ACCELEROMETER-BASED METHOD FOR CARDIAC FUNCTION AND THERAPY ASSESSMENT

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ABSTRACT
A method for determining a change in function of a patient's heart that includes the steps of collecting seismocardiographic (SCG) data corresponding to a heart motion of the patient's heart; determining a hemodynamic parameter based on the SCG data; and comparing the parameter with a predetermined measure of cardiac performance. The system used with the method includes one or more accelerometer sensors, a computer data analysis module, and may also include a 2D and 3D visual graphic display of analytic results, i.e. a Ventricular Contraction Map.

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INITIALIZE PACEMAKER AND SELECT APPROPRIATE SETTINGS
COLLECT ECG AND SCG DATA FROM THE PATIENT
FILTER AND SCALE ECG AND SCG SIGNALS
DIGITIZE ECG AND SCG DATA TO FORM COMPANION ECG AND SCG DATA SETS
LOCATE QRS COMPLEX IN THE ECG DATA SET
PERFORM RHYTHM ANALYSIS OF ECG DATA SET TO EXCLUDE NON-PACED BEATS
SET POINTERS INTO SCG DATA SET TO SELECT AND FORM REDUCED SCG DATA SET
USE QRS LOCATIONS IN ECG DATA TO SET FIDUCIAL MARK IN SCG DATA SET TO DEFINE SCG WAVELETS
ESTABLISH COMPARISON POINTS FOR SCG DATA SET BASED UPON QRS-QRS INTERVALS MEASURED IN COMPANION ECG DATA SET
PARTITION SCG WAVEFORM INTO COMPAREABLE SCG WAVELETS BASED UPON COMPARISON POINTS APPLIED BY PROCESS 57 AND 58
CROSS CORRELATE COMPAREABLE SCG WAVELETS TO DETERMINE SELF SIMILARITY AND TO CHECK FOR DOMINANT FAMILY
ADD SCG WAVELETS TOGETHER TO FORM CANONICAL SCG IF THERE IS A DOMINANT FAMILY
ADD CORRESPONDING COMPANION ECG WAVE SEGMENTS TOGETHER TO FORM CANONICAL ECG
EXTRACT Q-WAVE LOCATION AND V PACING EVENT FROM CANONICAL ECG
EXTRACT AS, MC, IM, AO, RE, AC, MO, AND RF FROM CANONICAL SCG
COMPUTE TIME INTERVALS SUCH AS (Q TO AD) AND (AD TO AC)
REPEAT AND LOOK FOR BEST SETTINGS UNTIL OPTIMAL CARDIAC RESYNCHRONIZATION IS ACHIEVED
FIG. 1
FIG. 2

FIG. 5

OPTIMAL LEAD PLACEMENT

PATIENT'S HEART

ACCELEROMETER SENSOR

PACING AT DIFFERENT PACING SITES

DATA PROCESSING (COMPUTER ALGORITHM)

PACING LEADS AND PACEMAKER

ANALYTIC RESULTS DISPLAY (VENTRICULAR CONTRACTION MAP, etc...)
FIG. 3

50 INITIALIZE PACEMAKER AND SELECT APPROPRIATE SETTINGS

51 COLLECT ECG AND SCG DATA FROM THE PATIENT

52 FILTER AND SCALE ECG AND SCG SIGNALS

53 DIGITIZE ECG AND SCG DATA TO FORM COMPANION ECG AND SCG DATA SETS

54 LOCATE QRS COMPLEX IN THE ECG DATA SET

55 PERFORM RHYTHM ANALYSIS OF ECG DATA SET TO EXCLUDE NON-PACED BEATS

56 SET POINTERS INTO SCG DATA SET TO SELECT AND FORM REDUCED SCG DATA SET

57 USE QRS LOCATIONS IN ECG DATA TO SET FIDUCIAL MARK IN SCG DATA SET TO DEFINE SCG WAVELETS

58 ESTABLISH COMPARISON POINTS FOR SCG DATA SET BASED UPON QRS-QRS INTERVALS MEASURED IN COMPANION ECG DATA SET

59 PARTITION SCG WAVEFORM INTO COMPARABLE SCG WAVELETS BASED UPON COMPARISON POINTS APPLIED BY PROCESS 57 AND 58

60 CROSS CORRELATE COMPARABLE SCG WAVELETS TO DETERMINE SELF SIMILARITY AND TO CHECK FOR DOMINANT FAMILY

61 ADD SCG WAVELETS TOGETHER TO FORM CANONICAL SCG IF THERE IS A DOMINANT FAMILY

62 ADD CORRESPONDING COMPANION ECG WAVE SEGMENTS TOGETHER TO FORM CANONICAL ECG

63 EXTRACT Q-WAVE LOCATION AND VPACE EVENT FROM CANONICAL ECG

64 EXTRACT AS, MC, IM, AO, RE, AC, MO, AND RF FROM CANONICAL SCG

65 COMPUTE TIME INTERVALS SUCH AS (Q TO AO) AND (AO TO AC)

66 COMPUTE INDEX OF CARDIAC PERFORMANCE FOR THE SELECTED A-V DELAY INTERVAL, THE SELECTED PACING RATE, AND THE SELECTED MODE (e.g., COMPUTING (Q/MC)/LVET,(VP/MC)/LVET,MC/AO/LVET)

67 REPEAT AND LOOK FOR BEST SETTINGS UNTIL OPTIMAL CARDIAC RESYNCHRONIZATION IS ACHIEVED
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**FIG. 4**
ACCELEROMETER-BASED METHOD FOR CARDIAC FUNCTION AND THERAPY ASSESSMENT

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of, and claims priority to, U.S. patent application Ser. No. 10/629, 881, filed on Jul. 29, 2003, which claims priority to U.S. Provisional Patent Application Ser. No. 60/399,028, which was filed on Jul. 29, 2002 by the same inventors.

BACKGROUND OF INVENTION

[0002] 1. Field of Invention

[0003] The present invention relates generally to accelerometer use and to methods for determining a change in function of a patient's heart.

[0004] 2. Description of Related Art

[0005] Heart failure afflicts about twenty-five million people worldwide, with about two million new cases diagnosed each year. In the United States, hospitalization for heart failure amounts to more than 6.8 million days a year, and the total cost of treatment is more than $38 billion annually, which is increasing as the population ages. The prevalence of congestive cardiac failure is also increasing due to improved survival from both myocardial infarction and hypertension that has resulted from the use of drug therapies, such as angiotension-converting enzyme inhibitors, beta-blockers, and digoxin. Nevertheless, many patients remain markedly symptomatic despite maximal medical therapy. Furthermore, patients with left ventricular failure are at an increased risk of progressive heart failure or sudden death.

