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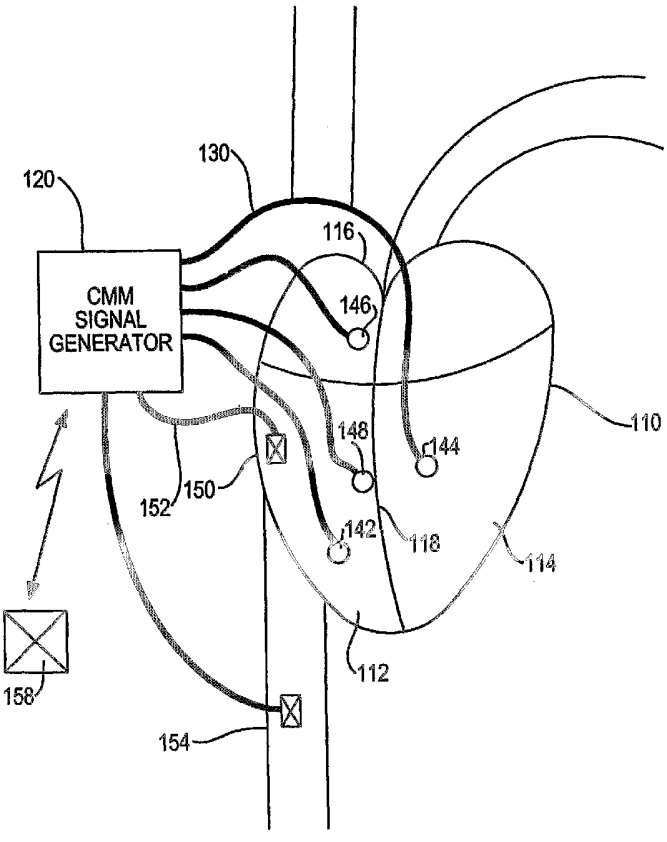
(54) Title: APPARATUS AND METHOD FOR DELIVERING ELECTRICAL SIGNALS TO MODIFY GENE EXPRESSION IN CARDIAC TISSUE

(57) Abstract: Method and apparatus (120) for modifying gene expression in cardiac muscle cells (110), by the application of electric fields.



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APPARATUS AND METHOD FOR DELIVERING ELECTRICAL SIGNALS TO MODIFY GENE EXPRESSION IN CARDIAC TISSUE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit under 35 USC 119(e) of U.S. provisional patent application Serial No. 60/453,349, filed March 10, 2003, and U.S. provisional patent application Serial No. 60/503,075, filed September 10, 2003, the disclosures of which are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

The present invention is related to the field of cardiac muscle control. In some embodiments, the invention relates to the use of electrical signals to treat heart failure and/or other diseases, by modification of gene expression.

BACKGROUND OF THE INVENTION

Heart Failure affects (and/or is possibly caused by) several mechanisms that are involved in the heart functioning. Among those mechanisms the expression of some genes may be affected to a depressed or over expressed condition, which affects the normal functioning of the cells and the muscle as a whole. The expression of several genes is also used as a clinical marker for the progression of the disease.

Within the literature dealing with changes in gene expression and proteins associated with heart failure, one could find changes in mRNA gene expression of brain and atrial natriuatic peptides (BNP, ANP), basic fibroblast growth factor (bFGF), mRNA gene expression for alfa myosin heavy chain aMHC, and gap junction protein connexin 43. Plasma levels of brain (B-Type) and atrial (A-Type) natriuretic peptides are increased in heart failure (HF) and are predictive of poor outcome. Increased levels of basic fibroblast growth factor (bFGF) is associated with increased angiogenesis, with increased capillary density, and with improved left

ventricular (LV) ejection fraction (as demonstrated also in dogs with heart failure). Myosin heavy chain (MHC) is a key component of the cardiac contractile machinery. Recent studies showed that a switch from the aMHC to the ßMHC isoform occurs in patients with heart failure. This switch may partly contribute to the progressive deterioration of left ventricular function characteristic of heart failure.

Loss of gap junctions and impaired intracellular communications are characteristic features of remodeling in heart failure and result from rapid loss of the gap junction protein connexin 43. Loss of connexin 43 has also been reported to result in malignant ventricular arrhythmias in patients with heart failure.

It has previously been shown that in dogs with heart failure, delivery of non-excitatory cardiac contractility modulation (CCM) electrical signals to left ventricular muscle during the absolute refractory period leads to chronic improvement in left ventricular function and remodeling. In patients and dogs with heart failure, chronic CCM therapy was also associated with suppression of ventricular arrhythmias.

Excitable tissue control (ETC) devices are devices which modulate the activity of excitable tissues by application of non-excitatory cardiac contractility modulation (CCM) electrical field signals to the excitable tissue through suitable electrodes in contact with the tissue. For example, ETC devices may be used, *inter alia*, to increase or decrease the contractility of cardiac muscle *in vitro*, *in vivo* and *in situ*, as disclosed in detail in PCT application No. PCT/IL97/00012 (International Publication No. WO 97/25098) to Ben-Haim et al., titled "ELECTRICAL MUSCLE CONTROLLER" and U.S. Patent No. 6,317,631, the disclosures of both of which are incorporated herein in their entirety by reference.

OBJECTS OF THE INVENTION

It is an object of some embodiments of the invention to provide a method and device for cardiac muscle control.

It is an object of some embodiments of the invention to provide non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals to affect the heart such as to treat arrhythmias.

It is an object of some embodiments of the invention to provide non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals to affect the heart such as to enable improved contraction of the heart muscle.

It is an object of some embodiments of the invention to provide a method and apparatus for delivering non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals to modify gene expression and protein levels associated with the functioning of the heart to improve cardiac function.

It is an object of some embodiments of the invention to provide a method and apparatus to treat heart failure by modifying the expression of genes associated with the excitable heart tissue.

These and other objects of embodiments of the invention will become more apparent in the discussion below.

SUMMARY OF THE INVENTION

According to some embodiments of the present invention non-excitatory signals such as cardiac contractility modulation signals, or non-excitatory and excitatory signals delivered to cardiac tissue of a failing heart for several hours or longer or shorter periods of time, change the expression of several genes that effect the cardiovascular system function. The changes in the

expression improve cardiac function and may lead to reversal of the progression of heart failure disease or even return the heart to more normal functioning.

As reflected in the experimental evidence discussed below, CCM signal delivery causes improvement in cell and muscle activity as evidenced by mRNA expression. More specifically, CCM signals reduce the mRNA gene expression of brain and atrial natriuatic peptides (BNP, ANP), increase levels of basic fibroblast growth factor (bFGF), and normalize mRNA gene expression for alfa myosin heavy chain aMHC.

Plasma levels of brain (B-Type) and atrial (A-Type) natriuretic peptides are increased in heart failure (HF) and are predictive of poor outcome. According to certain embodiments of the invention CCM therapy reduces mRNA gene expression of both B-Type and A-Type natriuretic peptides.

Increased levels of basic fibroblast growth factor (bFGF) are associated with increased angiogenesis. It was previously shown that increased mRNA gene expression of bFGF is associated with increased capillary density in dogs with chronic heart failure. It was also shown that an increase in capillary density is associated with improved left ventricular ejection fraction, for example, in dogs with heart failure. According to certain embodiments of the invention CCM therapy restores mRNA gene expression for bFGF to above normal level or above diseased levels. CCM therapy appears to enhance expression of bFGF and, as such, may be a therapeutic modality that enhances angiogenesis, a condition that is likely to be important in the treatment of chronic heart failure and possibly angina pectoris.

