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(12) **United States Patent**  
**Bardy**

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(54) **SYSTEM AND METHOD FOR EVALUATING  
A PATIENT STATUS FOR USE IN HEART  
FAILURE ASSESSMENT**

(75) Inventor: **Gust H. Bardy**, Seattle, WA (US)

(73) Assignee: **Cardiac Pacemakers, Inc.**, St. Paul,  
MN (US)

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claimer.

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(Continued)

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(52) **U.S. Cl.**  
CPC ..... **A61B 5/7275** (2013.01); **A61B 5/0002**  
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(58) **Field of Classification Search**

USPC ..... 600/301  
See application file for complete search history.

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*Primary Examiner* — William Levicky

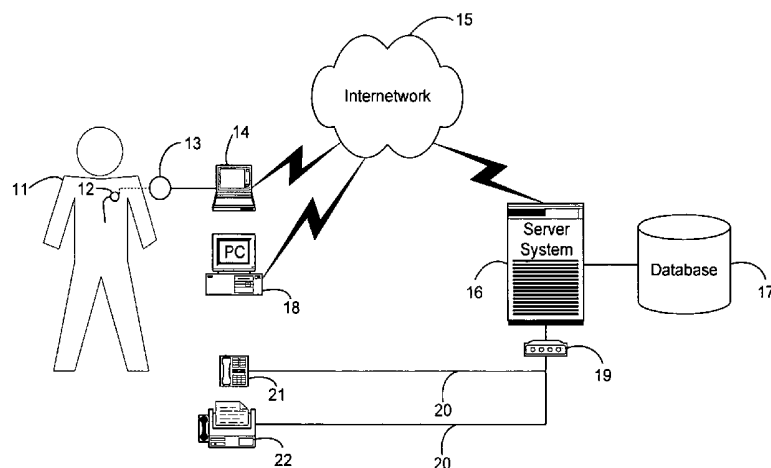
(74) *Attorney, Agent, or Firm* — Pauly, DeVries Smith &  
Definer, LLC

(57)

**ABSTRACT**

A system and method for evaluating a patient status from  
sampled physiometry for use in heart failure assessment is  
presented. Physiological measures, including at least one of  
direct measures regularly recorded on a substantially con-  
tinuous basis by a medical device and measures derived  
from the direct measures are stored. At least one of those of  
the physiological measures, which relate to a same type of  
physiometry, and those of the physiological measures, which  
relate to a different type of physiometry are sampled. A  
status is determined for a patient through analysis of those  
sampled measures assembled from a plurality of recordation  
points. The sampled measures are evaluated. Trends that are  
indicated by the patient status, including one of a status quo  
and a change, which might affect cardiac performance of the  
patient, are identified. Each trend is compared to worsening  
heart failure indications to generate a notification of param-  
eter violations.

**24 Claims, 20 Drawing Sheets**



**Related U.S. Application Data**

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Fig. 1.