[0006] In some heart patients, congestive cardiac failure affects the synchronous beating of the ventricles. Accordingly, the left ventricle is not able to pump blood efficiently to supply the body with needed oxygen and nutrients. In approximately 30% of patients with heart failure, an abnormality in the heart’s electrical conduction system, called an intraventricular conduction delay or bundle branch block, causes the left ventricle to beat in an asynchronous fashion. This greatly reduces the efficiency of the left ventricle in patients whose hearts are already damaged. In addition, the right and left ventricles begin to beat slightly out of phase instead of beating simultaneously.

[0007] A significant minority of patients with congestive heart failure have marked prolongation of the QRS complex of their electrocardiographic (ECG) profile, which represents the time it takes for the depolarization of the ventricles. The prolongation is an indicator of intraventricular conduction abnormality and is associated with decreased left ventricular systolic function. The development of new QRS prolongation is associated with reduced left ventricular function.

[0008] Normally, electrical activation is conducted by the His bundle and Purkinje system, and an impulse spreads transmurally from the septum to multiple paraseptal regions resulting in synchronous contraction of the ventricles. Many patients with heart failure have poor electrical conduction in the heart that results in a pattern called left bundle branch block (LBBB) or intraventricular conduction delay. In these patients, the duration of the QRS complex may exceed 130 milliseconds (ms) compared with a normal duration of less than 100 ms. In LBBB, the left ventricle is activated belatedly throughout the septum from the right ventricle, with antero-septal crossing preceding infero-septal crossing. The latest activation is in the posterior inferior aspect of the left ventricle, often remote from the base.

[0009] Additionally in patients with LBBB, the delay between the onset of left and right ventricle systole may be prolonged to 85 ms, resulting in significantly later aortic opening, aortic valve closure, and mitral valve opening. LBBB does not affect the timing of right ventricle events, and the delay in the left ventricle events leads to a reversal of the usual sequence of right and left ventricle systole. In addition, the range for isovolumic contraction times in patients with LBBB is wide (20-100 ms), suggesting heterogeneity of left ventricle activation. The delay in aortic valve closure leads to a relative decrease in the duration of left ventricle diastole. In patients with LBBB, prolonged depolarization or abnormal depolarization may result in regional myocardial contraction into early diastole, causing a delay of mitral valve opening with prolongation of left ventricle isovolumic relaxation time of up to 300% and shortened left ventricle filling time. LBBB is also associated with abnormal diastolic function on Doppler echocardiography examination. Further, left ventricle intraventricular conduction delay may add significantly to dyssynchrony, particularly in ischemic heart disease.

[0010] In patients with an intraventricular conduction defect or with LBBB, cardiac resynchronization therapy (CRT) shortens the duration of the QRS complex and has been shown to improve the patient’s symptoms markedly. CRT is the use of a specialized pacemaker to improve contraction coordination of the left ventricle. The specialized pacemaker may also be programmed to coordinate the beating of the two ventricles by pacing the left ventricle individually to match the beating of the right ventricle or both ventricles simultaneously. It has been shown that resynchronization of abnormal intraventricular and interventricular asynchrony with left ventricular or biventricular pacing may symptomatically improve patients with severe ventricular failure. While the results have been positive, most studies have shown that approximately 30% of patients do not obtain any measurable benefit from the therapy. It is now being tested to see if this therapy will increase the duration of life.

[0011] In biventricular pacing, one wire or catheter is implanted in the right ventricle and another is threaded into a vein, the coronary sinus, which drains into the right atrium to pace the left ventricle. The coronary sinus catheter is then guided to the lateral or posterior part of the left ventricle. Alternatively, a left ventricular lead can be implanted by thoracotomy (i.e., through a small incision between the ribs, the lead is implanted on the surface of the left ventricle) or even by crossing the atrial septum and inserting the lead inside the left ventricle. Yet, the exact and best position for each catheter position is difficult to determine at the time of insertion. In fact, there are no physiological means to determine the best site at the time of lead placement except possibly the use of echocardiography, which is time consuming and poses a problem in keeping the operative field sterile.
[0012] In addition, it is difficult to predict the effectiveness of CRT before the insertion of the cardiac pacing device. Currently, physicians often measure a decrease in QRS duration after biventricular pacing to evaluate CRT. However, the decrease in the QRS duration does not correlate well with the improvement of cardiac function in some patients. Other parameters have been used to determine the effectiveness of CRT, such as improvement of New York Heart Association (NYHA) classification score, six-minute hall walk results, etc. However, these parameters cannot be evaluated in real time and do not provide information that physicians need to know at the time of lead and device implantation to determine if the patient will benefit from CRT. Finally, it is not clear if one lead implanted into the coronary sinus is as good as two leads implanted into the right and left ventricles.

[0013] Another problem encountered, particularly with the use of dual-chamber pacemakers, is the proper setting of the so-called “A-V delay interval.” Basically, the A-V delay interval refers to the time interval between a ventricular stimulation pulse and a preceding atrial depolarization. Because the sequence of atrial and ventricular pacing is vital to the efficiency of the heart as a pump, a non-optimal A-V delay interval can seriously impact heart performance. Indeed, relatively small departures from the optimal A-V delay interval value can greatly reduce the hemodynamic contribution of the atria in patients with congestive heart failure.

[0014] At present, physicians select and program the A-V delay interval empirically. Since the hemodynamic contribution of the atrial depolarization to cardiac output is well known, every effort is made to select the optimal A-V delay interval for a given patient. However, the optimal A-V delay value can vary over time as the patient ages or the disease state changes.

[0015] More generally, the acquisition and comparative analysis of seismocardiographic data (either alone or combined with other parameters) has heretofore found limited use as an adjunct to diagnosis, as a means for deriving useful cardiac performance indices, and as a means to better characterize cardiac valvular opening and closure and the state of cardiac interval.

[0016] Therefore, there is a need for a way to provide a reliable prediction for whether a patient would be a good candidate for cardiac resynchronization therapy, for a way to determine the optimal placement of leads of a cardiac pacing device in real time while the pacing device is implanted into the patient, and for a way to optimize the selection of the A-V delay interval, both during the initial placement of a dual-chamber pacemaker and during follow-up evaluations. Moreover, the assessment of cardiac function and the testing of potential cardiac therapies through seismocardiographic measurements taken through an accelerometer would provide a non-invasive means for further improving cardiac care.