Myosin heavy chain (MHC) is a key component of the cardiac contractile machinery. Recent studies showed that a switch from the aMHC to the ßMHC isoform occurs in patients with heart failure. This switch may partly contribute to the progressive deterioration of LV function characteristic of heart failure. According to certain embodiments of the invention CCM therapy improves mRNA gene expression for aMHC and may bring it to levels which are

considered substantially normal. Since aMHC is associated with faster velocity of shortening of cardiac muscle compared to the slow-contracting ßMHC, this normalization may be responsible, in part, for the observed improvement of LV EF after CCM therapy and can be used for the treatment of heart failure in patients.

Since CCM signals may be used to reduce mRNA gene expression of both B-Type and A-Type natriuretic peptides, restore mRNA gene expression for bFGF to above normal level and/or normalize mRNA gene expression for aMHC, this therapy may be used to improve cardiac function and may be used as a therapeutic modality that enhances angiogenesis, a condition that is likely to important in the treatment of chronic heart failure and possibly angina pectoris.

Moreover, since aMHC is associated with faster velocity of shortening of cardiac muscle as compared to the slow-contracting ßMHC, treating the failing heart by means of CCM delivery aimed to improve, or to normalize, ANP and BNP levels may be used to attain better contraction, and may be responsible, in part, for the observed improvement of LV EF after CCM therapy.

According to some embodiments of the invention, the non-excitatory cardiac contractility signals are used for treatment of arrhythmias and/or improvement of interacardiac connections between the cells by promoting the expression of associated genes and, in particular, the connexin 43 protein that is a contributor to the creation of the gap junction between the cells. This may be used to achieve improved contraction and/or synchronization of the ventricles. Improved contraction of the left ventricle can improve the synchronicity of the contraction and increase cardiac contractility and may also alleviate a patient's suffering from heart failure.

While some particular examples of genes are shown to have their expression modified, it is expected that other genes have their expression modified as well. In an exemplary embodiment of the invention, the effect of applying a CCM signal is to improve the expression profile of some of the cardiac cells to be healthier and/or better suited for their functioning.

In some embodiments of the invention non-excitatory fields are applied which do not have a clinically significant cardiac contractility modification effect.

In an exemplary embodiment of the invention, a device is used to apply a CCM signal and the effects on gene expression are monitored, so that application of the CCM or other non-excitatory signal can be modified. Optionally, CCM application is stopped when a desired gene expression effect is achieved. Optionally, CCM parameters are optimized for a particular patient or disease state. Optionally, the device includes a closed loop which sensing the gene expression effect of the CCM signal and modifies it accordingly.

There is thus provided in accordance with an exemplary embodiment of the invention, a device capable of delivering non-excitatory or non-excitatory and excitatory signals to heart tissue that will modify gene expression of cells in the heart tissue in a way to improve the cardiac function.

There is also provided in accordance with an exemplary embodiment of the invention, a device capable of delivering non-excitatory cardiac contractility or non-excitatory and excitatory modulation signals to heart tissue that will modify the expression of BNP and ANP in the heart tissue for treatment of heart failure.

There is also provided in accordance with an exemplary embodiment of the invention, a device capable of delivering non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals to heart tissue that will normalize or better the expression of alfa myosin heavy chain aMHC in the heart tissue for treatment of heart failure.

There is also provided in accordance with an exemplary embodiment of the invention, a device capable of delivering non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals that will modify the expression of basic fibroblast growth factor (bFGF) in the heart tissue for treatment of heart failure.

There is also provided in accordance with an exemplary embodiment of the invention, a method for improving heart function by modifying the expression in heart tissue of genes that effect cardiovascular system function.

There is also provided in accordance with an exemplary embodiment of the invention, a method for treating heart failure by modifying the expression in heart tissue of genes that effect cardiovascular system function. Optionally, the heart failure is congestive heart failure. Alternatively or additionally, the non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals are delivered to heart tissue to modify gene expression in the heart tissue. Optionally, the signal or signals reduce mRNA gene expression of BNP, ANP, or both BNP and ANP. Optionally, the signal or signals restore mRNA gene expression for bFGF to above normal level. Optionally, there is also provided in accordance with an exemplary embodiment of the invention, a the signal or signals normalize or better nRNA gene expression for aMHC.

There is also provided in accordance with an exemplary embodiment of the invention, a method of treating a patient with a cardiac related disease, comprising:

determining a desired gene expression profile in cardiac tissue; and

applying a non-excitatory signal to the cardiac tissue to achieve the desired gene expression profile.

There is also provided in accordance with an exemplary embodiment of the invention, a device adapted to apply a non-excitatory field to a heart, characterized in that the device is adapted to take an effect on gene expression into account in its functioning. Optionally, said device is implantable. Alternatively or additionally, said device includes a feedback control loop which modifies an application of non-excitatory field in response to an indication of a gene expression effect of a previous application of a non-excitatory field. Optionally, said device

includes a watchdog which stops or modifies application of an electrical signal to a heart responsive to an effect of such application on gene expression in the heart.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of an apparatus useful to deliver electrical signals according to an exemplary embodiment of the invention;

Fig. 2 is a more detailed schematic representation of an apparatus useful to deliver electrical signals according to an exemplary embodiment of the invention;

Fig. 3 is a flow chart representing a method of treating a patient for heart failure according to an exemplary embodiment of the invention; and

Fig. 4 represents the bands of different genes on agarose-ethidium gel.

DETAILED DESCRIPTION OF THE INVENTION

According to some embodiments of the invention, non-excitatory or non-excitatory and excitatory CCM signals are applied to cardiac tissue in a patient's heart. The signals applied may be either completely non-excitatory or a mixture of non-excitatory and excitatory signals. The signals may be superpositioned, or may be applied intermittently, for example, in a ratio of from about 20:1 to about 1:10, or in a ratio of from about 10:1 to about 1:1, for example, based upon the respective voltages. The signals may each have a frequency, for example, from about 0.1 Hz to about 1000 H. In another example, one may use signal frequencies in the range of from about 10 to about 80 Hz. The signals may each have a voltage of from about 10 mV to about 50 V. In another example, one may limit the voltage to the range of from about 1 to about 15 V, or even further limit to use voltage in the range of from about 3 to about 10 V. In another example, the signals may be delivered in synchronization with the heart activity, in a configurable delay and duration from local muscle activity. For example, it is possible to apply signals in a delay of up

to 150 msec from local electrical activity detection. The delay may further be limited to up to 100 msec. In another example, one may apply the signals in a duration of up to 150 msec. It is possible to limit the range even further to use a duration of up to 50 msec, for example, about 10 msec, about 20 msec, about 30 msec or about 40 msec. In another example one may use a signal duration which is longer than 3 times the chronaxie, or even longer than 5 msec. In another example, one may use a signal duration which is longer than 8 msec, for example, 20 msec or 40 msec.

Optionally, the signal has a balanced waveform, for example, being in the shape of a byphasic pulse.

The time duration of application of a CCM therapy can vary greatly. It could be, for example, 10 minutes, 1 hour, 2 hours, 6 hours, a day, a week, or a month. One or more break periods and/or periods of rest to test the chronic effect of the signal may be provided, for example, to test if a gene expression remains altered even after a week without CCM application. It should also be appreciated that gene expressions levels may change over times. For example, a cell with missing connexin 43 may respond to a CCM signal by significant expression of connexin 43 mRNA fragments and, once its needs are met, reduce such expression. An improvement in cell function may be immediate or may be delayed and/or gradual and/or dependent on other factors. In any case, such changes in gene expression caused by lack of need of a cell are optionally taken into account when measuring positive effect of the CCM signal. Optionally, cells are periodically rested so that they can be pumped for more generation of desired secretions and/or proteins.

