the accelerometer signal to determine a displacement signal, representing the displacement of the accelerometer over time, which correlates to displacement of the heart wall. LCP **100** may compare a maximum amplitude of a portion of this displacement signal, such as during a filling of the heart, to one or more thresholds to determine whether a tamponade condition is occurring. For instance, the maximum amplitude of the displacement signal in the monitored portion may relate to the amount of movement of the cardiac wall during filling. As blood pools in the pericardial sac, the maximum value of this signal will decrease over time. Accordingly, LCP **100** may monitor whether this value decreases below one or more threshold and, if so, determine an occurrence of a tamponade condition. Like with the accelerometer signal, LCP **100** may use a feature of the cardiac electrical signal to determine which portion of the displacement signal to monitor. For instance, LCP **100** may track a period of time from a cardiac electrical event and begin monitoring the displacement signal for the maximum amplitude within a sensing window beginning upon expiration of the period of time. In at least some embodiments, the period of time used for the accelerometer signal and the period of time used for the displacement signal are different.

[0121] In still other embodiments, LCP **100** may include other sensors and may use signals from those sensors to determine whether a tamponade condition is occurring. Some other example sensors include a pressure sensor and/or a gyroscope. When provided, a gyroscope may be a multi-axis gyroscope and generate signals similar to the multi-axis accelerometer described above. In some cases, as mentioned previously, signals generated by a gyroscope may have a certain synchrony with the cardiac electrical signals which may change during a tamponade condition. Loss of the synchrony of a peak value of the gyroscope signal and the cardiac electrical events may indicate a tamponade condition is occurring. In other embodiments, LCP **100** may employ any of the techniques described with respect to the accelerometer signal to the gyroscope signal to determine whether a tamponade condition is occurring.

[0122] Further, as a tamponade condition is worsening, the intra-chamber blood pressure, and in particular the intra-chamber blood pressure as the heart contracts to pump the blood, may change over time in a diminishing manner. In these embodiments, LCP **100** may monitor an intra-chamber blood pressure signal detected via a pressure sensor and/or detected via heart sounds via an accelerometer or the like. For example, the amplitude of the first heart sound (S1), which can be detected by an accelerometer or the like, is proportional to the rate of left ventricular pressure rise (LV dP/dt). LCP **100** may compare a maximum amplitudes of this blood pressure signal taken over time to one or more thresholds. In general, any of the threshold techniques described above with respect to the maximum amplitude of the accelerometer may be applied to the blood pressure signal.

[0123] In some further embodiments, LCP **100** may monitor a time duration of the peak of the dP/dt signal, such as by monitoring how long the dP/dt signal stays within a certain percentage of the peak dP/dt signal value over a cardiac cycle, such as within about three percent, about five percent, about eight percent, or about ten percent. During a tamponade condition, this time value may lengthen. Accordingly, LCP **100** may compare this determined time value to a threshold, and LCP **100** may determine that a tamponade condition is occurring if the value rises above a threshold.

[0124] In still other embodiments, LCP **100** may monitor heart sounds for indications of valve closures, for instance based on deflections in the heart sounds signal. If LCP **100** determines that there is a lack of detected expected valve closures, LCP **100** may determine an occurrence of a tamponade condition. For instance, LCP **100** may expect to detect two, three, or four heart sound features in the heart sounds signal for each cardiac cycle. If LCP **100** detects less than is expected, LCP **100** may determine that a tamponade condition is occurring. Additionally, or alternatively, LCP **100** may determine that a tamponade condition is occurring if a monitored maximum amplitude of the heart sounds signal falls below a threshold for one or more cardiac cycles, or the heart sounds signal differs from a template heart sounds signal.

[0125] Accordingly, in any these above embodiments, instead of using signals from an accelerometer, LCP **100** may use signals from the gyroscope, the blood pressure sensors, or any other sensors in any manner described above to determine whether a tamponade condition is occurring.

[0126] In still other embodiments, LCP **100** may use multiple signals to determine whether tamponade is occur-

ring. For instance, LCP **100** may perform analyses on multiple signals generated by the accelerometer, gyroscope, and/or blood pressure sensor. In some of these embodiments, LCP **100** may determine that a tamponade condition is occurring if analysis on any one signal indicates a tamponade condition. However, in other embodiments, LCP **100** may only determine that a tamponade condition is occurring if multiple of the signals indicate a tamponade condition, such as two signals, three signals, four signals, all of the signals, or any other suitable number of signals.