SUMMARY OF INVENTION

[0017] The invention generally relates to a real time method for the acquisition and comparative analysis of seismocardiographic data (either alone or combined with other data) as an adjunct to diagnosis, for deriving useful cardiac performance indices, and as a means to better characterize cardiac valvular opening and closure, as well as the state of cardiac interval. Advantageously, and in contrast to methods requiring sensor placement inside the body, the acquisition of SCG data is not invasive; i.e., it may be acquired from sensors applied to an exterior surface (e.g., chest and/or neck) of a patient. The system of the invention includes an accelerometer sensor, a computer data analysis module, and may include a 2D and 3D visual graphic display of analytic results, i.e., a ventricular contraction map.

[0018] In one aspect of the invention, the method includes placing the leads of a cardiac pacing device, collecting seismocardiographic (SCG) data corresponding to heart motion during both paced and unpaced beats of a patient’s heart, determining hemodynamic parameters based on the SCG data, and using this data to screen patients for CRT and to determine optimal lead placement.

[0019] In another aspect of the invention, the method includes collecting SCG data via an accelerometer during an imposed condition, collecting SCG data via an accelerometer without an imposed condition, and comparing both sets of data to determine a difference indicative of a cardiac function, diagnosis, or performance index.

[0020] Accordingly, a main objective of the present invention is to determine if a patient is experience a narrowing or blockage of one or more coronary arteries.

[0021] An additional objective of the present invention is to determine the optimal site(s) of implantation for cardiac resynchronization therapy, and, therefore, enhance the effectiveness of the therapy.

[0022] Another objective of the present invention is to determine if the patient needs only the left ventricular pacing instead of biventricular pacing in real time during an electrophysiology study.

[0023] According to a preferred embodiment, an accelerometer placed over a patient’s chest at the time of a imposed condition, such as a stress test. Preferably, three accelerometers are located (one each) at the chest apex and lower sternum and over the carotid artery on the neck. A computer algorithm processes complementary seismocardiographic measurements taken from all three accelerometers and generates SCG data, such as that illustrated in FIG. 1. A computer algorithm processes the seismocardiographic measurements and generates a ventricular contraction mapping, which displays the rate (acceleration and velocity) of pre-ejection and ejection, the duration of the pre-ejection period, duration of systole, and duration of isovolumic relaxation period. Examining changes in the relevant data at different times before, during, and/or after the test results in the determination of changes in SCG that correlate with a particular cardiac function, diagnosis, or performance index. For example, an increase in contractility during head-up tilt testing may indicate that blood is pooling in the venous system, resulting in reflex sympathetic stimulation.

[0024] Comparison of accelerometer signals (SCG data) before and during stress testing can indicative increased contractility. The changes that are expected in a patient with coronary disease are as follows. First, the normal response with exercise is that the rate of contraction is faster; therefore the time from the onset of the electrical activity (onset of the Q wave of the ECG) to aortic valve opening should shorten. In a patient with coronary obstruction, the heart cannot increase its contractility; therefore it does not shorten or the time lengthens.
The second expected change is in the wave that represents early filling of the ventricle. Normally the amplitude of this wave does not change because the heart muscle adapts and can accept the increase in blood with exercise readily. With marked narrowing or blockage of one or more coronary artery, the amplitude of this wave, called the rapid filling wave, becomes larger.

Moreover, continuous monitoring with an accelerometer can be used to assess a change in cardiac contractility as an indication of decreased cardiac function, cardiac instability or infarction during anesthesia or other surgical events. Continuous monitoring with an accelerometer could also be used in patients with suspected or acute myocardial infarction for detection of decrease in heart function so that pharmacological or other measures can be promptly instituted to prevent further deterioration in cardiac function that could result in an extension of the area of heart muscle damage or even prevent cardiac arrest.

It also is possible that accelerometer patterns will help identify patients who would be likely to benefit from CRT by showing a recognizable pattern of no or minimal desynchronization (in which case CRT would not be beneficial) or marked desynchronization (in which case CRT would be most helpful).

The invention also may be used during an electrophysiology study (EPS) to help determine if CRT is an effective treatment for a particular patient. During an EPS, catheters are placed in the heart and electrically stimulate different areas to identify abnormalities in the heart's conductive system. According to the present invention, an accelerometer measures the seismocardiographic behavior at different stimulation locations. The resulting data is analyzed to determine whether the patient only needs left ventricular or biventricular pacing or if CRT would be beneficial at all. If CRT is found to be an effective treatment, the cardiac pacing device could be implanted during the same procedure with the leads placed at an optimal location. Since one third of patients who have left ventricular or biventricular pacing do not improve with this procedure, the accelerometer-guided ventricular pacing could diminish this high incidence of ineffectiveness. Thus, the method and system of the invention can provide reliable prediction whether the patients would be candidates for CRT as well as provide optimal location for pacing lead placement during the implantation. Also, optimal settings for delay between onset of right and left ventricular contraction could be determined.

Furthermore, the method of the invention may be used to select an optimal A-V delay interval for a patient based on comparing an index of cardiac performance for several delay intervals. In a preferred embodiment, various candidate A-V delay intervals and pacing rates are programmed into the pacemaker and real-time seismocardiographic (SCG) and electrocardiographic (EGC) data are collected. The collected data is processed to develop a canonical SCG waveform. Next, certain features in the SCG waveform are identified and used to determine time intervals between the atrial depolarization and ventricular stimulation pulse events. This time interval information is used to define an index of cardiac performance that can be compared with other indices representing several different pacemaker A-V delay intervals.

Various other purposes and advantages of the invention will become clear from its description in the specification that follows. Therefore, to the accomplishment of the objectives described above, this invention includes the features hereinafter fully described in the detailed description of the preferred embodiments, and particularly pointed out in the claims. However, such description discloses only some of the various ways in which the invention may be practiced.

**BRIEF DESCRIPTION OF DRAWINGS**

**FIG. 1** is a schematic diagram depicting the relationship between pacemaker events, electrocardiogram (ECG) events, seismocardiographic (SCG) events, and the physical motion of the heart.

**FIG. 2** is a schematic depiction of an SCG/ECG analysis system and pacemaker lead placement test system connected to wires or catheters inside a patient.

**FIG. 3** is a flowchart illustrating the method used to collect and analyze the ECG and SCG waveforms in FIG. 1. Abbreviations are defined in the Detailed Description.