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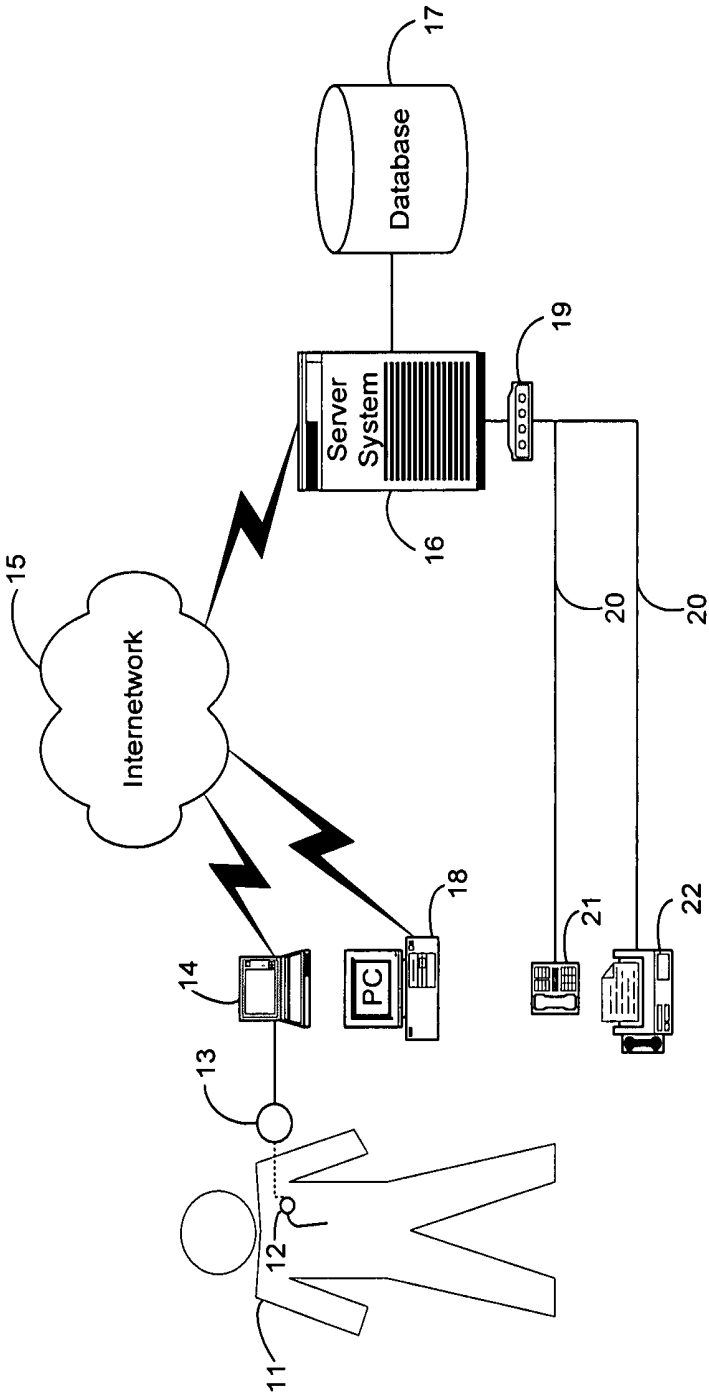
