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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 January 2002 (03.01.2002)

PCT

(10) International Publication Number
WO 02/00296 A1

(51) International Patent Classification[7]: A61N 1/37

(21) International Application Number: PCT/SE01/01424

(22) International Filing Date: 19 June 2001 (19.06.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0002514-8 30 June 2000 (30.06.2000) SE

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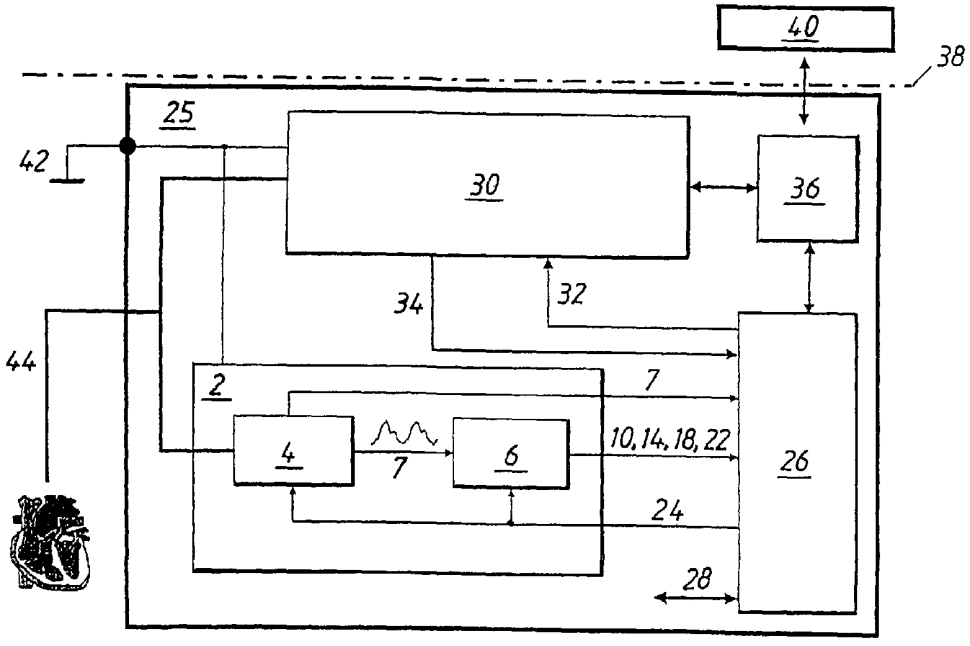
(81) Designated State *(national)*: US.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: IMPLANTABLE MEDICAL DEVICE WITH VALVE OPENING DETECTING MEANS



(57) Abstract: Medical device comprising valve opening detecting means (2) for dtecting opening of valve or valves in the left side of a heart. The detecting means includes an impedance measuring means (4) for measuring the electrical impedance bewteen measurement poles, wherein at least one of the poles is adapted to be arranged in the coronary sinus and/or in the great cardiac vein of the heart. The detecting means includes impedance signal processing means (6) for processing a detected impedance signal so that the opening of one or both valves in the left side of the heart is detected. An implantable heart stimulator (25) using the valve opening detector is also disclosed.

WO 02/00296 A1

Title

IMPLANTABLE MEDICAL DEVICE WITH VALVE OPENING DETECTING MEANS

Field of the invention

The present invention relates to an implantable medical device according to preamble of the independent claim.

Background of the invention

Impedance measurements in relation with detection of the flow mechanical function of a heart are known in the art for a long time.

In US-5,792,194 a transvalvular impedance measurement is disclosed. The measurement is made between an atrium and a ventricle electrode of an implanted electro-catheter to provide information indicative of the mechanical state of the heart. The information may be used to control the pacing rate of a rate responsive pacemaker, stimulation intensity self adjust or pacing mode switching. The maximum measured impedance is indicative of the tricuspid valve (the valve between the right atrium and the right ventricle) being closed and the minimum measured impedance is indicative of the tricuspid valve being open. In the device of US-5,792,194 a signal generator generates a square wave of frequency 4 kHz, amplitude 3 volts. A voltage level is detected at one of the electrodes inside the heart and the detected signal is amplified in an amplifier having a gain in region 50 to 200 and filtered in a filter network. The filter network comprises a notch filter to reject mains frequency (50 or 60 Hz) and also a low pass filter to reject frequencies exceeding 100 Hz, since the frequencies of the signals of interest being well below that level. In that way noise generated in impedance measurement can be reduced.

Impedance measurement using four poles is disclosed in US-4,730,619 where an electrode lead adapted to be inserted into a heart is provided with a first and a second ring electrode and a tip electrode. A measurement current at any one of several frequencies is applied between the pacer can and the tip electrode and the voltage measured between the ring electrodes is proportional to impedance. The measured impedance is used to determine changes in volume of blood in the right ventricle and to determine opening and closing of the pulmonary valve to

determine ejection time. The pulmonary valve is the valve between the right ventricle and the pulmonary artery.

Impedance measurements within a heart may be used to confirm capture, i.e. to confirm that a stimulation pulse applied to heart tissue has caused a heart contraction. US-5,737,883 and US-5,902,325 both relate to implantable cardiac stimulators provided with capture detection based upon impedance measurements.

Through impedance measurements, blood volume changes are detectable within the area of measurement. Blood has higher conductivity (lower impedance) than myocardial tissue and lungs. The impedance-volume relationship is inverse; the more blood – the smaller impedance.