In an exemplary embodiment of the current invention, CCM signals are set to a voltage of 3-7.5 Volts, train of 1-5 biphasic pulses delivered every beat, all together with a duration of 10-80 msec, with a delay from local electrical activity of up to 100 msec. It is expected that other pulse parameters will be able to produce a desired gene expression effect.

In a preferred embodiment, the signal is delivered during the absolute refractory period of the local tissue, where the parameters are tuned to produce a desired gene expression effect. In yet another embodiment, the signal includes pacing, followed by a non-excitatory signal where the parameters provide a desired gene expression effect. In yet another embodiment, the signal is a prolonged pacing signal, having the a first excitatory edge, continued by a signal longer than 5 msec, where the parameters are tuned to produce a desired gene expression effect.

In an exemplary embodiment of the invention, the non-excitatory and/or the excitatory signals will be generated by a signal generator unit, whether implanted or external. The device may comprise a sensor of cardiac activity, and may comprise additional sensors and/or inputs from other sensors, associated directly or indirectly with the levels of relevant gene expression, to enable tuning of the signal delivery such as to achieve desired change in the measured parameters.

EXEMPLARY IMPLEMENTATION

Figure 1 describes an exemplary embodiment of the present invention. A CCM signal generator unit 120 is connected to a heart 110 with leads 130 and one or more electrodes 142-148. Electrodes 142, 144, 146, 148 may be located, for example, in various locations such as right ventricle 112, left ventricle 114, atria 116 or septum 118, respectively, whether through endocardial, epicardial or intravenous approach. The electrodes and leads are optionally used to sense cardiac activity from one or more locations and may be used to deliver CCM signals to one or more locations. CCM signal generator unit 120 may receive input measured from various sensors. For example, one or more such sensors 150 may be attached to the heart (whether inside or outside). In additional example, one or more such sensors 154 may be located in blood vessels, or in another body organ. Such sensors may be directly connected via connectors 152 to convey the measured signal to the CCM signal generator unit 120. In an additional example, unit 120 may receive input measured by sensors 158 which are not directly connected to the unit 120, for

example, by external sensors with, for example, wireless connection. Such sensors may be used to measure the levels of various biochemical compounds, including, for example, levels of mRNA, proteins, peptides, etc. These sensors may be made of commercially available technologies of bio-chips used for analysis of compounds in biological specimens (for example, bio-chips by Affymetrix, Inc. for DNA analysis). The CCM signal generator may receive the signals from the sensors or may be tuned according to such readings, and may receive signals related to cardiac activity to determine parameters and deliver the CCM signals, such as to affect the levels of relevant gene expression and relevant proteins. Optionally, generator (device 120) includes a limited number of biochemical testing cells, each of which is selectively activated when a state of gene expression is to be determined. Such miniaturized genomic and biochemical systems are known in the art. For example, a blood inlet with 10 cells for testing blood may be provided. In another example, a tube is provided with an inner screw element for removing a tissue sample and conveying it to a testing chamber in the device. Alternatively, an external control unit is provided, for example, to which test results or tissue biopsies is provided. this external control unit decides on changes and/or receives input form a human user.

Fig. 2 describes an example of a system that may be used for CCM signal generation to control levels of proteins and gene expression. The system may be comprised of sensors 222, and may receive information from remote sensors 220. The system may comprise a sensor analysis unit 230 that process the input signals. The system may further be comprised of a cardiac activity analysis unit 250, that may be used to process information received from one or more electrodes 270 attached to the heart. The system may comprise a control unit 240 that determines the parameters of the CCM signals to be delivered according to the desired treatment, and may take into account analyzed information from the sensors and cardiac activity (units 230 and 250, respectively). The system comprises of a CCM delivery unit 260 that incorporates the necessary electrical circuitry to produce the desired CCM signals. These signals are delivered to one or more of electrodes 270 and 280, to affect the levels of relevant gene expression and relevant proteins.

In one exemplary use, device 120 is tuned during implantation (or a follow-up period) to achieve a best effect as measured by gene expression. In another exemplary usage device 120 can modify its generation of CCM signals responsive to changes in the measured gene expression. It is noted that some of the sensors described herein can be used for closed loop control of device 120. Optionally, human interaction is accepted or requested. A standard type telemetry unit, for example, may be used. Such telemetry may be used, for example, for data logging, for programming and/or for real-time or off-line parameter control. It is appreciated that it is not always possible, or practical, or necessary, to achieve optimal CCM signal parameters. For example, for reasons of safety, power limitations, physiological limitations, electrode placement, time to optimize, or the like, a pulse with suboptimal parameters may be sufficient to achieve a useful therapeutic signal.

In an exemplary embodiment of the invention, device 120 is an implanted device used for relatively longer term treatment, for example, over one week, over one month, for several months or permanently. In an alternative embodiment of the invention, device 120 is an external device, for example, with implanted leads. Alternatively, an electric field for the CCM is applied from outside the body. External devices may be useful, for example, for patients which show a gene expression response after a short treatment (e.g., 1 hour or less, a day), or for acute use (e.g., temporary heart failure). Depending on the patient, a desired or suitable gene expression modification may be achieved by application of CCM at various periodicies, for example, once a minute, once an hour, once a day, once a week or less or more often. As described below, CCM may also be provided on demand in response to its effect, for example, when a gene expression profile reaches a certain threshold. In some situations, CCM may be applied acutely, for example, using a catheter, for example, during surgery or as a stand-alone treatment.

Though the mechanism of action is yet to be explored and without limiting the actual application, one may theorize that the electrical current modulates ion availability to organelles which availability modulation affects biochemical reactions and/or directly affects gene

transcription. Another possible explanation is that the signal induces mechanical and electrical functionality of the tissue, which alleviates stress on the cells thus eliminates the triggers for irregular genes. Alternatively, such induces functionality may in itself cause, trigger or modulate certain gene transcription. Possibly, any signal which improves the functioning of the cells and/or reduces stress on them and/or increases (or decrease) plateau durations and/or calcium availability inside the cells or organelles thereof, may have a utilizable gene transcription and/or expression effect.

It is further another preferred embodiment of the current invention to include in the device inputs from biochemical sensors, whether incorporated in the device or connected to the device, reporting the levels of the desired analyst. In yet another preferred embodiment, the changes in level of expression are indirectly deduced from indirect measurements, including electrical or mechanical sensors (e.g., arrhythmia changes or contraction force) related to the activity of the analysts. Optionally, a chronic change in contractility, for example, is correlated with changes in gene expression. Thus, changes in gene expression of various genes may be deduced (in one patient or in a group of patients) from changes in electrical and mechanical behavior of the heart or other body systems (e.g., measuring fluid retention). In some implementations one of the genes described here is detected as a marker for indicating that other genes are having their expression modified and/or as an indicator of a particular gene expression profile. Alternatively, a different gene may be used as a marker or indicator for the genes described herein or for other genes.

Various design making methods may be applied for stopping, starting or modifying CCM signal application and parameters. In one example, device 120 changes CCM delivery based on measured levels, based on a pre-programmed decision rules. Alternatively or additionally, device 120 applies a CCM signal or signal series whenever the analyst level cross a threshold. Alternatively or additionally, device 120 applies the signal when a calculation combining multiple parameters crosses a threshold. Alternatively or additionally, the signal parameters

(delay duration, frequency, voltage, polarity, pulse train, signal shape) are changes such as to achieve the desired levels to the measured parameters. Alternatively or additionally, a negative rule is applied, for example, not applying an excitatory or non-excitatory signal that has a negative effect on gene expression.