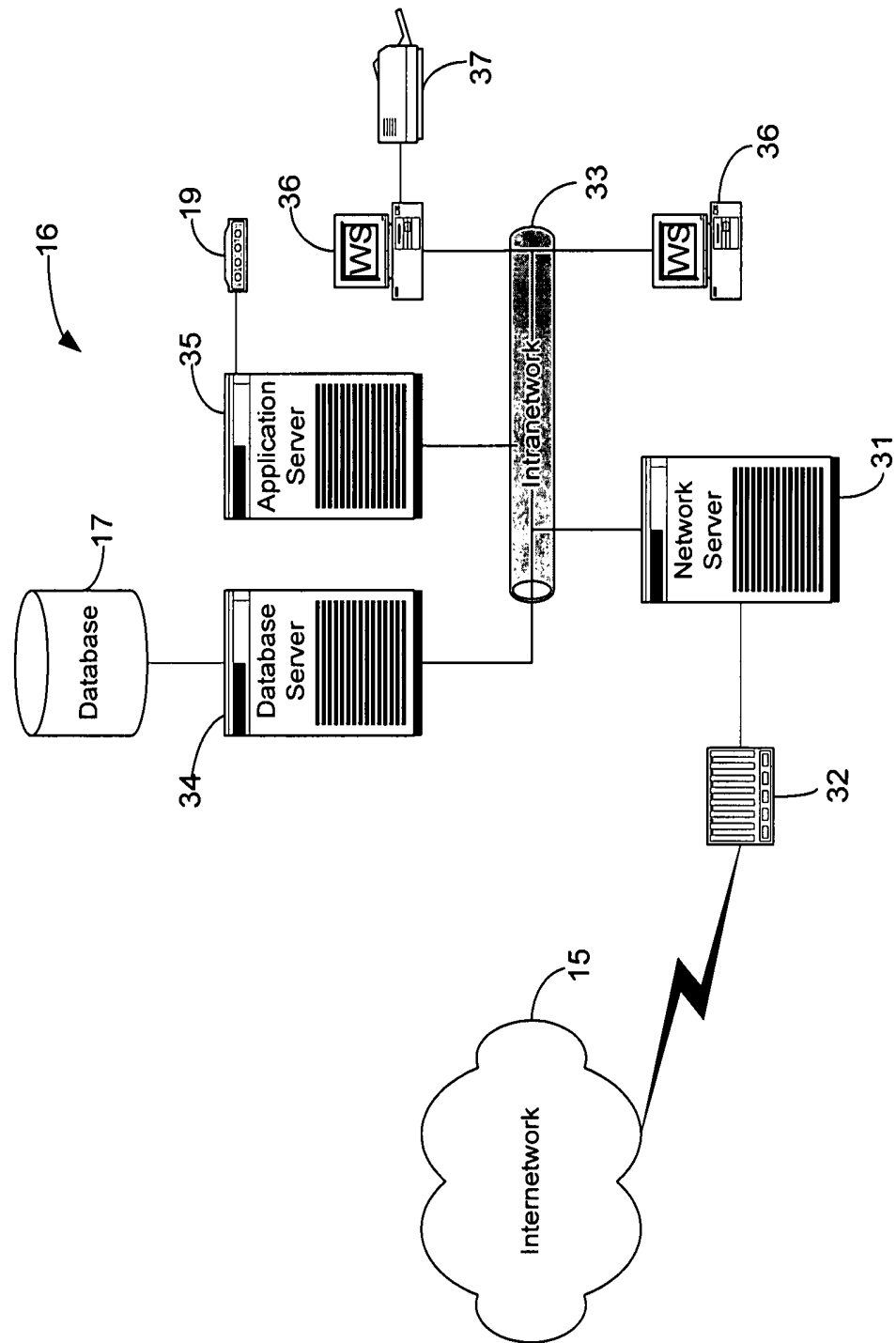
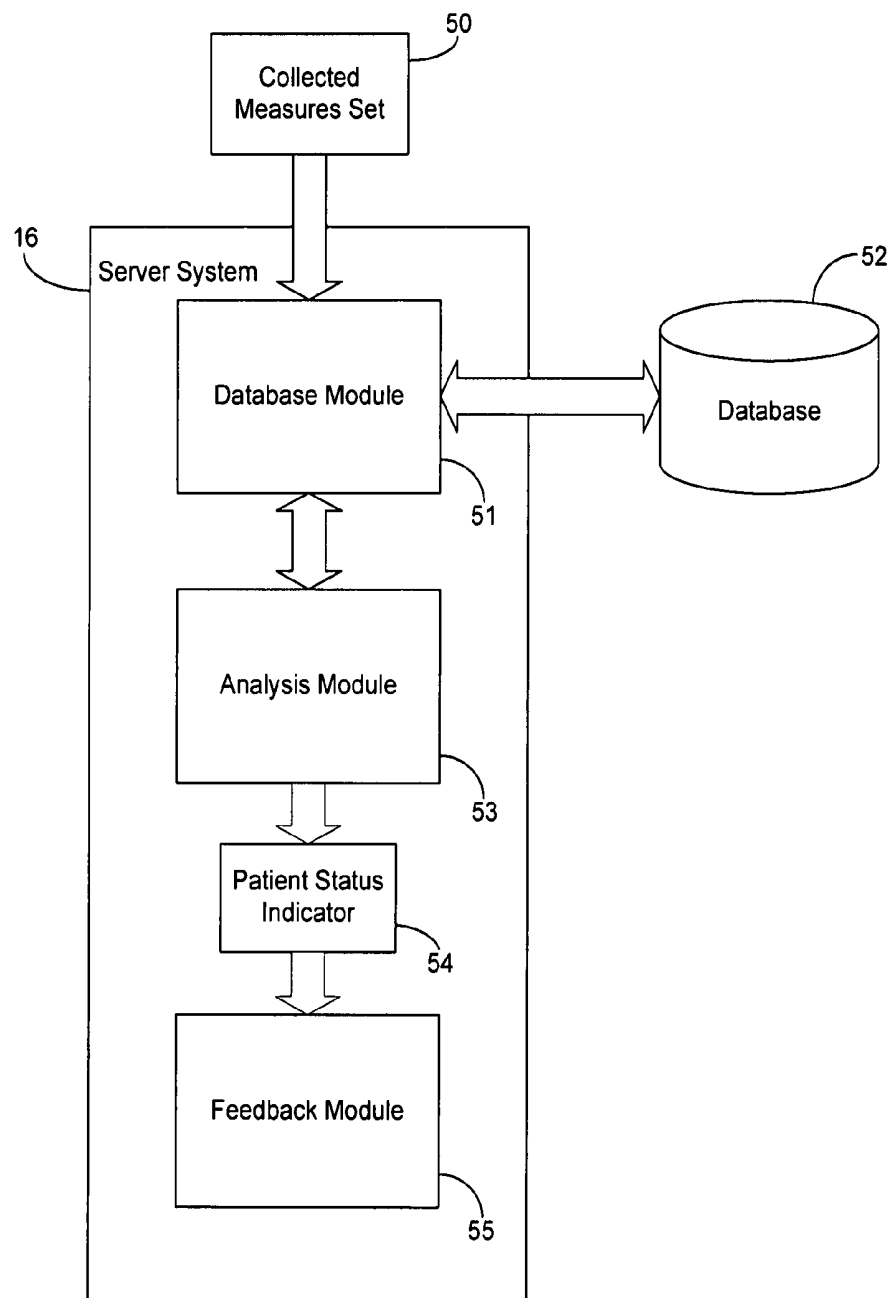