[0127] Where LCP **100** uses multiple signals to determine whether tamponade is occurring, LCP **100** may, in some examples, analyze the signals in a cascading fashion. For instance, LCP **100** may initially only monitor a single signal. After determining that the first signal indicates that a tamponade condition is occurring, LCP **100** may then begin to monitor a second signal. In some instances, only after the second signal has indicated that a tamponade condition is occurring does the LCP **100** determine that a tamponade condition is occurring. In some cases, LCP **100** may be able to cascade the analysis of the signals in order to save energy. For instance, in some embodiments LCP **100** may be configured to monitor a first signal from an accelerometer while the other channels of the accelerometer or other sensors are turned off. Only after the first accelerometer signal indicates that a tamponade condition is occurring does the LCP **100** turn on another channel of the accelerometer or other sensor(s) in order to analyze a second signal. In different embodiments, LCP **100** may use any of the above described signal(s) in any cascading combination in order to determine whether a tamponade condition is occurring.

[0128] Additionally, although the techniques of the present disclosure were described in relation to a maximum amplitude of the signal from the accelerometer or other sensor, in other embodiments, LCP **100** may use different characteristics of the signals. As one example, the value of the integral, or double integral, of the analyzed signal within the sensed window may be used instead of the maximum amplitude of the signal. In these embodiments, the value of the integral or double integral may be compared to one or more thresholds, in a similar manner to that described with respect to the maximum amplitude of the signal, to determine whether a tamponade condition is occurring. In another example, a peak width of a signal may be used. For example, as detailed, above, how long a dP/dt signal stays within a certain percentage of the peak dP/dt signal value may be used to determine if a tamponade condition is occurring.

[0129] After determining that a tamponade condition is occurring, LCP **100** may generate an alarm signal or message and communicate the alarm signal to a device external to LCP **100**. For instance, where LCP **100** is part of a medical device system, such as system **400**, LCP **100** may communicate the alarm signal to external support device **420**. External support device **420** may then generate a visual or audible alarm to notify a user in the vicinity of external support device **420** that LCP **100** has determined that a tamponade condition is occurring. In other embodiments, LCP **100** may communicate the alarm signal to another internally implanted device, for instance pulse generator **406**, and the other internally implanted device may communicate the alarm signal to a device outside of the patient. In some embodiments, LCP **100**, or another device which receives the alarm signal from LCP **100**, may be connected to one or more wireless networks. LCP **100**, or another device of the system, may connect to the wireless network to communicate the alarm signal to a remote device, such as a pager, cell phone, or other remote device connected to the wireless network.

[0130] Additionally, although the above described techniques are centered around LCP **100** performing the sensing and determining functions, where LCP **100** is part of a device system, such as system **400** of FIG. **4**, other devices of the system may perform at least some of these functions. For example, LCP **100** may monitor or sense signals from an accelerometer or pressure sensor of the LCP **100** and communicate those signals, or portions of those signals, to another device, such as pulse generator **406**. Pulse generator **406** may then determine whether a tamponade condition is occurring. If pulse generator **406** determines that a tamponade condition is occurring, pulse generator **406** may then communicate an indication that a tamponade condition is occurring, for instance as described with respect to LCP **100**. In other embodiments, the device doing the determining, based on signals received from LCP **100**, may be external support device **406**.

[0131] 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.

[0132] 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 method for detecting a tamponade condition of a patient's heart after attachment of a leadless cardiac pacemaker to the patient's heart, the leadless cardiac pacemaker having a motion sensor that produces a motion signal, the method comprising:

monitoring the motion signal of the leadless cardiac pacemaker;

identifying a characteristic of the motion signal;

determining when the tamponade condition is indicated based at least in part on whether the identified characteristic of the motion signal changes over time in a predetermined way; and

in response to determining that the tamponade condition is indicated, providing a notification of the tamponade condition for use by a physician to take corrective action.

2. The method of claim **1**, wherein the motion sensor comprises an accelerometer, and the motion signal comprises an accelerometer signal.