In a well functioning heart the left and the right side of the heart contract more or less simultaneously starting with the contraction of the atria flushing down the blood through the valves separating the atria from the ventricles. In the right side of the heart through the tricuspidalis valve and in the left side of the heart through the mitralis valve. Shortly after the atria contraction the ventricles contract resulting in increasing blood pressure inside the ventricles that first closes the one way valves to the atria and after that forces the outflow valves to open. In the right side of the heart it is the pulmonary valve, that separates the right ventricle from the pulmonary artery that leads blood to the lung to be oxygenated, which is opened. The right side of the heart is termed the low pressure side of the heart since the pressure is several times lower than the pressure in the left side of the heart – termed the high pressure side. In the left side of the heart the aortic valve separates the left ventricle from the aorta that transports blood to the whole body. The outflow valves, the pulmonary valve and the aortic valve, open when the pressure inside the ventricles exceeds the pressure in the pulmonary artery and the aorta, respectively. The ventricles are separated by the intraventricular elastic septum.

The heart is supplied with blood via the left and right coronary arteries having its openings close to the aortic valve. The venous blood is returned to the right atrium by the great cardiac vein to the coronary sinus having its opening close to the inferior vena cava.

The measurement device disclosed in US-5,792,194 is adapted to perform measurements in the right side of the heart, the low pressure side of the heart. There is a great interest in making measurements reflecting the hemodynamic of the left side of the heart in order to increase the possibilities to correctly analyze the function of the heart.

The object of the present invention is to achieve a medical device adapted to detect the opening of the valve or valves of the left side of the heart.

Summary of the invention

The above-mentioned object is achieved by a medical device provided with the features set forth in the characterizing portion of the independent claim.

Preferred embodiments are set forth in the dependent claims.

The inventors have found that the opening of valves in the left side of the heart may be detected by measuring the electrical impedance using at least one measurement pole placed in the coronary sinus or in the great cardiac vein and by performing a tailored processing of the detected impedance signal.

According to a preferred embodiment is the detected valve opening, especially the aortic valve opening, used as an indication of capture in a stimulation threshold search algorithm in an implantable heart stimulator.

Short description of the appended drawings

Figure 1 shows an anterior view (above) and a posterior view (below) of a human heart;

Figures 2a and 2b disclose tracings of an impedance signal obtained by unipolar impedance measurement and other measured signals;

Figures 3a and 3b disclose tracings of an impedance signal obtained by bipolar impedance measurement and other measured signals;

Figures 4a and 4b disclose tracings of an impedance signal obtained by quadropolar impedance measurement and other measured signals;

Figure 5 shows a block diagram of the valve opening detecting means according to the present invention, and

Figure 6 shows a block diagram of an implantable heart stimulator provided with a valve opening detecting means 2 according to the present invention.

Detailed description of preferred embodiments of the invention

Figure 1 shows an anterior view (above) and a posterior view (below) of a human heart. A simplified description of the coronary vessels is given in the following with references to figure 1. The right and left coronary arteries supply the heart tissue with arterial blood. As can be seen from the anterior view they are supplied with blood via openings close to aorta. The venous blood is returned into the right atrium via the great cardiac vein and coronary sinus that has its outflow close to the interior vena cava. The coronary sinus essentially follows the horizontal plane of the valves separating the atria from the ventricles. Also the first part of the great cardiac vein follows the horizontal plane a short distance before it turns down towards apex.

By arranging an electrode lead provided with stimulation electrodes and/or sensing means within coronary sinus or great cardiac vein sensing and stimulation of the left side of the heart is possible. This is a well known technique and is e.g. described in US-5,129,394 that discloses a method and apparatus for controlling heart rate in proportion to left ventricular pressure. A lead with a pressure sensor near its distal end is placed transvenously through the coronary sinus and located in the coronary vein. The pressure that is sensed in that location is proportional to the left ventricular pressure.

The opening of the aortic valve and the mitralis valve is normally soundless in contrast to the closing of the valves that might be detected e.g. by a stethoscope or by any suitable phonographic recording.

As indicated above, when describing related prior art, impedance measurements may be performed by using different numbers of measurement poles.

According to a preferred embodiment of the invention is unipolar impedance measurement performed by positioning one measurement pole in coronary sinus (CS) or in great cardiac vein (GCV), abbreviated CS/GCV. The other measurement pole is the indifferent plate (electrode) of the housing of the medical implant. Impedance current is applied between the CS/GCV

measurement pole and the indifferent plate (4kHz square wave having amplitude of 10μA). A voltage is sensed between the same poles.

Figure 2a discloses tracings of about four complete heart cycles of an impedance signal (at the top) obtained by unipolar impedance measurement and a number of other measured signals illustrating different heart events in relation to the impedance signal. Below the impedance signal can be seen right and left ventricular pressure obtained by fast response pressure sensor elements of a conventional type. A fluid colon pressure sensor measures the arterial pressure using a sensor element positioned in aorta. The last two tracings are the bipolar internal electrocardiograms (IECG) in the right atrium (RA) and in the right ventricle (RV), respectively.

The measurement values shown to the left in the figure are only included to illustrate the magnitudes of the values.

The aortic valve opening is indicated in the aortic pressure tracing and it can easily be identified in the impedance signal as a clear distinct notch.

Figure 2b shows close-up tracings covering a bit more than one heart cycle. From top to bottom is shown the aortic pressure (AOP), the left ventricular pressure (LVP), the internal electrocardiogram in right ventricle, in coronary sinus and in right atrium, respectively (IECG_RV, IECG_CS, and IECG_RA, respectively), the impedance signal (Imp_dZ3), the external electrocardiagram (ECGII) and the first derivative of left ventricular pressure (dLVP/dt).

Different events are identified in the figure by numbers 1-5.

1. The CS/GCV blood volume is increasing during ventricular systole, which is shown by the decreasing impedance signal.
2. The CS/GCV blood volume is decreasing during early ventricular diastole, which is shown by the increasing impedance signal.
3. The slope of the great cardiac vein impedance signal is slightly changing at mitral valve opening which makes it possible to detect the start of diastole.
4. The CS/GCV blood volume is increasing during atrial systole which is seen as an decreasing impedance signal.
5. The distinct notch in the great cardiac vein blood impedance corresponds to the aortic valve opening.