Fig. 2.



**Fig. 3.**

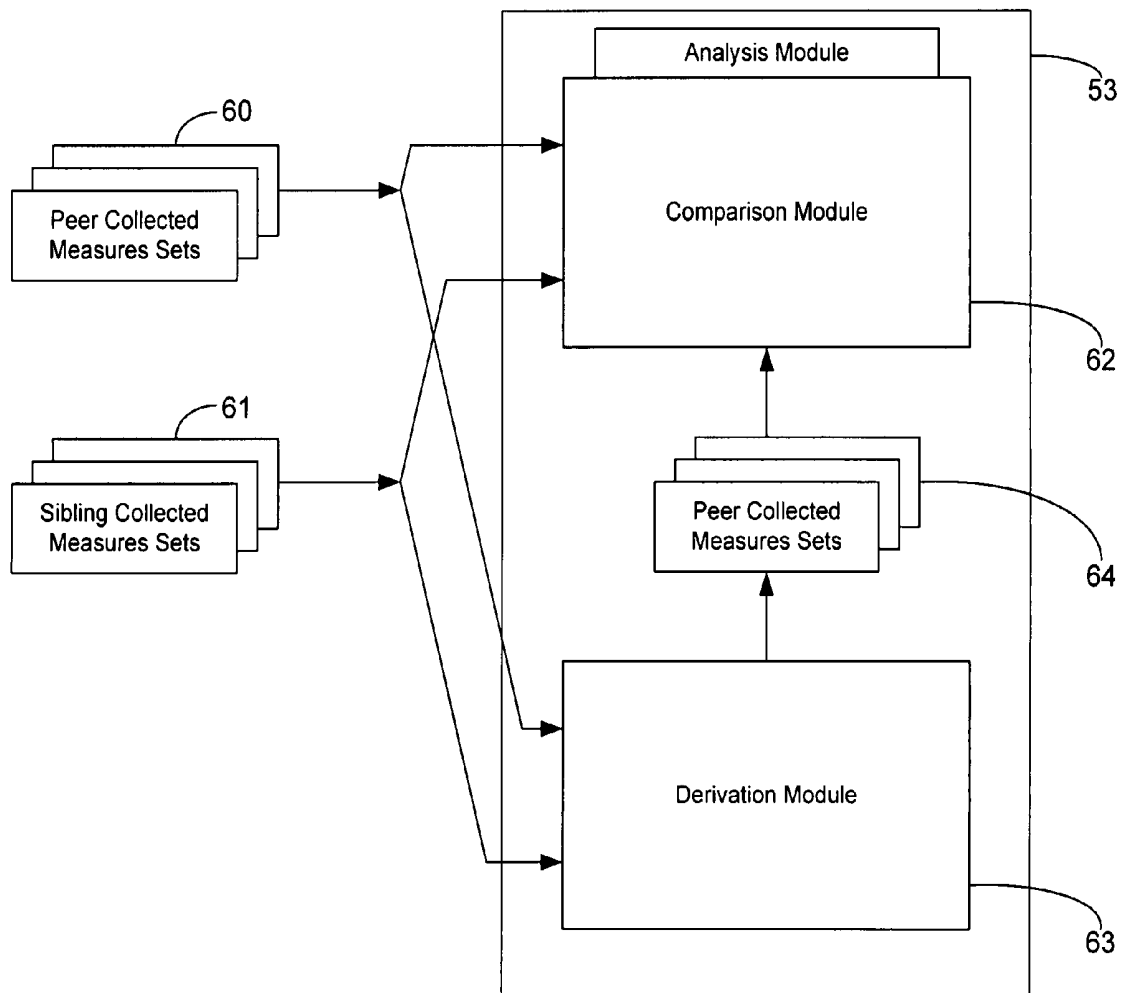
**Fig. 4.**



Fig. 5.

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71	72	73	74	75	76	77	78	79	80	81	82
Atrial Electrical Activity	Ventri- cular Electrical Activity	Time of Day	Activity Level	Cardiac Output	Oxygen Level	Cardio- vascular Pressure Measures	Pulmo- nary Pressure Measures	Interven- tions Made	Success of Inter- ventions Made	Battery Status	Program Settings