**FIG. 4** is a partial screen display generated by the SCG/ECG analysis system.

**FIG. 5** is a block diagram showing in outline the optimal lead placement method for cardiac resynchronization therapy.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

The invention relates in general to a method for determining a change in function of a patient's heart that includes the steps of collecting seismocardiographic (SCG) data from an external surface of a patient corresponding to a heart motion of the patient's heart; determining a hemodynamic parameter based on the SCG data; and comparing the parameter with a predetermined measure of cardiac performance.

Seismocardiography (SCG) is a method derived from the field of seismology to non-invasively measure compression waves generated by myocardial motion. These compression waves are measured by a low frequency accelerometer placed on the sternum, and recorded chest movement induced by ventricular motion is analyzed by software in a computer. The seismograph tracings identify cardiac time intervals that correlate with the opening and closing of cardiac valves, left ventricular (LV) systolic and diastolic time intervals, isovolumetric contraction and relaxation intervals, LV filling interval and pre-ejection periods.

Using a unique algorithm, the data collected from accelerometer could be used to generate other cardiac performance index i.e. dp/dt of the rate of LV pressure change, Ejection fraction of LV (EF) and Myocardial performance index (MPI), etc. Thus, the invention has application outside of the context of CRT in that SCG data may be collected only during cardiac motion corresponding only to natural (i.e., unpaced) beats rather than those resulting from a pacemaker.

The invention also relates to a method for testing or evaluation of a cardiac function. Preferably, this method includes the steps of: (a) collecting seismocardiographic
(SCG) data corresponding to heart motion of a patient’s heart during a non-testing condition; (b) determining a hemodynamic parameter based on the SCG data of step (a); (c) imposing a test condition upon the patient; (d) collecting seismocardiographic (SCG) data corresponding to heart motion of the patient’s heart during the test condition; (e) determining the hemodynamic parameter based on the SCG data of step (d); and (f) comparing information from steps (b) and (e) to determine the cardiac function. The testing condition may, for example, include stress or tilt testing.

In one embodiment, the method of the invention also relates to detecting hemodynamic parameters corresponding to the motion of a patient’s heart with an accelerometer, converting the detected parameters into digital data that is fed into an analysis module for calculation and display of ventricular contraction mapping, and comparing the results generated by different pacemaker lead placement to provide an optimal lead location. In another embodiment, hemodynamic parameters are detected and compared to those generated by an unpaced heart, thereby predicting whether CRT is an appropriate option for a given patient.

The invention further relates to a method for selecting an A-V delay interval for a pacemaker patient that includes the steps of selecting and setting an initial A-V delay value, collecting SCG data corresponding to heart motion during paced beats of the patient’s heart, locating the mitral valve closure point, the atrial valve opening point, and the atrial valve closing point in the SCG data, calculating the time interval between the aforementioned points, computing an index of cardiac performance based on the aforementioned points, and selecting the A-V delay value that optimizes the index of cardiac performance.

FIG. 2 is a schematic diagram representing the various connections between the pacemaker patient 31, the pacemaker programmer 41, and the SCG/ECG analysis system 32. The drawing shows a dual chamber pacemaker 35 implanted in the pacemaker patient 31 and coupled to the patient’s heart 33 through a suitable lead 36. Although one lead is shown, it should be recognized that pacemakers having more than one lead may be used with the invention (for example, a pacemaker with an atrial lead and one or more a ventricle leads). The pacemaker programmer 41 communicates with the implanted pacemaker 35 through a programming head 42 shown in position over the pacemaker 35 implant site. The pacemaker programmer 41 can be used to alter the A-V delay interval, the right ventricle to left ventricle delay, pacing rate, and pacing mode of the implanted pacemaker 35 via telemetry.

The SCG/ECG system 32 is coupled to the pacemaker patient 31 and used to collect real time ECG data from an array of surface electrodes 37, 38, and 39 which are placed upon the patient’s chest 34. The surface ECG reflects both the electrical activity arising from the patient’s heart 33 and the pacing artifacts arising from the pacemaker 35. The SCG/ECG system 32 can detect and distinguish both sensed and paced cardiac events. Paced cardiac events typically generate a narrow pulse artifact on the surface ECG of the patient. PACING may also cause inversion of the associated physiologic waveform. Therefore, it is preferred to use ECG “QRS” detection algorithms that recognize narrow pacing artifacts and that recognize negative going and positive going physiologic waveform forms. While any of a variety of well known techniques can be used to achieve this result, it is preferred to discriminate the atrial and ventricular pacing artifacts based upon their high slew rate and to recognize physiologic wave forms based upon the absolute value of their amplitudes rather than the sign of their amplitudes.

The SCG/ECG system 32 may be coupled to the pacemaker programmer 41 through a data link 30, which permits the system 32 to receive marker channel diagnostic telemetry from the implanted pacemaker 35. Diagnostic telemetry permits the pacemaker programmer 41 to access near real time sensing and pacing information from the implanted pacemaker 35. Examples of such cardiac events include the occurrence of atrial events, both sense (AS) and pace (AP), and ventricular events, both sense (VS) and pace (VP).

Suitable SCG/ECG systems 32 for carrying out the invention are manufactured by Bard Electrophysiology of Lowell, Mass., GE Medical Systems, or EPMD. The preferred instrument is a multiple-channel electrophysiologic recording and analysis system that can acquire physiological signals, i.e., surface and intracardiac electrograms, hemodynamic data (e.g., arterial blood pressure), as well as fluoroscopic, ultrasound, MRI and/or CT images. These signals could be acquired in both analog and digital format. The SCG signal would be acquired by the accelerometer 40 and fed into the physiological system. The SCG signal would then be processed by special computer algorithm and a series of hemodynamic parameters would be generated or interpolated. For example, the patient’s $dp/dt$ (the rate of change of the ventricular pressure) and ejection fraction (EF, an indication of the ventricular function), etc. can be determined directly or indirectly. For example, one can calculate the $dp/dt$ from a SCG signal of the left ventricular pressure curve during the contraction using previously developed algorithms. For the EF, a value could be interpolated.

Thus, to evaluate the effectiveness of pacing and assess the optimal leads placement, baseline SCG parameters would be collected and analyzed. Then the SCG parameters collected during pacing at the testing sites would be collected and analyzed. The change of those key parameters will be served as a Stoke Index to determine the optimal pacing site and/or settings (e.g., A-V or right ventricle to left ventricle interval delay).