The protocol for the actual delivery and/or implantation of wires to deliver the signals is set forth in the aforementioned PCT publication No. WO 97/25098 and U.S. Patent No. 6,317,631, both of which are incorporated herein by reference in their entirety. Following is a list of patents and publications which describe apparatus and methods which may be useful in conjunction with the present invention, the disclosures of all of which are incorporated herein by reference:

Cardiac output enhanced pacemaker, U.S. Patent No. 6,463,324, Apparatus And Method For Controlling The Contractility Of Muscles, U.S. Patent No. 6,233,484, Controlling Heart Performance Using A Non-Excitatory Electric Field, U.S. Patent No. 6,317,631, Muscle Contraction Assist Device, U.S. Patent No. 6,285,906, Modulation Of Intracellular Calcium Concentration Using Non-Excitatory Electrical Signals Applied To The Tissue, PCT WO01/24871 and PCT WO00/12525, Electrical Muscle Controller, U.S. Patent No. 6,363,279, Electrical Muscle Controller using a Non-Excitatory Field, U.S. Patent No. 6,330,476, Cardiac Output Controller, U.S. Patent No. 6,298,268, Cardiac Output Enhanced Pacemaker, U.S. Patent No. 6,463,324, Sensor Based Regulation of Excitable Tissue Control of the Heart, WO00/27475, Regulation of Excitable Tissue Control of the Heart based on Physiological Input, WO00/27476, Trigger Based Regulation of Excitable Tissue Control of the Heart, U.S. Patent No. 6,587,721, Pacing with Hemodynamic Enhancement, PCT IL99/00392, ETC Delivery via RV Septum, PCT WO0182771A3, Anti-Arrhythmia Device having Cardiac Contractility Modulation Capabilities, PCT WO01/30445, and Anti-Arrhythmic Device & a Method for Delivering Anti-Arrhythmic Cardiac Therapy, PCT WO01/30139.

EXEMPLARY TREATMENT METHOD

Figure 3 is an exemplary flowchart representing a method for treating a patient. Data is collected (300) from various sensors measuring the levels of gene expression and/or proteins. The input data may be further analyzed (310) by signal conditioning, statistical tools, classification, or other mathematical methods that produce informative result. The collected data and/or the results of analysis may be further compared (320) with a first set of thresholds to determine if CCM should be applied (322) according to a first set of parameters. If the criteria is not met, additional comparison (330) to a second set of threshold may be used to determine if CCM should be applied (332) according to a second set of parameters. Additional sets of thresholds and parameters may be used as well. If none of the criteria is met, a default set of CCM parameters may be used, or CCM may be not delivered at all. The different CCM sets may represent, for example, different power levels or different stress levels on the heart (for which reason limits on their use may be desirable)

TREATMENTS

As will be seen form the examples below, the effects of gene expression modification can be short term or long term. For example, connexin proteins stay in the cell and modify its behavior. BFGF is an example of a material which exits the cell. However, it may have a long term effect by promoting angiogenesis.

In an exemplary embodiment of the invention, CCM signals are applied to achieve a particular beneficial effect, which is optionally monitored and/or managed by device 120.

In an example of angiogenesis promotion, device 120 is optionally positioned to electrify cardiac cells upstream of an area in need of angiogenesis.

In an exemplary embodiment of the invention, for angiogenesis, CCM is applied until a sufficient amount of angiogenesis promoting materials are secreted. Optionally, additional

treatments which are expected to promote angiogenesis are provided at a same time, for example, exercise or drug treatments.

Optionally, the duration (e.g., minutes, hours, days, months) of a therapy may be determined according to the severity of a disease, as indicated by the levels of the relevant gene expressions and/or other physiological or biochemical indicators, such as those known in the art. Alternatively or additionally, other parameters, such as intensity may be set according to disease parameters.

In an example of treating or assisting arrhythmias, a CCM signal is optionally applied (e.g., continuously or periodically) to a cardiac muscle section until a desired improvement in conduction velocity is achieved. For example, in atrial fibrillation, a CCM signal may be applied to all or part of an atria. Optionally, conduction velocity is modeled, for example, by reducing activity of some muscle sections, possibly preventing the effect of a CCM signal. Alternatively or additionally, some signals may be found to have a negative effect on gene expression. However, such negative effect may be utilized for modeling muscle mass and/or conduction velocity in a heart. Exemplary arrhythmias other than atrial fibrillation includes, PVC, VT, heart block and ventricular de-synchronization. It is believed that some or all of these conditions may be improved by selective or non-selective enhancement of gene expression in portions of the heart.

Other conditions may also be treated. It is noted that the results of cardiac gene expression may be found outside the heart, for example, directly, such as in preventing fluid retention (e.g., by direct action of a secreted material on the kidneys) or indirectly (e.g., reversing symptoms of CHF, or reducing pain of angina pectoris.

An interaction may be found between certain drugs and CCM effects on gene expression. In an exemplary embodiment of the invention, drug dosage is changed and/or drugs stopped as a result of CCM effect on gene expression. Alternatively or additionally, some drugs may be stopped, for example, if they are found to prevent the effect of CCM (for example, possibly calcium channel blockers) on cardiac tissue or if the combination is pro-arrhythmic. Other drugs

may be found to have a synergistic effect. Optionally, such drugs may be typically applied to parts of the heart to selectively prevent or enhance the effect of CCM. Optionally, CCM gene expression modification is used to enhance the activity of a drug or to overcome its negative effects (e.g., conduction velocity reduction for some anti-arrhythmia drugs).

TREATMENT VARIATIONS

Some variations on applying CCM signals to achieve gene expression are now described. In one variation, CCM signals are applied (e.g., continuously or periodically) until a gene expression improvement is stable. Possibly, periodic follow-up testing and/or CCM application may be needed.

In an exemplary embodiment of the invention, device 120 is used to determine in a particular patient parameters for gene expression modification. For example, device 120 is used to determine a minimum or optimum length of CCM signal application series which has a desired gene expression effect. This may be useful is reducing power requirements. Other exemplary parameters which can be thus determined are a repetition frequency of CCM and a power level of CCM. It should be noted that a CCM signal can have a gene expression effect even if little or no acute clinical contractility improvement is found directly from a beat-to-beat application of CCM.

Optionally, device 120 is used to experiment on a patient to determine parameters which are optimal for that patient. Alternatively or additionally, parameters which adversely affect gene expression are also found.

It should be noted that a there may be multiple suitable/healthy/allowable gene expression profiles. A device 120 can, for example, aim for one of these profiles and/or aim to avoid one or more known bad expression profiles and/or certain low or high gene expression values for particular genes. Optionally, a target gene expression profile or thresholds for various genes, are

found by sampling large populations and/or by sampling healthy cells in the same patient. It is also noted that an optimal gene expression profile may vary between ages, races, genomic profiles, diseases, functional activity of a cell (e.g., including workload), and locations in the heart.

In some cases, gene expression values naturally fluctuate. Device 120 (or other feedback means, such as a person) optionally take these fluctuations in to account, for example, by averaging. Alternatively or additionally, these fluctuations are intentionally aimed for by cyclically stimulating and not stimulating a cell so that gene expression profiles can fluctuate more like a healthy cell.

In an exemplary embodiment of the invention, device 120 is used to map a patient's response of gene expression (or study a group of patients) to various CCM sequences and/or other parameters.