According to a second preferred embodiment of the invention is bipolar impedance measurement performed by positioning two measurement poles in CS/GCV. Impedance current is applied between the CS/GCV measurement poles (4kHz square wave having amplitude of 10μA). A voltage is sensed between the same poles.

Figure 3a discloses tracings of about four complete heart cycles of an impedance signal (at the top) obtained by bipolar impedance measurement and a number of other measured signals illustrating different heart events in relation to the impedance signal. These other signals correspond to the signals shown in figure 2a.

Figure 3b shows close-up tracings covering a bit more than one heart cycle. The shown tracings correspond to the tracings shown in figure 2b.

According to a third preferred embodiment of the invention is quadropolar impedance measurement performed by positioning two measurement poles in CS/GCV and using the tip and ring electrodes of a ventricular electrode lead. Impedance current is applied between one of the CS/GCV measurement poles (4kHz square wave having amplitude of 10μA) and one of the ventricular electrodes. A voltage is sensed between the other electrodes.

Figure 4a discloses tracings of about four complete heart cycles of an impedance signal (at the top) obtained by quadropolar impedance measurement and a number of other measured signals illustrating different heart events in relation to the impedance signal. These other signals correspond to the signals shown in figure 2a.

Figure 4b shows close-up tracings covering a bit more than one heart cycle. The shown tracings correspond to the tracings shown in figure 2b.

The quadropolar impedance reflects aortic valve opening and the opening of the mitral valve. A change in the impedance signal is seen prior to the atrial contraction (X) possibly indicating a time at which sufficient filling is at hand. Quadropolar impedance is decreasing at atrial systole (Y), thus enabling hemodynamical atrial capture verification.

Figure 5 shows a block diagram of the valve opening detecting means 2 according to the present invention.

The detecting means 2 comprises impedance measuring means 4 that perform impedance measurement by applying and receiving impedance measuring signals 5 to and from heart tissue, respectively, e.g. according to the above described technique. The impedance measuring means 4 filters and amplifies the detected impedance signal. The thus filtered and amplified impedance signal 7 is then applied to an impedance signal processing means 6 provided with a number of individual detectors. These detectors are an aortic valve opening detector 8 adapted to generate a first detection signal 10, a mitralis valve opening detector 12 adapted to generate a second detection signal 14, a third detector 16 adapted to generate a third detection signal 18 and a forth detector 20 adapted to generate a fourth detection signal 22. Each detector is individually set to identify a specific part of the impedance signal representing a specified heart event. The number of used detectors is naturally optional and depends only on the application.

Figure 6 shows a block diagram of an implantable heart stimulator 25 provided with a valve opening detecting means 2 according to the present invention. The heart stimulator 25 comprises a sensor control unit 26 connected to a heart stimulating unit 30 via connection 32 that provides sensor rate values and timing information to the stimulating unit 30 and also via connection 34 that provides stimulation status and timing information to the sensor control unit 26. The sensor control unit 26 controls the detecting means 2 via connection 24. The timing information is for instance the detection of a spontaneous QRS or if a stimulation pulse is delivered. The sensor control unit 26 is the interface to the detection signals from the impedance measurement but also to additional sensors connected thereto via connection 28 and additionally, it controls the measurement timing and weighting of the obtained sensor values.
The sensor control unit 26 provides the heart stimulating unit 30 with a sensor rate value that controls the stimulation rate of the pacemaker in dependence of a measured sensor value. This is established technique used in rate responsive pacemakers and is therefore not described any further in the present application.

The sensor control unit 26 and the heart stimulating unit 30 is also connected to a telemetry unit 36 that communicates, preferably via radio-waves, with a programmer 40 placed outside the skin 38 of a patient.

The sensor control unit 26 comprises a memory where pre-selected events are stored for diagnostic purposes. The memory content can be transferred to the programmer for further analysis. It is also possible to load special algorithms from the programmer into the sensor control unit 26 and heart stimulating unit 30.

In figure 6 is also shown an indifferent electrode 42 which preferably is arranged on the housing of the heart stimulator 25 and electrode lead means 44 that include at least one electrode lead provided with one or many impedance sensing electrode(s) adapted to be arranged in coronary sinus or in great cardiac vein. The electrode lead means 44 may also include one or many other electrode leads adapted to be arranged in the atrium and/or in the ventricle of the heart.

The aortic valve opening detector 8 includes first impedance signal processing means for processing a detected impedance signal according to a predetermined first signal processing, so that the opening of the aortic valve may be detected. The first signal processing is performed by amplifying and filtering the impedance signal in a first filter means having first filter characteristics to filter out the relevant part of the impedance signal, i.e. the sharp notch shown in figures 2-4.

The mitralis valve opening detector 12 includes a second impedance signal processing means for processing a detected impedance signal according to a predetermined second signal processing. The second signal processing is performed so that the opening of the mitralis valve may be detected. The second signal processing is performed by amplifying and filtering the impedance signal in a second filter means having second filter characteristics.

Each of the first and second filter characteristics includes one band-pass filter part with variable lower and upper border frequencies. The lower and upper border frequencies are set in dependence of the predetermined heart event to be detected. According to a preferred embodiment of the invention the border

frequencies are set for the aortic valve opening detector 10-30 Hz and for the mitralis valve opening detector to 2-16 Hz. The filtered signal is then preferably applied to a threshold detector having a, preferably programmable, threshold set in relation to the detected event. The threshold detector may be arranged to be active during a detection window synchronised with a detected QRS-complex or a stimulation pulse. With respect to the aortic valve opening detector the detection window is about 100-200 ms wide (preferably 100 ms), starting immediately after the occurrence of a QRS-complex or the delivery of a stimulation pulse. With respect to the mitralis valve opening detector the detection window is about 100-200 ms wide (preferably 100 ms), starting about 200-300 ms after a detected QRS-complex or the delivery of a stimulation pulse and ending with the next occurrence of a QRS-complex or the next delivery of a stimulation pulse. Preferably, the width of the time windows as well as the starting point in time for the (mitralis valve) window could be dependent on heart rate, such that a higher heart rate is reflected in shorter detection windows and an earlier starting point. The detection of a valve opening could preferably be used for determining, by well-known timer means in control unit 26, the time interval for the detection within a heart cycle starting from e.g the occurrence of a QRS-complex or the delivery of a stimulation pulse. This timing information for a valve opening detection can be used e.g for increased reliability in discrimination between the occurrence of the aortic valve opening and the mitralis valve opening, as well as for determining an exact point in time for hemodynamic capture verification (aortic valve opening).