In addition, real time baseline SCG parameters, i.e., PEP, LVET, PEP/LVET, also could be displayed and analyzed. The real time data could be stored as a template for comparisons later. Then the set of real time-time SCG parameters could be collected and compared with the template and the changes of those parameters and the correlation coefficient, $r$, could be generated. Based on the magnitude of the changes of the SCG parameters and the correlation coefficient, the optimal site of the leads placement could be determined.

Any apparatus capable of carrying out the process of the invention may be used. Moreover, the invention may
be used with wireless data transmission technology to remotely access and analyze the SCG data via the accelerometer to evaluate the patient’s cardiac function and/or assess therapeutic results. An accelerometer sensor could be non-invasively placed on a patient’s body and the SCG signal is acquired and digitalized, then the digitalized SCG data is sent to a receiver of remote sites, i.e., doctor’s office, laboratory, the hospital data center, etc. By using wireless transmission and reception technology (e.g., Bluetooth), the physician is able to evaluate the cardiac function of a patient in remote location and advise the patients with diagnosis and/or the treatment order according to SCG data. The physician is also able to use wireless technology to adjust the parameters of implanted cardiac device, if any, to optimize the outcomes of the implanted device remotely.

[0050] An example of how the method of the invention can be practiced is shown in FIG. 3. Process 50 involves initializing the pacemaker and requires selection of an initial candidate A-V delay interval. It is preferred to have this value and subsequent values set by a physician through the use of a pacemaker programmer 41. However, process 50 may be performed automatically by the pacemaker, or invoked by the SCG/ECG system through the data link 30.

[0051] The preferred method for carrying out process 50 is illustrated in the pacemaker marker channel telemetry wave form 10 (FIG. 1), which shows A-V sequential pacing (DVI) of the patient’s heart at a rate above the patient’s intrinsic rate. The V-V lower rate escape interval 19 selected for the patient and the A-V delay interval 18 are shown in the telemetry wave form 10. Consecutive lower rate escapes result in a sequence of paced beats depicted in the telemetry wave form 10, while the response of the heart 33 to this pacing regime is shown in the canonical ECG wave form 12. The corresponding motion of the heart is depicted in the canonical SCG wave form 14, while the corresponding state of the heart valves are set forth in the heart pictograph panel 16.

[0052] More specifically, an initial atrial paced (AP) event is shown as atrial paced event 13 in wave form 12 and as atrial paced event 11 in wave form 10. The atrial sequential pacing regime also gives rise to the ventricular paced event (VP) shown in wave form 12 as ventricular paced event 15 and shown in wave form 10 as ventricular paced event 17. This ventricular paced event occurs after the programmed A-V delay interval 18 shown in the telemetry wave form 10. A second set of atrial paced events 20 and 22 are shown with corresponding ventricular paced events 21 and 23 in FIG. 1.

[0053] Although the pacing modality and range of pacing rates may be varied, the purpose of this process 50 is to generate a sequence of ventricularly paced events. Preferred pacing rates range from about 60 bpm to about 115 bpm (that latter rate would be appropriate during exercise). For each given pacing rate, the A-V delay interval 18 may be varied from a nominal minimum value of less than about 100 ms to a nominal maximum value of approximately 250 ms. As would be recognized by one skilled in the art, the pacing rate must be faster than the intrinsic heart rate of the patient. Otherwise, one sees no paced beats if the pacemaker is set in inhibited mode or some beats if it is not. Also, the pacemaker may be set to pace the atrium, but with a shorter A-V delay than normal for the patient so that the ventricles are paced and captured.

[0054] Process 51 represents the collection of real time ECG data from the electrode array 37, 38, 39 and the collection of real time SCG data from the seismic sensor 40. After appropriate isolation, these real time signals are band-pass filtered in process 52 to eliminate noise. The filtering and scaling functions of process 52 may be carried out in analog hardware as taught by the incorporated references or in the digital domain by a dedicated processor or other software forming a part of the SCG/ECG instrument 32. It has been determined that the low frequency cutoff is the most important bandpass characteristic for the real time signals and the lowest possible low frequency corner is preferred for both ECG and SCG signals.

[0055] Process 53 completes digitization of the ECG and SCG real time signals and generates a pair of data sets, referred to as the SCG data set and the ECG data set. The temporal relationship between these two data sets is preserved during processing and the SCG data and ECG data sets may be considered “companions.” Typically, subsequent software processes will generate pointers from the ECG data set to point into the companion SCG data set to collect segments of the companion SCG data for further analysis.

[0056] In process 54, the ECG data set is analyzed to find the location of the QRS complexes. The algorithm must detect naturally occurring depolarization as well as paced complexes from unipolar and bipolar pacers. At present, the preferred detection rule looks for the high amplitude rapid rise pace maker artifact to identify ventricular and atrial paced events, although other detection techniques may be freely substituted without departing from the scope of the invention. The principle purpose of this process is to find the QRS reference point to facilitate further analysis of the SCG data.

[0057] In optional process 55, a rhythm analysis is performed on the ECG data set based upon the locations of the QRS complexes in the ECG data. The primary purpose of the rhythm analysis of the ECG data is to exclude those segments of the companion SCG data from further processing which arise from electrically abnormal heart beats. This process is skewed toward over exclusion of beats to prevent corruption of the canonical SCG wave form. Reference may be had to the incorporated references for details on a suitable exclusion rhythm analysis process. However, it should be understood that there is great flexibility in carrying out this process. Also, many patients do not exhibit premature ventricular beats (PVCs) when paced above their intrinsic rate. This step may be used optionally, and the exemplary data shown in FIG. 4 was not submitted to rhythm analysis.

[0058] In optional process 56, the rhythm analysis of process 55 is used to point into the companion SCG data set to select segments of the companion SCG data for further processing. The selected SCG data is referred to as the “reduced SCG data set.” The primary purpose of this optional process is to exclude non-sinus, non-paced beats from further analysis, because such data would otherwise frustrate the development of the canonical SCG.

[0059] In process 57, the location of the QRS complex is used to define a set of fiducial points which are transferred into the SCG data set. These fiducial points are used to break the SCG data into “wavelets.”

[0060] In process 58, the instantaneous heart rate is used to define a set number of comparison points and to define a
comparison window. It is preferred to set the comparison window to eighty percent of this measured heart rate interval, and to use approximately one hundred comparison points.