In an exemplary embodiment of the invention, device 120 or a user monitor negative effects on gene expression of certain pacing sequences and protocols and/or certain non-excitatory sequences, for example, "fencing" sequences. This may be used to limit the application of such sequences and/or to counteract their effect by a gene expression promoting signal. Possibly, a pacing regime may be found to have a beneficial effect in a certain patient, disease state and/or group of patients and thus be deemed desirable.

Optionally, gene expression monitoring is used as a safety feature in standard-type pacemakers, to indicate if a negative effect is being caused to a heart. Optionally, the gene expression effect is determined by periodically measuring the sensitivity of cardiac tissue to a CCM signal. Changes in the sensitivity are expected to be correlated, in some patients and in some cases to changes in gene expression. For example, conduction velocity might change markedly in tissue where conduction velocity was not impaired. In another example, fluid

retention will either be improved or not based on whether tissue can generate additional suitable secretions. A baseline is optionally collected for patients before such use.

Another optional safety feature is tracking the heart to see abnormal ECG signals or an increase in various danger signals, like ST variability. Such variations may indicate that the changes in gene expression are not beneficial, and should be stopped, slowed down and/or supplemented by excitatory or non-excitatory signals which protect the heart and/or counteract such negative effects.

Alternatively or additionally, to stopping or modifying CCM application, an alert may be generated to a user, a physician or a caretaker.

In an exemplary embodiment of the invention, the application of standard CCM or other non-excitatory signals is modified to take into account the combination acute effects of a CCM signal and chronic effect caused by gene expression changes. For example, a degree of contractility enhancement and/or a timing may be changed to take into account changes in conduction. Optionally, a database is generated in which is stored the expected effect and/or progression of effect of a CCM signal on gene expression and the resulting changes in CCM application.

In an exemplary embodiment of the invention, prior to implantation or programming of an implanted device, a patient is tested to see if certain known CCM sequences have a desired gene expression effect and/or the degree of the effect. If the effect is small or negative, that patient may be contra-indicated for implantation. Alternatively, the results of such testing are used to classify the patients into groups of known patient types having known (e.g., previously collected) genomic or other responses to CCM signals. Optionally, non-genomic indicators, such as contractility modification are correlated with the gene expression effect. Thus, one effect can be used to predict one or more properties of the other effect.

In an exemplary embodiment of the invention, CCM is applied to achieve a numerical change in gene expression statistics. For example, an increase of 10%, 30%, 70%, 100%, 300% or any smaller, intermediate or greater percentage in the expression of a gene may be desirable. Optionally, what is desired is a reduction in expression of a gene, for example, by 20%, 50%, 80%, 90% or an intermediate or greater percentage. In some cases, a reduction (or increase) in any of a set of genes that are linked in a pathway is desired, for example, using the percentages above. In some embodiments, what is desired is an increase in volume of a secretion over time, or an absolute secretion amount or a secretion rate. For example, an increase of 20%, 50%, 200%, 1000% or a smaller, intermediate or greater amount may be a target. In some embodiments, a target is approaching a normal value, for example, halving the difference between current expression levels. In some embodiments, what is desired to make an expression profile similar to a base line, for example, differing by less than 50%, 30% or 20% from a baseline expression profile, over a set of 1, 3, 5, 10 or other number of genes or mRNA fragments.

It should be appreciated that the term "genes" was used in a general sense. However, a target may be expressed in the above numbers of a measurable quantity, such as mRNA fragments, peptides and serum analyts.

EXAMPLES

Results of three studies are presented below to demonstrate, in a non-limiting manner, the basis for the use of non-excitatory signals for changing the levels of expression of three different types of genes and by this provide therapy for heart failure:

Example 1

In one study, we examined whether four hours of continuous therapy with cardiac contractility modulation (CCM) signals from an OPTIMIZER-II ETC device (available from

Impulse Dynamics) normalizes gene expression of A-Type and B-Type natriuretic peptides in LV myocardium of dogs with HF induced by coronary microembolizations. CCM leads were implanted on the anterior surface of the LV in an open chest preparation.

Signal parameters used were: CCM voltage of 3-7.5 Volts, train of 2-4 biphasic pulses delivered every beat, all together with a duration of 20-35 msec, with a delay from local electrical activity of up to 100 msec. We expect other pulse parameters to achieve the result as well, though these parameter settings were enough to produce the desired effect.

A total of three dogs were studied. LV tissue from three normal (NL) dogs and three dogs untreated HF dogs was used for comparison. LV tissue obtained at sacrifice was used to extract total RNA. By use of specific primers in reverse transcriptase-polymerase chain reaction (RT-PCR), B-Type and A-Type natriuretic peptides were identified on agarose-ethidium gel; corresponding fluorescent bands were quantified in densitometric units. The results are shown in the table below:

Table 1

	NL	HF-Untreated	HF + CCM
B-Type NP	2590 ± 1339	5181 ± 293*	2008 ± 796†
A-Type NP	1553 ± 306	4976 ± 1025*	3636 ± 1669†

*=P<0.05 vs. NL; †=P<0.05 vs. HF-Untreated

Gene expression of both B-Type and A-Type natriuretic peptides increased in untreated HF dogs compared to NL. CCM Therapy reduced mRNA expression of both B-Type and A-Type natriuretic peptides compared to untreated HF dogs.

Conclusions: The findings indicate that in dogs with HF, four hours of continuous CCM therapy reduces mRNA gene expression of both B-Type and A-Type natriuretic peptides. These findings are consistent with the observed reduction in atrial and ventricular size observed in dogs following CCM therapy.

Example 2

In another example we examined whether four hours of continuous therapy with cardiac contractility modulation (CCM) signals from an OPTIMIZER-II ETC device restores gene expression of bFGF in dogs with HF induced by coronary microembolizations. CCM therapy was previously shown to improve LV ejection fraction (EF) in dogs with HF. CCM leads were implanted on the anterior surface of the LV in an open chest preparation. CCM signal parameters were set to the same values as described above in Example 1. A total of three dogs were studied. LV tissue from three normal (NL) dogs and three dogs untreated HF dogs was used for comparison. LV tissue obtained at sacrifice was used to extract total RNA. By use of specific primers in reverse transcriptase polymerase chain reaction (RT-PCR) and restriction enzyme analysis of the RT-PCR product, bFGF was measured, and bands were quantified in densitometric units. Results are shown in the table below:

Table 2

	NL	**HF-Untreated**	**HF + CCM**
bFGF (densitometric units)	6099 ± 1486	4798 ± 223*	7600 ± 145†
*=p<0.05 vs. NL; †=p<0.05 vs. HF-Untreated			

mRNA expression for bFGF was significantly reduced in untreated HF dogs compared to NL. CCM therapy was associated with restoration of mRNA expression of bFGF to above normal levels.

Conclusions: In dogs with HF, LV mRNA gene expression of bFGF is decreased compared to NL dogs. Continuous CCM therapy for four hours restored mRNA gene expression for bFGF to above normal level. CCM therapy appears to enhance expression of bFGF and, as such, may be a therapeutic modality that enhances angiogenesis, a condition that is likely to important in the treatment of chronic heart failure and possibly angina pectoris.