According to a preferred embodiment of the invention at least one impedance measurement pole is adapted to be placed in a cardiac venous vein, e.g. in the coronary sinus or the great cardiac vein. The measurement is then performed between one pole in the cardiac venous vein and an indifferent electrode on the housing of the medical device.

According to another preferred embodiment of the invention the measurement is performed between two poles on an electrode lead adapted to be placed in a cardiac venous vein, e.g. in the coronary sinus or the great cardiac vein.

According to still another embodiment of the invention the measurement is performed between three poles on an electrode lead adapted to be placed in a cardiac venous vein, e.g. in the coronary sinus or the great cardiac vein, and an indifferent electrode on the housing of the medical device.

The present invention is not limited to the above-described preferred embodiments. Various alternatives, modifications and equivalents may be used. Therefore, the above embodiments should not be taken as limiting the scope of the invention, which is defined by the appendant claims.

Claims

1. An implantable medical device comprising valve opening detecting means (2) for detecting the opening of valve or valves in the left side of a heart, characterized in that the detecting means includes an impedance measuring means (4) for measuring the electrical impedance between measurement poles and generating an impedance signal in correspondence thereto, wherein at least one of the poles is adapted to be arranged in the coronary sinus and/or in the great cardiac vein of the heart, said detecting means including impedance signal processing means (6) for processing said impedance signal such that the opening of one or both valves in the left side of the heart is detected.

2. Medical device according to claim 1, characterized in that said detecting means comprises an aortic valve opening detector (8) arranged to detect the opening of the aortic valve.

3. Medical device according to claim 2, characterized in that said aortic valve opening detector includes first impedance signal processing means for processing said impedance signal according to a predetermined first signal processing.

4. Medical device according to claim 3, characterized in that said first signal processing is performed by amplifying and filtering the impedance signal in a first filter means having first filter characteristics

5. Medical device according to claim 4, characterized in that said filter characteristics includes at least one band-pass filter with a band range of 10 to 30 Hz.

6. Medical device according to claim 5, characterized in that the lower and upper border frequencies within said band range are variable.

7. Medical device according to claim 1, characterized in that said detecting means comprises a mitralis valve opening detector (12) arranged to

detect the opening of the mitralis valve.

8. Medical device according to claim 7, characterized in that said mitralis valve opening detector includes second impedance signal processing means for processing said impedance signal according to a predetermined second signal processing.

9. Medical device according to claim 6, characterized in that said second signal processing is performed by amplifying and filtering the impedance signal in a second filter means having second filter characteristics

10. Medical device according to claim 9, characterized in that said filter characteristics includes at least one band-pass filter with a band range of 2 to 16 Hz.

11. Medical device according to claim 9, characterized in that the lower and upper border frequencies within said band range are variable.

12. Medical device according to any preceding claim, characterized in that the measurement is performed between one pole on an electrode lead and an indifferent electrode on the housing of the medical device.

13. Medical device according to any of claims 1-11, characterized in that the measurement is performed between two poles on an electrode lead and an indifferent electrode on the housing of the medical device.

14. Medical device according to any of claims 1-11, characterized in that the measurement is performed between three poles on an electrode lead and an indifferent electrode on the housing of the medical device.

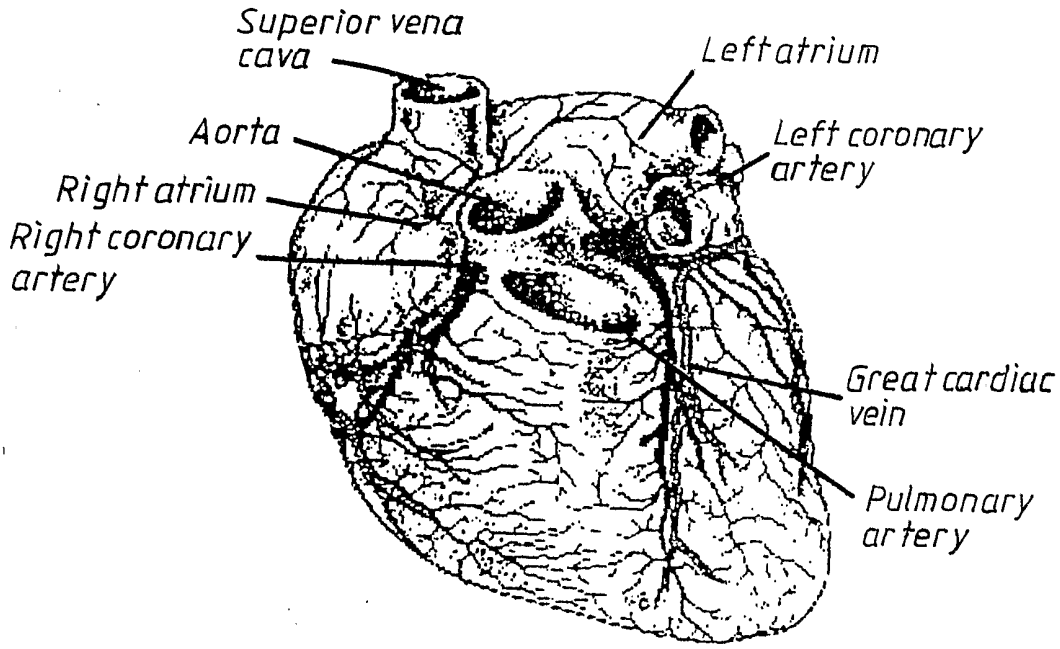
15. Implantable heart stimulator, characterized in that said stimulator comprises a medical device according to any preceding claims.