3. The method of claim 2, wherein the accelerometer comprises a multi-axis accelerometer, and the accelerometer signal is a multi-axis accelerometer signal.

4. The method of claim 2, wherein the identified characteristic of the motion signal is indicative of a displacement of a wall of the patient's heart.

5. The method of claim 2, wherein the identified characteristic of the motion signal is indicative of a filling volume of the patient's heart.

6. The method of claim 2, wherein the identified characteristic of the motion signal is indicative of a heart sound of the patient's heart.

7. The method of claim 1, further comprising:

monitoring two or more electrodes of the leadless cardiac pacemaker to detect a cardiac electrical signal of the patient's heart; and

determining when the tamponade condition is indicated based at least in part on whether the identified characteristic of the motion signal changes over time in a predetermined way during a sensing window that is defined at least in part by one or more characteristics of the cardiac electrical signal.

8. The method of claim 2, wherein the leadless cardiac pacemaker further comprises a pressure sensor that produces a pressure signal, the method further comprising:

determining when the tamponade condition is indicated based at least in part on whether the identified characteristic of the motion signal changes over time in a predetermined way and based on the pressure signal.

9. The method of claim 1, wherein the motion sensor comprises a gyroscope and the motion signal comprises a gyroscope signal.

10. The method of claim 9, wherein the gyroscope comprises a multi-axis gyroscope, and the gyroscope signal is a multi-axis gyroscope signal.

11. The method of claim 9, further comprising:

monitoring two or more electrodes of the leadless cardiac pacemaker to detect a cardiac electrical signal of the patient's heart; and

determining when the tamponade condition is indicated based at least in part on whether a synchrony between the identified characteristic of the gyroscope signal changes over time relative to the cardiac electrical signal.

12. The method of claim 1, wherein the leadless cardiac pacemaker performs the monitoring, determining and providing steps.

13. The method of claim 1, wherein the leadless cardiac pacemaker performs the monitoring step.

14. The method of claim 1, wherein an external device programmer performs one or more of the monitoring, determining and providing steps.

15. The method of claim 1, wherein providing the notification comprises communicating a message from the leadless cardiac pacemaker for reception by an external device programmer.

16. A leadless cardiac pacemaker for use in pacing a patient's heart, comprising:

a plurality of electrodes;

a motion sensor for providing an motion signal;

a controller operatively coupled to the plurality of electrodes and the motion sensor, the controller configured to:

monitor the motion signal of the motion sensor over time;

identifying a characteristic of the motion signal;

determining when a tamponade condition is indicated based at least in part on whether the identified characteristic of the motion signal changes over time in a predetermined way; and

in response to determining that the tamponade condition is indicated, communicate a notification of the tamponade condition for use by a physician to take corrective action.

17. The leadless cardiac pacemaker of claim 12, wherein the motion sensor comprises an accelerometer and/or a gyroscope.

18. A leadless cardiac pacemaker, comprising:

a plurality of electrodes;

a motion sensor for providing a motion signal;

a controller operatively coupled to the plurality of electrodes and the motion sensor, the controller configured to:

monitor an indication of physical motion of a patient's heart over time using the motion sensor;

determine when the indication of the physical motion of the patient's heart changes over time in a predetermined way; and

when it is determined that the indication of the physical motion of the patient's heart has changed over time in the predetermined way, communicate a notification of a possible tamponade condition for reception by a remote device that is remote from the leadless cardiac pacemaker.

19. The leadless cardiac pacemaker of claim 18, wherein the controller is further configured to monitor a heart rate of the patient's heart over time and to determine if the heart rate increases over time by at least a predetermined heart rate amount.

20. The leadless cardiac pacemaker of claim 19, wherein the controller communicates a notification of the possible tamponade condition when it is determined that the indication of the physical motion of the patient's heart has changed over time in the predetermined way and the heart rate of the patient's heart has increased over time by at least the predetermined heart rate amount.

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摘要(译)

公开了用于确定填塞条件的出现的系统，方法和设备。一种示例性方法包括监测附接到心脏壁的无引线心脏起搏器的加速度计信号，确定是否至少部分地基于所监测的加速度计信号指示患者心脏的填塞状况，并且响应于确定填塞状况指示，提供填塞条件的通知以供医生用于采取纠正措施。