Example 3

In yet another experiment, we examined whether four hours of continuous therapy with cardiac contractility modulation (CCM) signals from an OPTIMIZER-II ETC device restores gene expression of aMHC in dogs with HF induced by coronary microembolizations. CCM therapy was previously shown to improve LV ejection fraction (EF) in dogs with HF. CCM leads were implanted on the anterior surface of the LV in an open chest preparation. CCM signal parameters were set to the same values as described above in Example 1. A total of three dogs were studied. LV tissue from three normal (NL) dogs and three dogs untreated HF dogs was used for comparison. LV tissue obtained at sacrifice was used to extract total RNA. Using specific primers in reverse transcriptase polymerase chain reaction (RT-PCR) and restriction enzyme analysis of the RT-PCR product, aMHC was measured and bands were quantified in densitometric units. Results are shown in the table below:

Table 3

	NL	**HF-Untreated**	**HF + CCM**
aMHC (densitometric units)	3486 ± 351	978 ± 63*	3090 ± 142†
*=p<0.05 vs. NL; †=p<0.05 vs. HF-Untreated			

mRNA expression for aMHC was significantly reduced in untreated HF dogs compared to NL. CCM therapy was associated with restoration of mRNA expression of aMHC to near normal levels.

Conclusions: In dogs with HF, LV mRNA gene expression of aMHC is decreased compared to NL dogs. Continuous CCM therapy for four hours normalized mRNA gene expression for aMHC. Since aMHC is associated with faster velocity of shortening of cardiac muscle compared to the slow-contracting ßMHC, this normalization may be responsible, in part, for the observed improvement of LV EF after CCM therapy.

The results discussed above are set forth in Fig. 4, which shows the bands of different genes on agarose-ethidium gel. The gel shows the expression levels of GAPDH, a housekeeping gene used to test that the accuracy of the process, and the four different genes previously discussed (ANP, BNP, aMHC, and bFGF)

In each strip there are three groups of bands:

NL- representing the expression in a normal tissue.

HF – representing the expression in heart failure tissue

HF+CCM – representing the expression in HF tissue that was treated with CCM signal for four hours.

Each group contain three different bands coming from three different tissues.

Example 4

Studies were performed in six dogs with coronary microembolization-induced HF. CCM signals were delivered continuously for four hours from epicardial leads placed on the LV

anterior wall via a left throracotomy. CCM signal parameters were set to the same values as described above in Example 1. At the end of therapy, tissue samples from the anterior wall were used to extract RNA. Similar tissue samples were taken from 6 normal (NL) and 6 untreated HF dogs. Gene expression for connexin 43 was measured using reverse trascriptase polymerase chain reaction (RT-PCR). The RT-PCR product was confirmed as a connexin 43 by gene sequencing. Bands were quantified in densitometric units and normalized to the housekeeping gene GAPDH.

Results: mRNA expression for GAPDH was similar in all 3 study groups. Connexin 43 mRNA expression decreased markedly in untreated HF dogs compared to NL (0.05 ± 0.002 vs. $\pm$ 0.62 ± 0.03, $P<0.001$). CCM therapy partially restored connexin 43 mRNA expression ($0.13 \pm$ 0.01, $P<0.001$).

Conclusions: CCM therapy in dogs with HF increased connexin 43 mRNA expression. These observations may explain, in part, the improvement of LV function and stabilization of electromechanical dysfunction seem following chronic CCM therapy in HF.

While the above described apparatus has focused on hardware, it should be understood that the present invention includes programmable hardware, software for programmable devices, software for programming such hardware and computers including software for programming devices. For example, an external programming station may be provided, which optionally communicates with an implantable device using telemetry. Data collection using telemetry may also be practiced. In addition, computer readable media including such programs are also included. Also included are micro-code and other types of programming, as well as hardwired circuitry and ASICs, This is a list of examples and should not be considered as limiting. An exemplary device software includes a decision making module, a timing module, a power module and/or a signal analysis modules.

The description above should not be construed as limiting the scope of the invention to the specific embodiments described, which are provided merely as examples or illustrations. The scope of the invention encompasses interchangeable substitutions that are known to or would be appreciated by those skilled in the art. Many other variations are possible. Thus, the scope of the invention should be determined by the appended claims and their legal equivalents, rather than by only the examples given above.

CLAIMS

1. A device capable of delivering non-excitatory or non-excitatory and excitatory signals to heart tissue that will modify gene expression of cells in the heart tissue in a way to improve the cardiac function.

2. A device capable of delivering non-excitatory cardiac contractility or non-excitatory and excitatory modulation signals to heart tissue that will modify the expression of BNP and ANP in the heart tissue for treatment of heart failure.

3. A device capable of delivering non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals to heart tissue that will normalize the expression of alfa myosin heavy chain aMHC in the heart tissue for treatment of heart failure.

4. A device capable of delivering non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals that will modify the expression of basic fibroblast growth factor (bFGF) in the heart tissue for treatment of heart failure.

5. A method for improving heart function by modifying the expression in heart tissue of genes that effect cardiovascular system function.

6. A method for treating heart failure by modifying the expression in heart tissue of genes that effect cardiovascular system function.

7. The method of Claim 6, wherein the heart failure is congestive heart failure.

8. The method of Claim 5 or 6, wherein the non-excitatory or non-excitatory and excitatory cardiac contractility modulation signals are delivered to heart tissue to modify gene expression in the heart tissue.

9. The method of Claim 8, wherein the signal or signals reduce mRNA gene expression of BNP, ANP, or both BNP and ANP.

10. The method of Claim 8, wherein the signal or signals restore mRNA gene expression for bFGF to above normal level.

11. The method of Claim 8, wherein the signal or signals normalize nRNA gene expression for aMHC.

12. A method of treating a patient with a cardiac related disease, comprising:

determining a desired gene expression profile in cardiac tissue; and

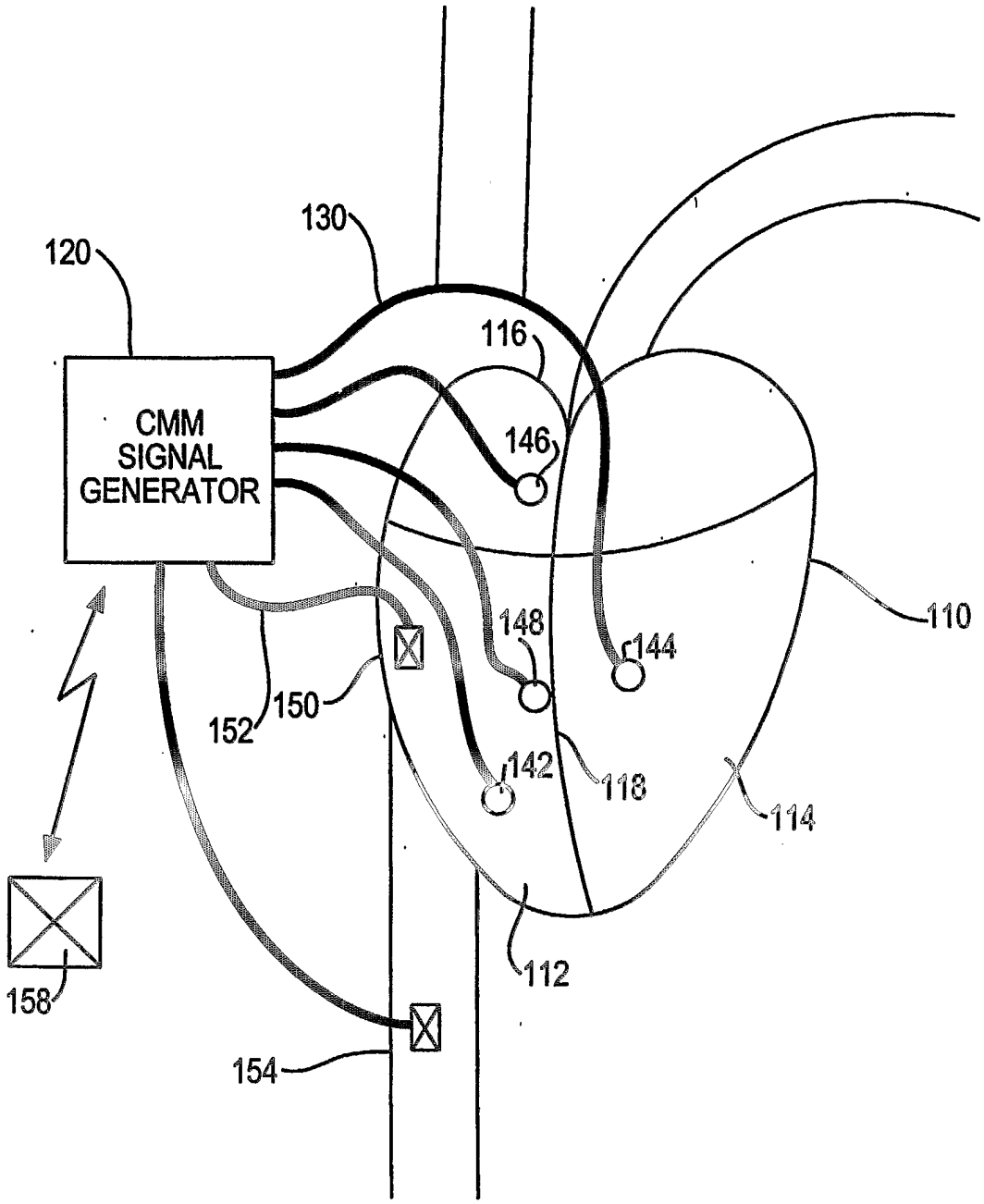
applying a non-excitatory signal to the cardiac tissue to achieve the desired gene expression profile.