**Fig. 6.**

Patient 1

Set 0				Set n-2	Set n-1	Set n
$X_0$	•	•	•	$X_{n-2}$	$X_{n-1}$	$X_n$
$Y_0$	•	•	•	$Y_{n-2}$	$Y_{n-1}$	$Y_n$
$Z_0$	•	•	•	$Z_{n-2}$	$Z_{n-1}$	$Z_n$

*time* →

Patient 2

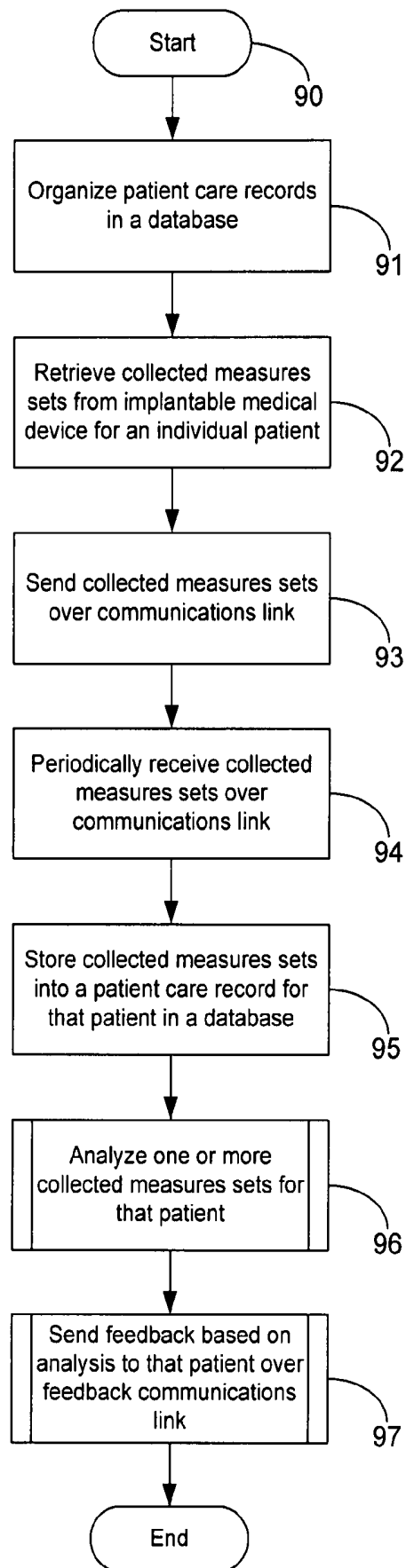
Set 0				Set n-2	Set n-1	Set n
$X_{0'}$	•	•	•	$X_{n-2'}$	$X_{n-1'}$	$X_{n'}$
$Y_{0'}$	•	•	•	$Y_{n-2'}$	$Y_{n-1'}$	$Y_{n'}$
$Z_{0'}$	•	•	•	$Z_{n-2'}$	$Z_{n-1'}$	$Z_{n'}$