16. Implantable heart stimulator according to claim 15, characterized in that said impedance signal processing means generates a detection signal in

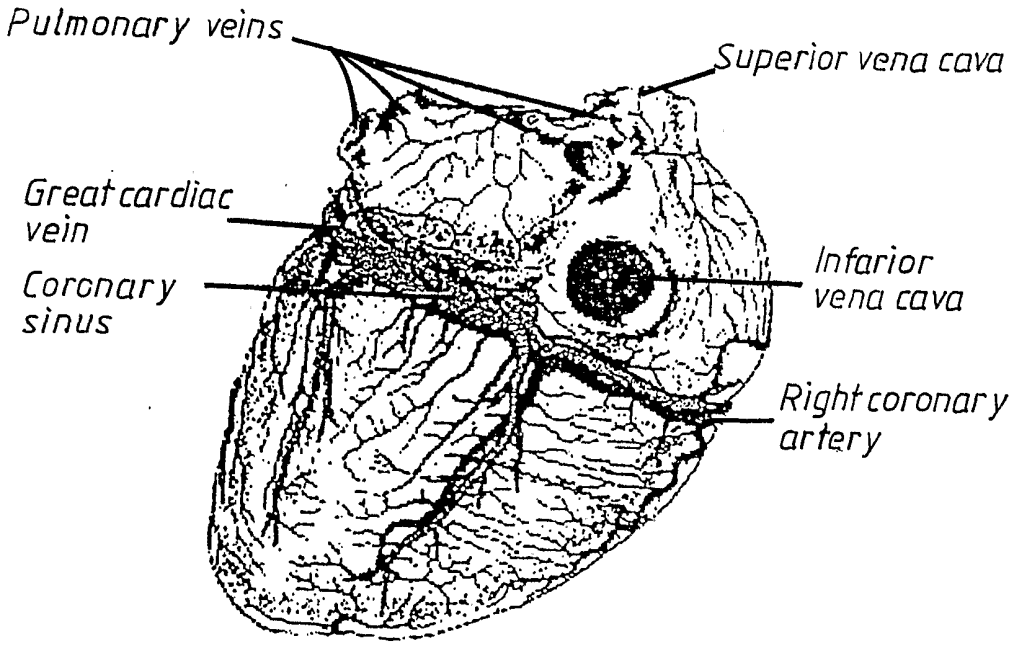
response of a detected aortic valve opening, wherein the detection signal is applied to a sensor control unit (26) where it is used as a capture indication signal.

17. Implantable heart stimulator according to claim 16, characterized in that said detection signal is used to control the timing of the generation of stimulation pulses to be applied to heart tissue.

Fig. 1

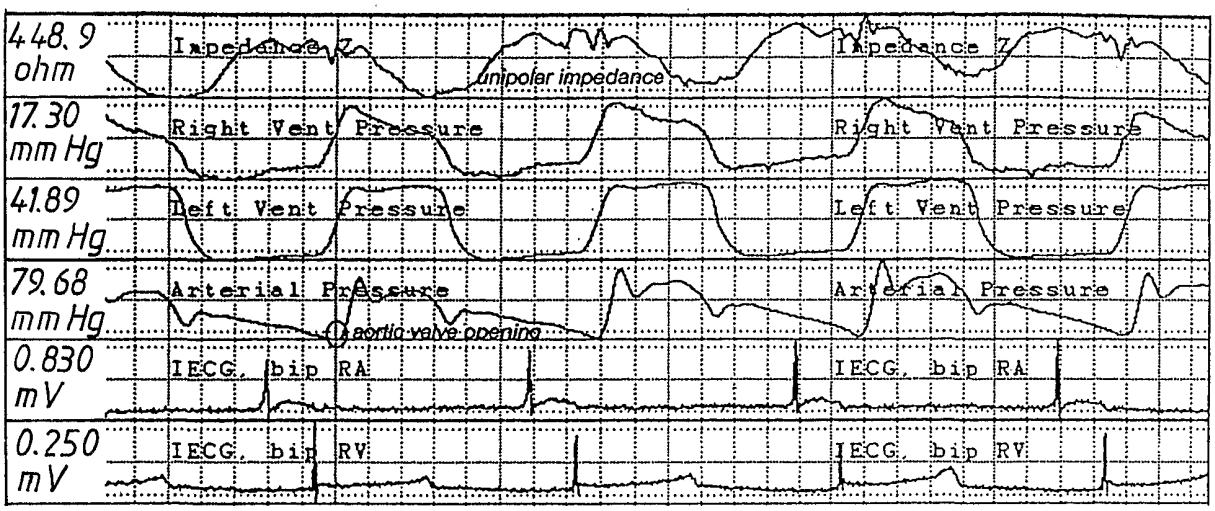


Anterior view



Posterior view

Fig. 2a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Impedance Z
unipolar impedance
Impedance Z
17.30 mm Hg
Right Vent Pressure
Right Vent Pressure
41.89 mm Hg
Left Vent Pressure
Left Vent Pressure
79.68 mm Hg
Arterial Pressure
aortic valve opening
Arterial Pressure
0.830 mV
IECG, bip RA
IECG, bip RA
0.250 mV
IECG, bip RV
IECG, bip RV