[0061] In process 59, the SCG data set is broken into comparable wavelets by applying the comparison points defined in process 58 about the fiducial points defined in process 57. In general, the fiducial point defines the origin for the distribution of the set of comparison points. It is preferred to distribute twenty percent of the comparison points to the SCG data collected prior to the QRS fiducial point and to apply eighty percent of the comparison points to the SCG data set collected after the QRS fiducial point. The application of comparison points in this process permits SCG wavelets recorded at different heart rates to be compared to each other without introducing rate induced distortions in the SCG morphology. The purpose of this process is to segment the SCG data set into comparable wavelets for subsequent cross-correlation.

[0062] In process 60, the individual wavelets are cross-correlated to ascertain the degree of similarity. Each wavelet is sequentially compared with all other wavelets. Those wavelets with a correlation coefficient of 0.9 or greater are grouped into one family. At the conclusion of the iterative cross-correlation, there is typically one dominant family with usually ninety percent or more of all the wavelets. If a dominant family of highly similar wavelets emerges, it is presumed that preceding processes have eliminated bad data from the analysis.

[0063] In process 62, the corresponding and complimentary or companion ECG data are also added or averaged together to form a canonical ECG wave form shown in FIG. 1 as wave form 12 and in FIG. 4 as wave form 77. Thus, FIG. 1 and FIG. 4 represent processed data and is not a representation of any particular real time wave forms.

[0064] In process 63, certain events are extracted from the canonical ECG data set. Referring back to FIG. 1, the underlying electrical events in the heart give rise to certain repetitive features which can be identified in the surface ECG shown as the canonical wave form 12. The atrial paced event 13 gives rise to the atrial depolarization of the heart shown as “P-wave” 80 in wave form 12. The subsequent ventricular paced event 15 generates the QRS complex, which includes the Q-wave 81, the R-wave 82, and the S-wave 83. The repolarization of the ventricular tissues give rise to the T-wave 79 feature in the wave form 12. A morphology detection algorithm is applied to the ECG data set to extract the R-wave 82 and the pacing spike associated with ventricular paced event 15. Peak/valley decision rules are applied to the digitized ECG data set. This “reduced data set” is evaluated for both the Q-wave and T-wave locations for individual heart beat cycles. The location of the Q-wave 81, and the (VP) ventricular paced event 15 are used in the subsequent resynchronization process, but additional events may be useful for further analysis of the canonical SCG waveform.

[0065] In process 64, certain repetitive features from the SCG recording are extracted. These events are identified on FIG. 1 by two-letter codes as follows: AS (atrial systole) event 91, MC (mitral closure) event 92, IM (isometric contraction) event 93, AO (aortic opening) event 94, RE (rapid emptying) event 96, AC (aortic closure) event 97, MO (mitral opening) event 98, and RF (rapid filling) event 99. These features of the canonical SCG wave form 14 have been related to underlying mechanical motions of the heart. The AS event corresponds to peak atrial systole as shown by heart pictograph 90. The AO event 94 corresponds to the opening of the aortic valve as seen in heart pictograph 87. The AC event 97 corresponds to the aortic valve closure as seen in heart pictograph 88. The MC event 92 correspond to the mitral valve closure as shown in heart pictograph 86.

[0066] Therefore, the ventricular heart beat cycle begins with the ventricular paced event 15, which causes a contraction of the ventricles as indicated by the Q-wave 81. After a brief electro-mechanical delay, 85, the SCG wave from 14 shows the MC event 92. The time interval from mitral valve closure as indicated by MC event 92 and the opening of the aortic valve as indicated by AO event 94 is an isometric contraction phase contained in the pre-ejection period shown as PEP 24 in FIG. 1. The systolic phase of the heart extends from the MC event 92 to the AC event, which indicates aortic valve closure.

[0067] The conclusion of the systole and the beginning of the diastole is reflected by the aortic valve closure point indicated by AC event 97, and this phase of the heart cycle extends to the next mitral valve closure point indicated as MC event 84.

[0068] Identification of these wave form features is done based upon slope and amplitude information. The preferred decision rules applied to the representative wave forms are set forth as follow:

[0069] The MC event is the first peak occurring in time after the peak of the ECG R-wave;

[0070] The AO event is the first valley after the MC;

[0071] The RE event is the next peak after the AO;

[0072] The AC event is the first peak after the end of the ECG T-wave;

[0073] The MO event point is taken as the second valley following the AC event;

[0074] The RF event is the next peak after the MO; and

[0075] The AS event is taken as the last peak before the onset of the Q-wave in the ECG.

[0076] It should be noted that T-waves are notoriously hard to locate due to the slow slope and low amplitude. In the absence of successful T-wave detection based upon slope information, the approximate T-wave position is defined based on measured QRS to QRS interval and the corresponding AC location is interpolated and defined as a result.

[0077] In process 65, time intervals are computed based upon the identified points. For example, the time interval 24 between the MC event 92 and the AO event 94 is measured and defined as the pre-ejection period. The time interval between the AO event 94 and the AC event 97 is measured and taken as the left ventricular ejection time. The specific interval measured relate to the specific index of cardiac performance that is selected for optimization.

[0078] In process 66, the preferred index of cardiac performance is the ratio of the pre-ejection period (PEP) to the left ventricular ejection time (LVET), which may be expressed as (PEP/LVET). For example, the maximum
cardiac output at any given heart rate is maximized by the A-V delay interval which minimizes the ratio of the pre-ejection period to the left ventricular ejection time and optimization of this ratio is desirable. It appears that the maximization of the LVET is more important than minimization of PEP for most pacemaker patients. Similarly, other indexes of cardiac performance can be defined including: (Qo to MC)/LVET and (VP to MC)/LVET. These non-traditional measures may be better indicators of cardiac performance for some pacemaker patients.

[0079] These ratios involve pacing events that are readily detected and include electrical and electromechanical delay components. It should be recognized that the normal sinus depolarization of the heart has a different activation sequence than a paced beat, and measured PEP may vary between paced and sinus beats. For this reason, it may be preferable to optimize A-V delay based upon one of these non-traditional indices of cardiac performance. Consequently, although the preferred ratio of PEP to LVET is described in detail, the methods of the present invention may be extended to these and other non-traditional indices of cardiac performance.

[0080] In process 67, the lead placement and pacemaker settings that result in optimal resynchronization are determined. To provide a method for screening CRT candidates, SCG data is acquired from patients who have benefited from CRT and compared to data from those who have not. For placement of pacemaker leads, the physician looks for an optimum location of leads, e.g., one that gives a global minimum for the ratios of PEP/LVET. Other parameters may be discovered during electrophysiological studies that are better indicators of CRT success for certain patients.