13. A device adapted to apply a non-excitatory field to a heart, characterized in that the device is adapted to take an effect on gene expression into account in its functioning.

14. A device according to Claim 13, wherein said device is implantable.

15. A device according to Claim 13, wherein said device includes a feedback control loop which modifies an application of non-excitatory field is response to an indication of a gene expression effect of a previous application of a non-excitatory field.

16. A device according to Claim 15, including a watchdog which stops or modifies application of an electrical signal to a heart responsive to an effect of such application on gene expression in the heart.


120
130
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GENERATOR
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144
150
152
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118
114
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154

FIG. 1

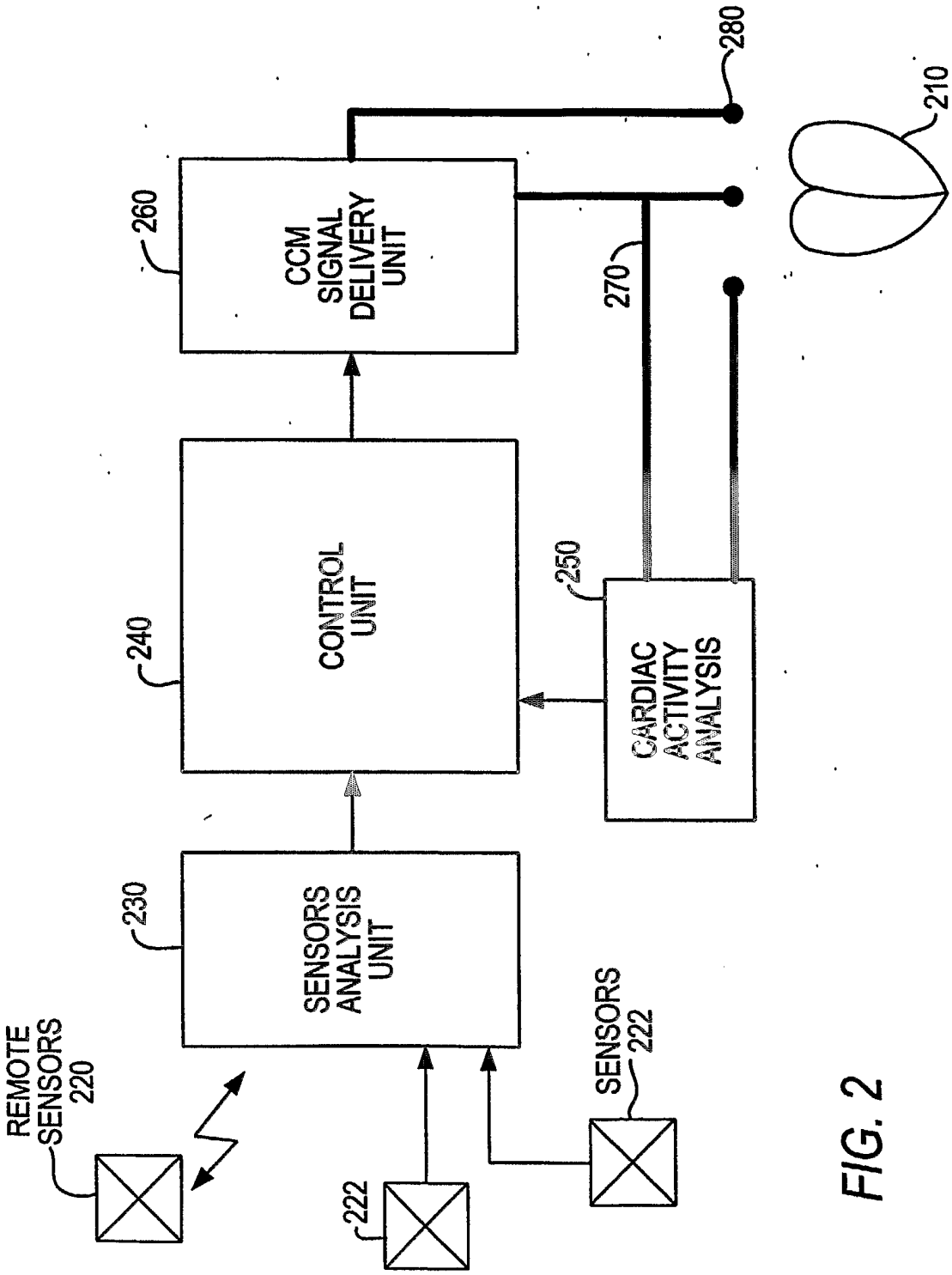
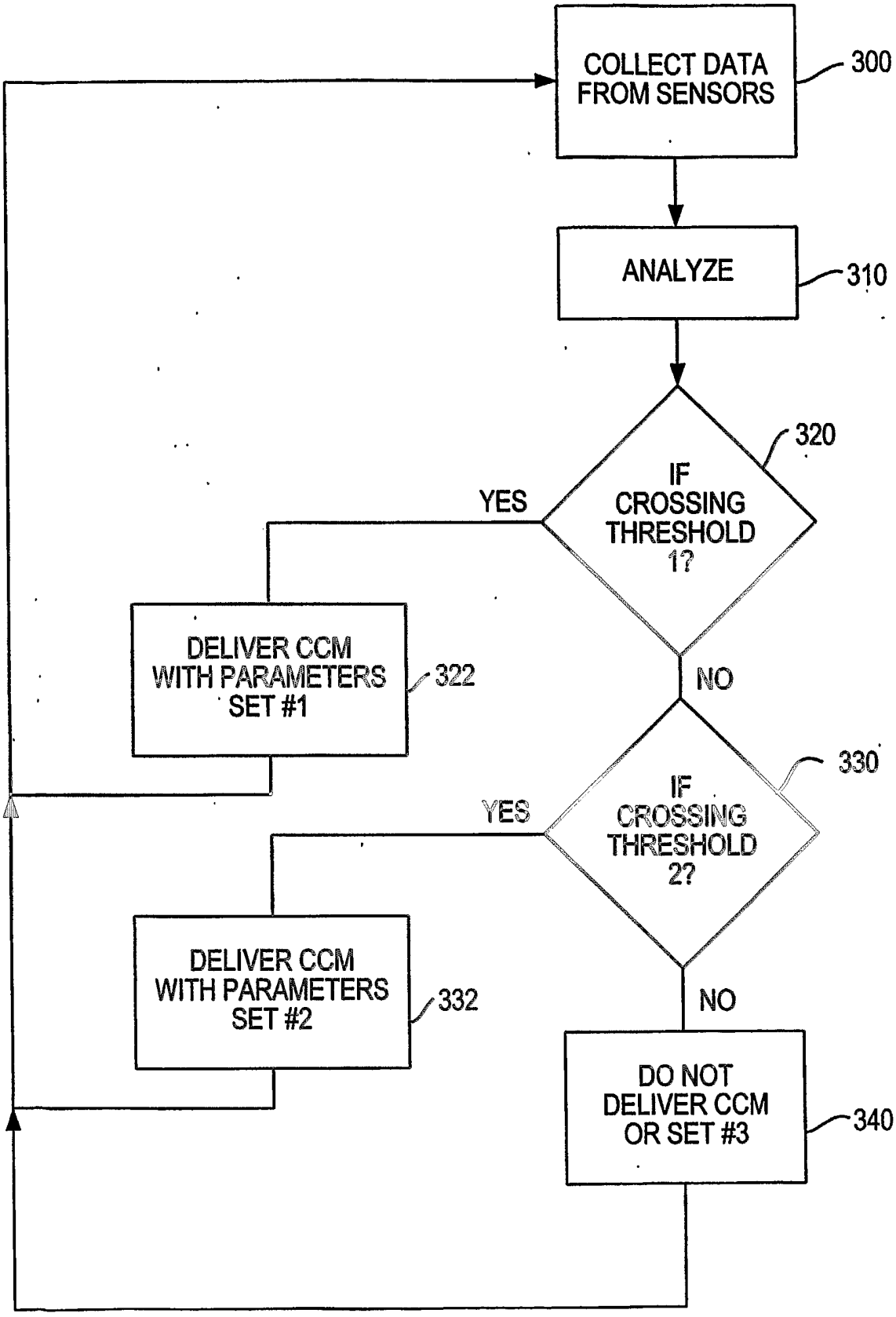