Fig. 2b

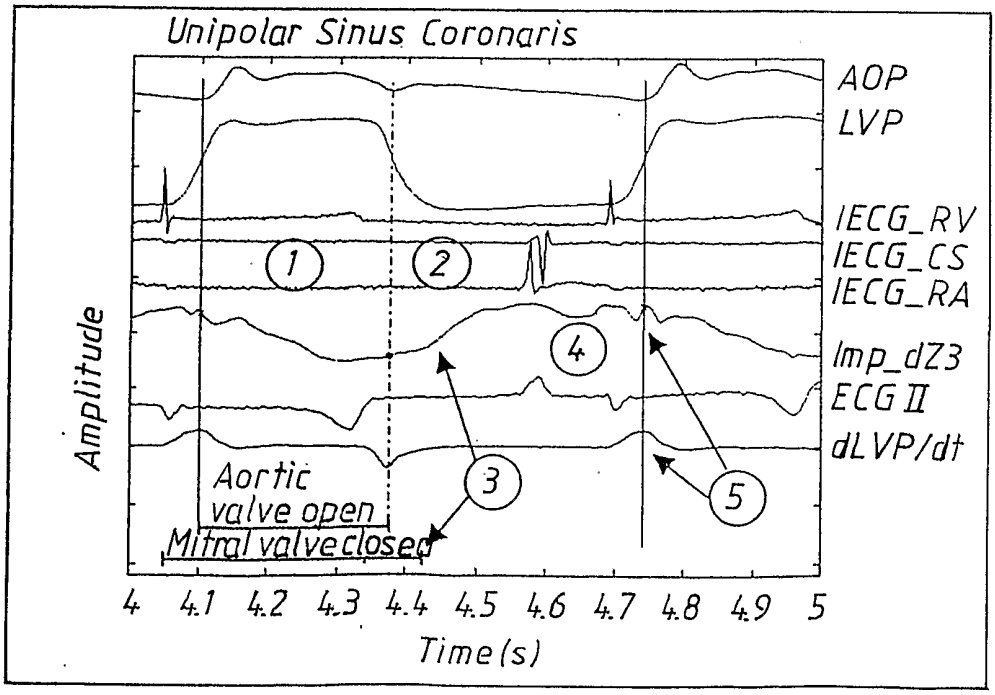

Unipolar Sinus Coronaris
AOP
LVP
IECG_RV
IECG_CS
IECG_RA
Imp_dZ3
ECG II
dLVP/dt
1
2
3
4
5
Aortic valve open
Mitral valve closed
Amplitude
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5
Time (s)

Fig. 3a

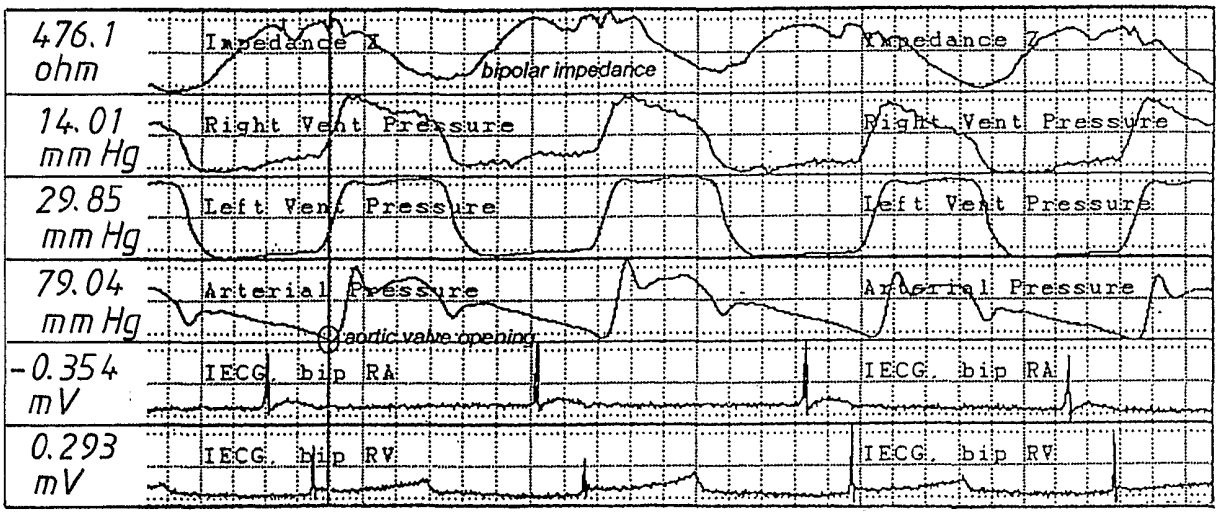

476.1 ohm
Impedance X
bipolar impedance
Impedance Z
14.01 mm Hg
Right Vent Pressure
Right Vent Pressure
29.85 mm Hg
Left Vent Pressure
Left Vent Pressure
79.04 mm Hg
Arterial Pressure
aortic valve opening
Arterial Pressure
-0.354 mV
IECG, bip RA
IECG, bip RA
0.293 mV
IECG, bip RV
IECG, bip RV