[0081] FIG. 4 is broken into panels that represent hard copy output 45 from printer 44. The upper panel 70 represents the canonical SCG and ECG waveforms annotated with SCG and ECG event locations. The table 72 of FIG. 4 shows the A-V delay intervals set and the corresponding time interval measurements along with computed ratios.

[0082] Process 67 selects the minimum value for the ratio of PEP/LVET and places the asterisk 74 in the table 72 to indicate the global minimum. This value can be considered by the physician and programmed into the pacemaker via the pacemaker programmer 41, or the value can be automatically selected and transmitted to the pacemaker programmer 41 via data link 30, to automatically program the pacemaker 35 to this value.

[0083] FIG. 5 schematically illustrates the optimal lead placement method for cardiac resynchronization. The system that accomplishes the method of the invention consists of the following components: an accelerometer sensor, pacing leads and a programmable electrical simulator (pacemaker), a computer analysis module, which includes unique algorithms that calculates numerous parameters during the cardiac cycle (including but not limited to duration of systolic period, duration and pattern of ventricular ejection and diastolic relaxation period), and a computerized 2D and 3D display which includes ventricular contraction mapping that represents details of ventricular contraction.

[0084] The pacing leads are generally first placed at the right ventricular apex and left ventricular posterior or lateral wall through the coronary sinus. Next, seismographic signals are obtained from an accelerometers that are placed on the chest of a patient and from signals from an accelerometer over the carotid artery and are processed by a computer algorithm. The results of this seismographic signal is analyzed and displayed as a ventricular contraction map with multiple parameters including the pre-ejection period, the duration of systole and the duration of isometric diastolic period as well as other parameters. Comparing these hemodynamic parameters during pacing with those during non-pacing (as well as at different pacing sites) will enable the physician to determine the best pacing site(s) and to screen candidates for CRT.

[0085] The present invention should provide data at the time of the pacing implant procedure to achieve the best resynchronization for left or biventricular pacing therapy. Numerous studies have reported that most patients with congestive heart failure, who have left bundle branch block and QRS duration of greater than 130 ms, can be markedly improved by CRT accomplished by left ventricular or biventricular pacing. In addition, the selection of patients who would benefit and the results of the procedure should be greatly improved if the best pacing site(s) could be determined at the time of implantation. If it is found that synchronization therapy will also provide therapeutic benefit for patients with right bundle branch block, this invention could also be applied to these patients.

[0086] Three recently published reviews provide background information about resynchronization therapy for the treatment of congestive heart failure in a select group of patients. Dr. William Abraham in “Reviews of Clinical trials and Criteria for Identifying the Appropriate Patient,” 2003 Vol. 4 (Supplement 2): S30-S37 reviewed the clinical trials that evaluated this treatment for heart failure. A total of 12 clinical trials has been completed or is still enrolling patients. The criteria for enrollment are generally patients who are in New York Heart Association function class 2-4, or congestive heart failure, who have a QRS duration of greater than or equal to 120 ms (normal less than 100 ms), and who are in sinus rhythm. Most patients suffer from intraventricular conduction delay or left bundle branch block. Relatively few patients evaluated for this therapy are in atrial fibrillation or have right bundle branch block. These studies have shown the results of cardiac resynchronization therapy include an improvement of quality of life score, an increase in functional class, an increase in distance walked in six minutes, and an increase in peak oxygen consumption during exercise. Furthermore, one trial, “the Companion Trial,” was powered and did show a decrease in all cause mortality and hospitalization.

[0087] However, most studies have shown that approximately 30% of patients identified by the above criteria do not obtain any measurable benefit from this therapy. Therefore, this represents a challenge. The lack of benefit may be due to lack of precision in selection criteria and/or lack of identification of the optimal pacing site or sites. A review by David A Cass “Ventricular Resynchronization: Pathophysiology and Identification of Responders” in “Reviews in Cardiovascular Medicine” 2003: Vol. 4 (Supplement 2: S3-S13) noted that QRS duration does not consistently narrow after biventricular pacing with many subjects displaying no change or even widening of the QRS duration.

[0088] Thus, QRS duration is at best an indirect correlation of mechanical desynchronization which is the real
substrate that causes a decline in chamber function. Therefore, data have confirmed the initial results showing a general correlation between the basal QRS duration with efficacy of biventricular pacing but with a poor predictive value for identifying responders versus non-responders. The ability to predict responders is not yet clear. However, among the factors that are being considered and evaluated primarily by echocardiography include the interventricular dysynchrony, the intraventricular dyssynchrony, successful lead placement, adequate pre-excitation, and physiological atrial-ventricular delay. Cass reviewed the data in the literature that show that a greater than 22% improvement in the maximum rise in left ventricular pressure (dp/dt max) acutely has been associated with consistent responders with few false negatives. Interventricular delay appears to be more important than interventricular delay for defining responders. Interventricular conduction delay may cause mechanical dispersion of motion between the septal and lateral walls. The most common means of detecting this is by echocardiography. Various techniques using echocardiography have been utilized including M-mode echo imaging and various tissue Doppler imaging techniques to detect and quantify dyssynchrony. Although these techniques may be useful in helping to identify patients who may benefit from cardiac resynchronization therapy, these techniques have not been evaluated on a large scale to assess the percentage of patients who will benefit from cardiac resynchronization therapy.

In addition, echo evaluation is difficult if not impractical to assess the site of optimal lead placement at the time of the procedure for inserting the leads. As noted in the Review article by Sulukhe T.V., Henen M.Y. and Sutton R., Pacing and Heart Failure: Patient and Pacing Mode Selection, European Heart Journal 2003, Vol. 24 pp. 977-986, the aim of the biventricular pacing or ventricular resynchronization therapy is to optimize segmental electrical excitation, timing of contraction, relaxation and consequently cycle efficiency and that is the aim of the present invention. Sulukhe et al. reviewed data from a retrospective study that attempted to identify predictors of responders to biventricular pacing. There was no significant difference between the left ventricular lead position sites between the responders and the non-responders, but there was a trend toward a greater number of lateral and anterior left ventricular sites in patients whose symptoms and exercise tolerance improved.

Nevertheless, there has not been a study in which the optimal pacing sites have been compared at the time of implantation since there has not been a practical way of identifying optimal resynchronization at the time of the implant procedure. It is recognized that there are technical difficulties in positioning the pacing lead in the left ventricle by the coronary vein site optimal sites may not always be accessible and are limited by venous anatomy by current lead placement technology. However, there are recent advances in lead placement technology including over-the-wire techniques and other methods that may permit greater flexibility in positioning the coronary sinus lead.