280
210
260
CCM SIGNAL DELIVERY UNIT
270
240
CONTROL UNIT
250
CARDIAC ACTIVITY ANALYSIS
230
SENSORS ANALYSIS UNIT
REMOTE SENSORS 220
SENSORS 222
222

FIG. 2


COLLECT DATA FROM SENSORS
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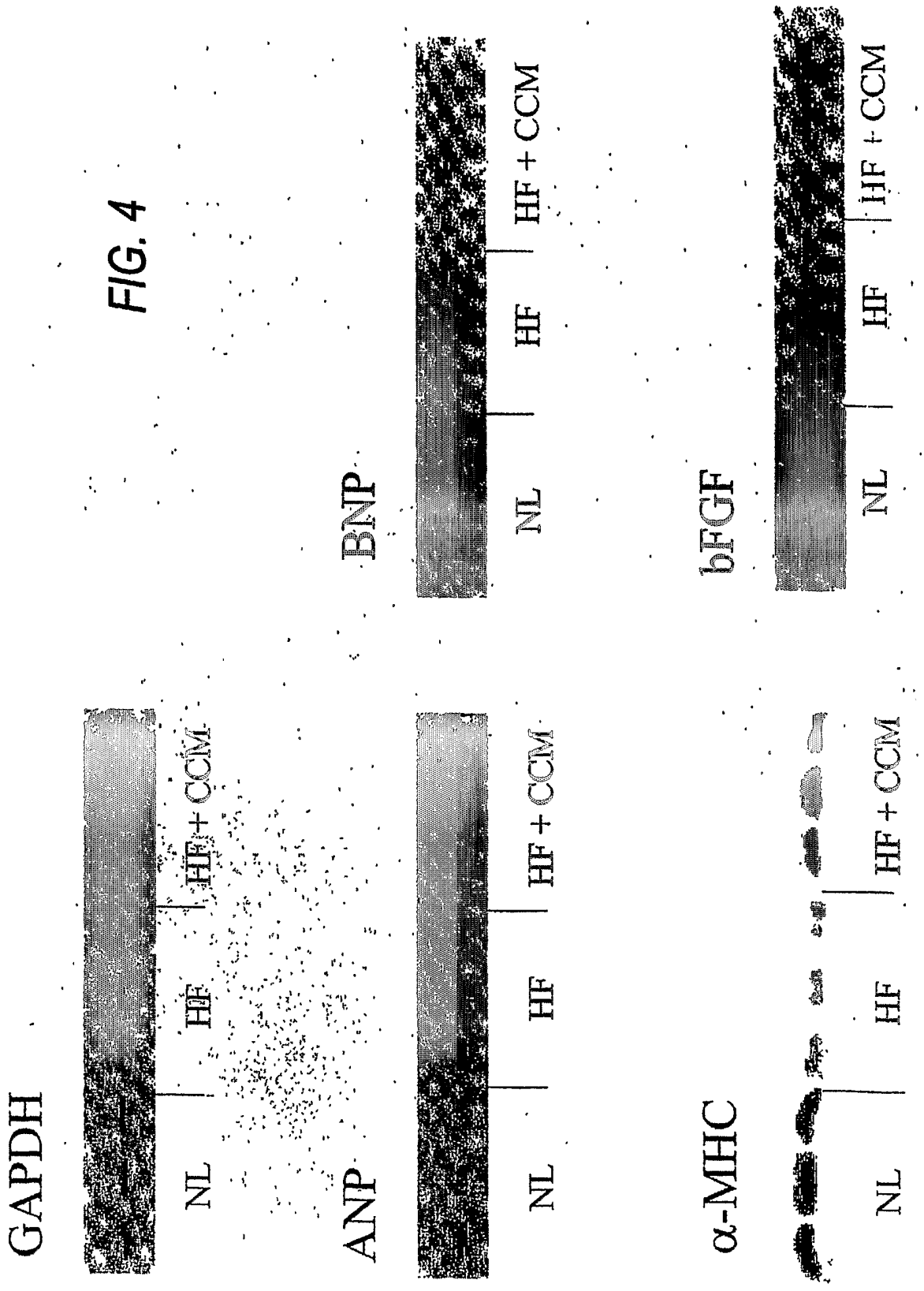
ANALYZE
310
IF CROSSING THRESHOLD 1?
320
YES
NO
DELIVER CCM WITH PARAMETERS SET #1
322
IF CROSSING THRESHOLD 2?
330
YES
NO
DELIVER CCM WITH PARAMETERS SET #2
332
DO NOT DELIVER CCM OR SET #3
340

FIG. 3

FIG. 4


GAPDH
NL
HF
HF + CCM
ANP
NL
HF
HF + CCM
BNP
NL
HF
HF + CCM
bFGF
NL
HF
HF + CCM
α-MHC
NL
HF
HF + CCM

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US04/07589

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : A61N 1/100

US CL : 607/2

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)

U.S. : 607/2, 4, 5, 9, 74

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

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

East: 607/1-75.ccls. and gene

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,463,323 B1 (CONRAD-VLASAK et al.) 08 October 2003 (08.10.2003), See entire document.	1-14

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

* Special categories of cited documents:

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 August 2004 (02.08.2004)	10 AUG 2004
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703) 305-3230	Authorized officer Jeffrey R. Jastrzab Telephone No. (703) 308-0858

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