Fig. 3b

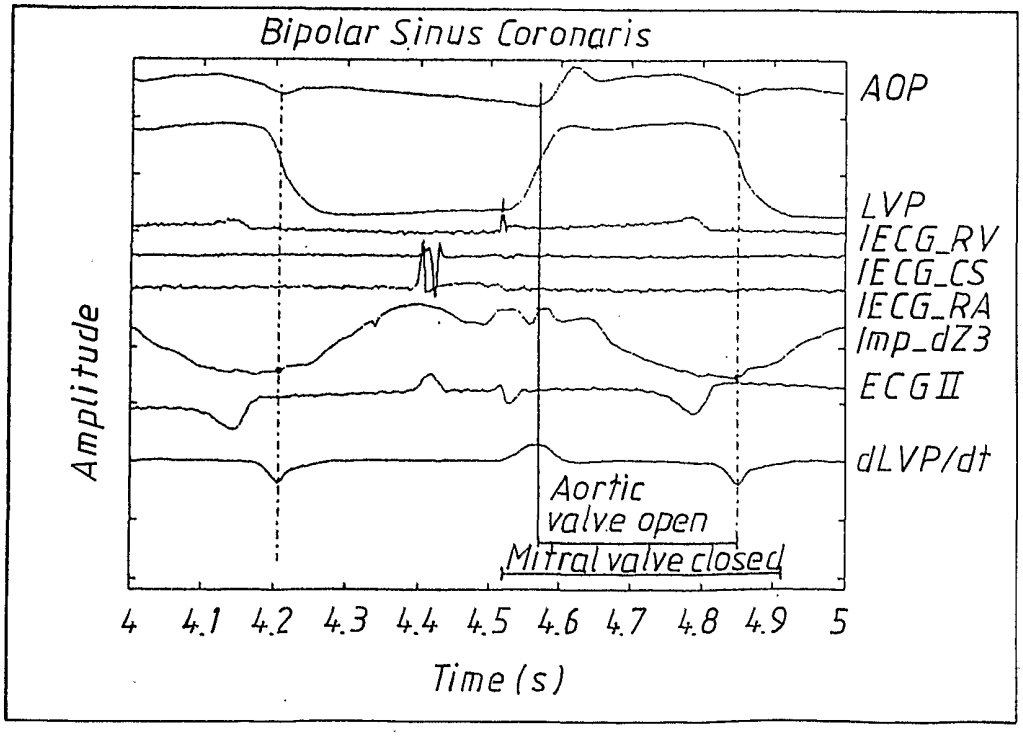
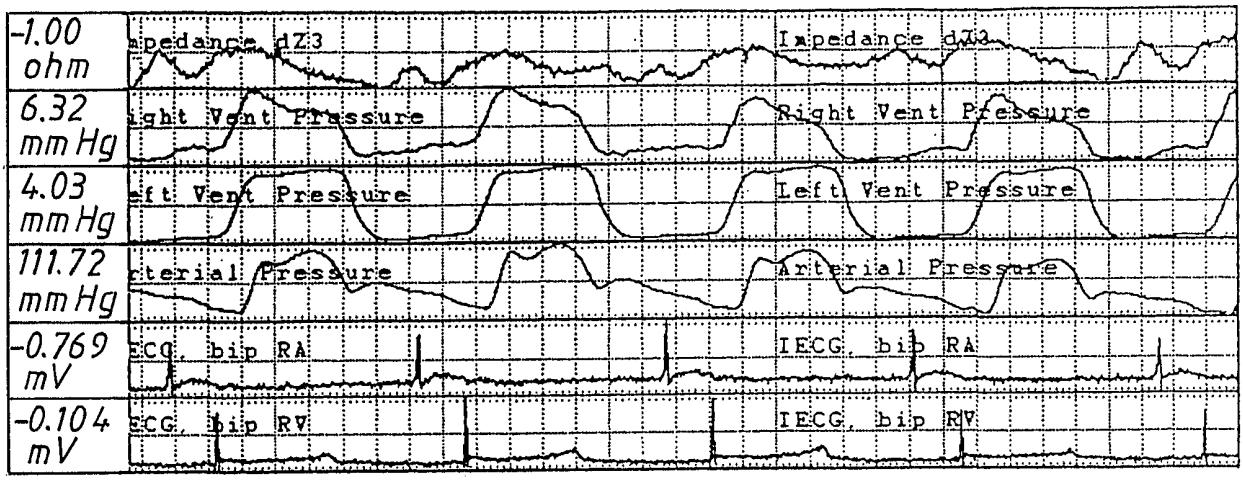

Bipolar Sinus Coronaris
AOP
LVP
IECG_RV
IECG_CS
IECG_RA
Imp_dZ3
ECG II
dLVP/dt
Amplitude
Aortic valve open
Mitral valve closed
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5
Time (s)

Fig. 4a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Impedance dZ3
6.32 mm Hg
Right Vent Pressure
4.03 mm Hg
Left Vent Pressure
111.72 mm Hg
Arterial Pressure
-0.769 mV
IECG, bip RA
-0.104 mV
IECG, bip RV

Fig. 4b

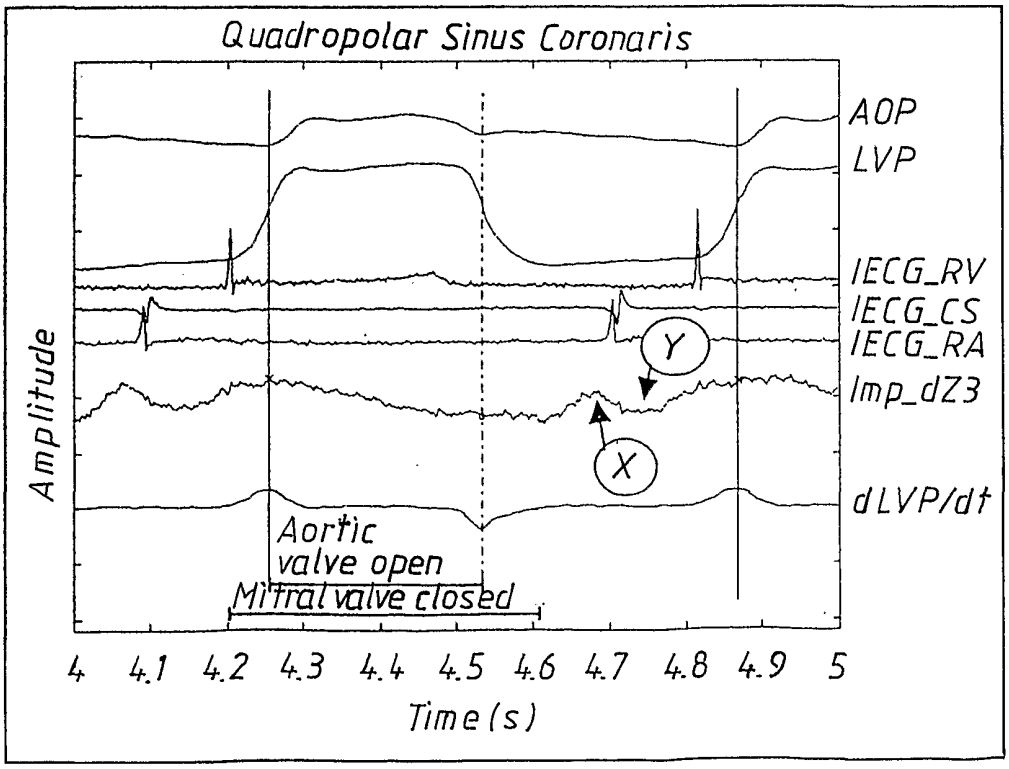
Quadropolar Sinus Coronaris
AOP
LVP
IECG_RV
IECG_CS
IECG_RA
Imp_dZ3
dLVP/dt
Y
X
Aortic valve open
Mitral valve closed
Amplitude
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5
Time (s)