Once again, an aim of the current invention is to obtain patterns of chest wall motion that reflect cardiac desynchronization to help select patients who may benefit from this procedure and, at the time of lead placement, to identify the optimal lead site that will accomplish this. Data that will also be collected to help identify the effect of different AV delays on identifying optimal patterns of optimal cardiac efficiency and output. These and other parameters can be assessed, including changes in the interventricular conduction delay. Additional parameters that can be assessed by the present invention are the duration of the pre-ejection period, the possible presence of mitral regurgitation as it affects the pre-ejection period, the rate of rise of the left ventricular ejection as determined by the accelerometer, the duration of systole, the rate of decrease of deceleration after peak acceleration and peak systole, the duration of systole, and the duration diastole.

Implant criteria for CRT devices for treatment of heart failure are based on electrical parameters (i.e., QRS prolongation) or dyssynchrony of contraction of the left ventricle. Unfortunately, up to 30% of patients do not respond to CRT using currently accepted criteria. Myocardial Performance Index (MPI) is a parameter that reflects overall cardiac performance rather than the electrical conduction of the heart or regional wall motion abnormalities. Thus, a MPI should be useful to assess cardiac function for screening heart failure patients for CRT procedure as well as to evaluate the outcome of the therapy.

Various changes in the details and components that have been described may be made by those skilled in the art within the principles and scope of the invention described in the specification and defined in the appended claims. Therefore, while the present invention has been shown and described herein in what is believed to be the most practical and preferred embodiments, it is recognized that departures can be made within the scope of the invention, which is not to be limited to the details disclosed herein but is to be accorded the full scope of the claims so as to embrace all equivalent processes and products.

We claim:

1. A method for determining a change in function of a patient’s heart, comprising the steps of:

   (a) collecting seismocardiographic (SCG) data from an external surface of a patient corresponding to a heart motion of said patient’s heart;

   (b) determining a hemodynamic parameter based on the SCG data of step (a); and

   (c) comparing said parameter of step (b) with a predetermined measure of cardiac performance.

2. The method of claim 1, wherein step (b) further comprises determining one or more parameters selected from the group consisting of isovolumetric contraction time (IVCT), isovolumetric relaxation time (IVCT), and left ventricle ejection time.

3. The method of claim 1, wherein said hemodynamic parameter of step (b) is selected from the group consisting of one or more of the following: a pre-ejection period, a rate of contraction of left ventricle, a duration of systole, a duration of an isovolumic relaxation period, a rate of change of ventricular pressure, and an ejection fraction.

4. The method of claim 1, wherein said SCG data of step (a) are collected by an accelerometer.

5. The method of claim 1, wherein said SCG data of step (a) are selected from the group consisting of one or more of the following: acceleration, velocity, and time intervals of valve sounds.
6. The method of claim 1, wherein said predetermined measure of cardiac performance comprises a change in cardiac contractility based on a change in the height or rate of rise of curves based on said SCG data.

7. The method of claim 1, wherein said predetermined measure of cardiac performance comprises a change in SCG data velocity or acceleration during early diastole as an indication of hypertrophic cardiomyopathy.

8. The method of claim 1, wherein said predetermined measure of cardiac performance comprises a change in SCG data velocity or acceleration during early diastole of a tilt test as an indication of reflex sympathetic stimulation.

9. The method of claim 1, wherein said hemodynamic parameter comprises a heart valve sound at a designated frequency range.

10. The method of claim 1, further including the step of comparing the SCG data of step (b) with data produced by a non-accelerometer-based technique to determine any correlation between a measure of cardiac function produced by said technique and said SCG data.

11. The method of claim 1, wherein step (b) further comprises subjecting a patient’s heart to biventricular pacing and determining whether there is a shorter isovolumetric contraction time as an indication that biventricular pacing is increasing heart contraction.

12. The method of claim 1, further including the step of subjecting a patient’s heart to sub-threshold pacing and determining whether there is a shorter isovolumetric contraction time as an indication that sub-threshold pacing is increasing heart contraction.

13. The method of claim 1, wherein step (a) further comprises providing a plurality of accelerometer sensors for collecting said SCG data.

14. The method of claim 13, wherein step (a) further comprises disposing said plurality of accelerometer sensors upon a neck, a chest apex, and a chest sternum of said patient.

15. The method of claim 1, wherein step (a) comprises collecting SCG data during cardiac motion corresponding to unpaced beats only.

16. A method for testing or evaluation of a cardiac function, comprising the steps of:

(a) collecting seismocardiographic (SCG) data corresponding to heart motion of a patient’s heart during a non-testing condition;

(b) determining a hemodynamic parameter based on the SCG data of step (a);

(c) imposing a test condition upon said patient;

(d) collecting seismocardiographic (SCG) data corresponding to heart motion of said patient’s heart during said test condition;

(e) determining said hemodynamic parameter based on the SCG data of step (d); and

(f) comparing information from steps (b) and (e) to determine said cardiac function.

17. The method of claim 16, wherein the SCG data of steps (a) and (d) are collected by an accelerometer sensor.

18. The method of claim 16, wherein said hemodynamic parameter of steps (b) and (e) is selected from the group consisting of one or more of the following: a pre-ejection period, a rate of contraction of left ventricle, a duration of systole, a duration of an isovolumic relaxation period, a rate of change of ventricular pressure, and an ejection fraction.

19. The method of claim 16, wherein said test condition is selected from the group consisting of stress testing and tilt testing.

20. The method of claim 16, wherein step (e) further comprises determining that heart contractility does not shorten, or the time of contractility lengthens, during a stress test as an indication of coronary blockage.

21. The method of claim 16, wherein step (e) further comprises determining that an amplitude of a rapid filling wave becomes larger during a stress test as an indication of a coronary blockage.

22. A system for determining a change in function of a patient’s heart, comprising:

means for collecting seismocardiographic (SCG) data from an exterior surface of a said patient corresponding to a heart motion of said patient’s heart;

means for determining a hemodynamic parameter based on said SCG data; and

a processing device that compares said hemodynamic parameter with a predetermined measure of cardiac performance.

23. The apparatus of claim 22, wherein said means for collecting SCG data comprises an accelerometer.

24. The apparatus of claim 23, wherein said accelerometer is adapted for wireless communication with said means for determining a hemodynamic parameter.

25. The apparatus of claim 22, wherein said means for determining a hemodynamic parameter is adapted for wireless communication with said processing device.

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