Fig. 5

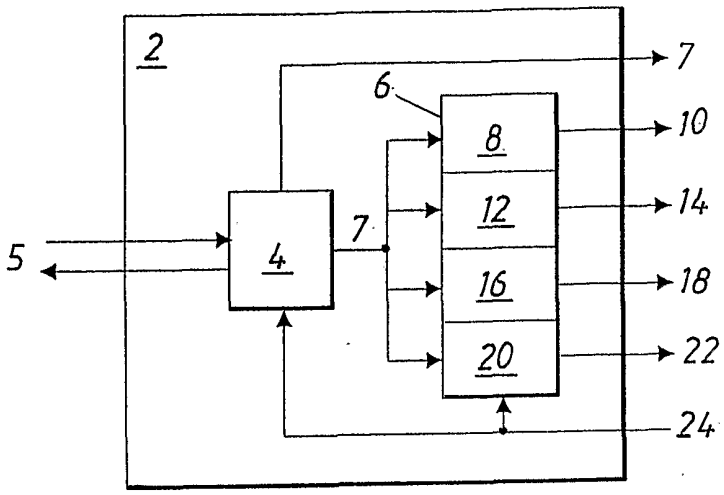
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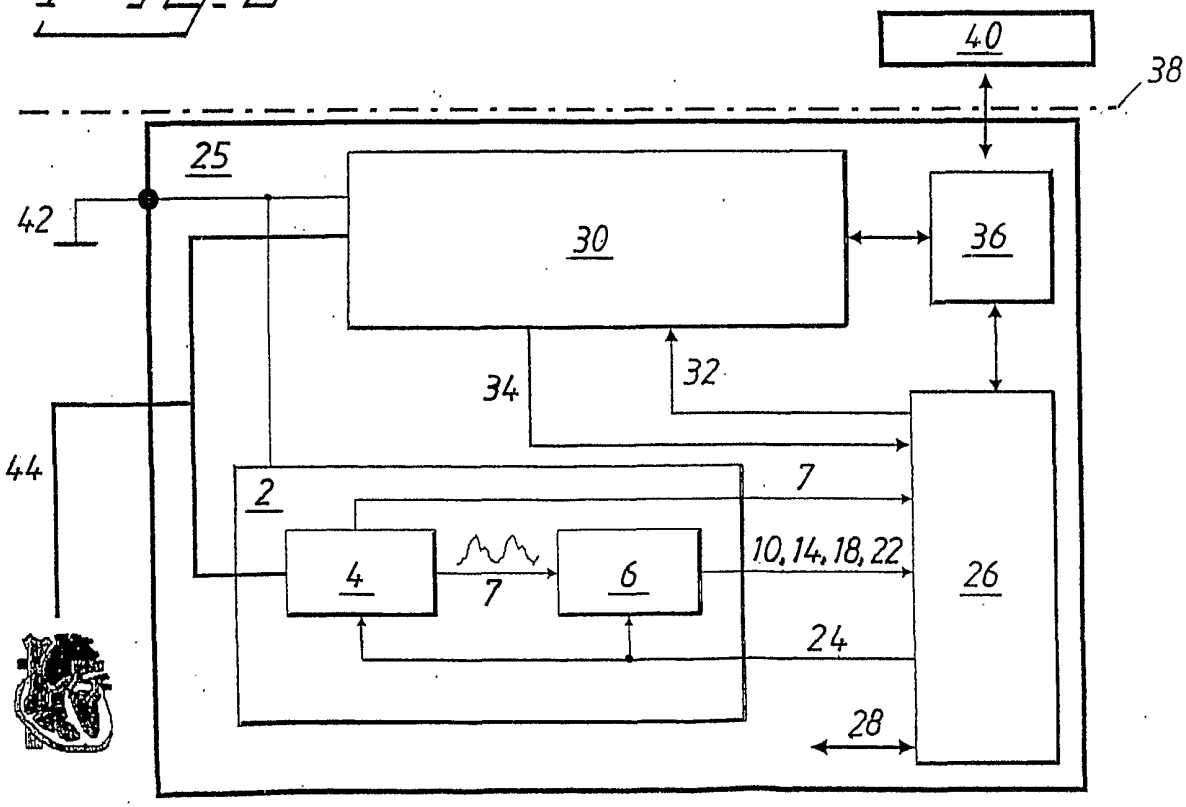
Fig. 6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10, 14, 18, 22
26
24
28

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/01424

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: A61N 1/37
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: A61N

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

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI, PAJ, INSPEC, MEDLINE, BIOSIS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5954752 A (LUC R. MONGEON ET AL), 21 Sept 1999 (21.09.99), column 13, line 3 - line 43; column 16, line 4 - line 59	1-17
A	US 5995870 A (SERGE CAZEAU ET AL), 30 November 1999 (30.11.99), column 3, line 44 - line 51	1-17
A	US 4730619 A (GERRIT KONING ET AL), 15 March 1988 (15.03.88), column 5, line 7 - line 15; column 15, line 50 - line 59	1-17

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 October 2001	11-10-2001
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Frida Plym Forshell/AE Telephone No. +46 8 782 25 00

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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International application No.
PCT/SE 01/01424

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