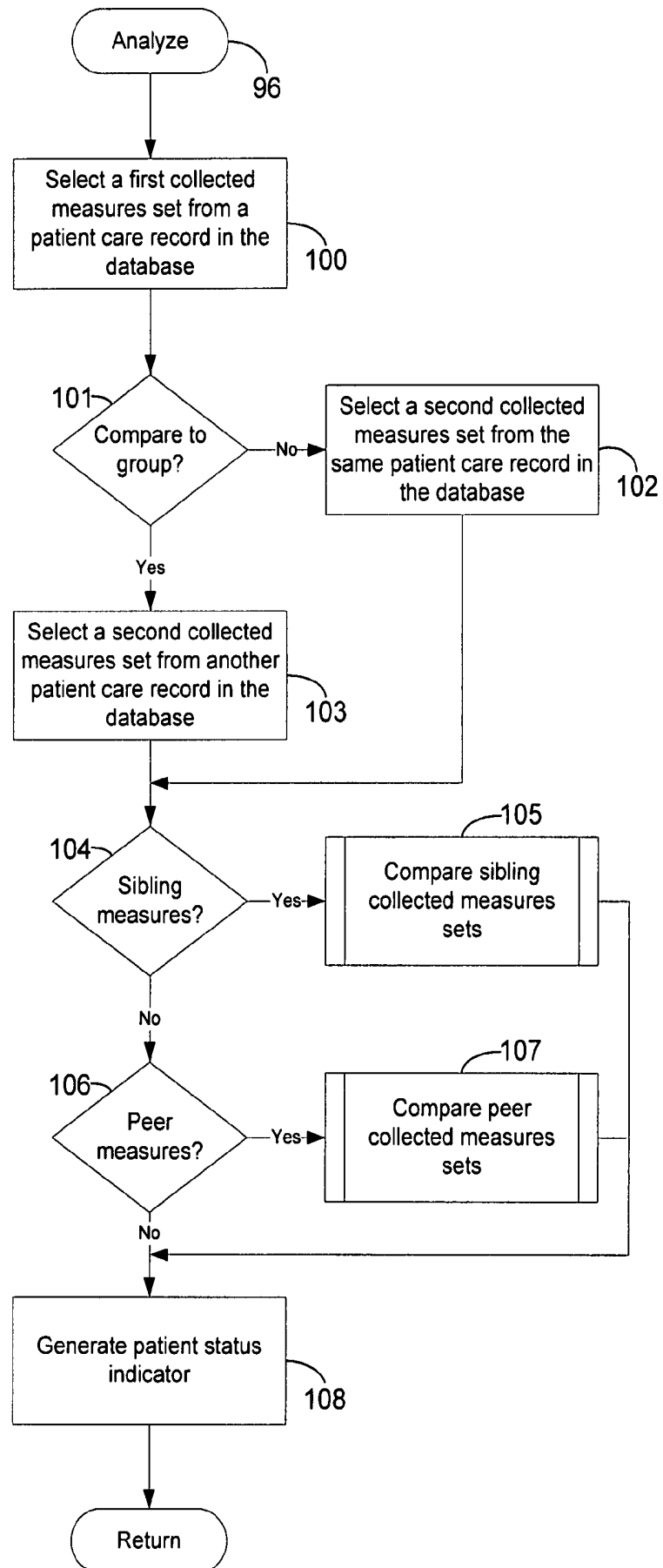
*time* →

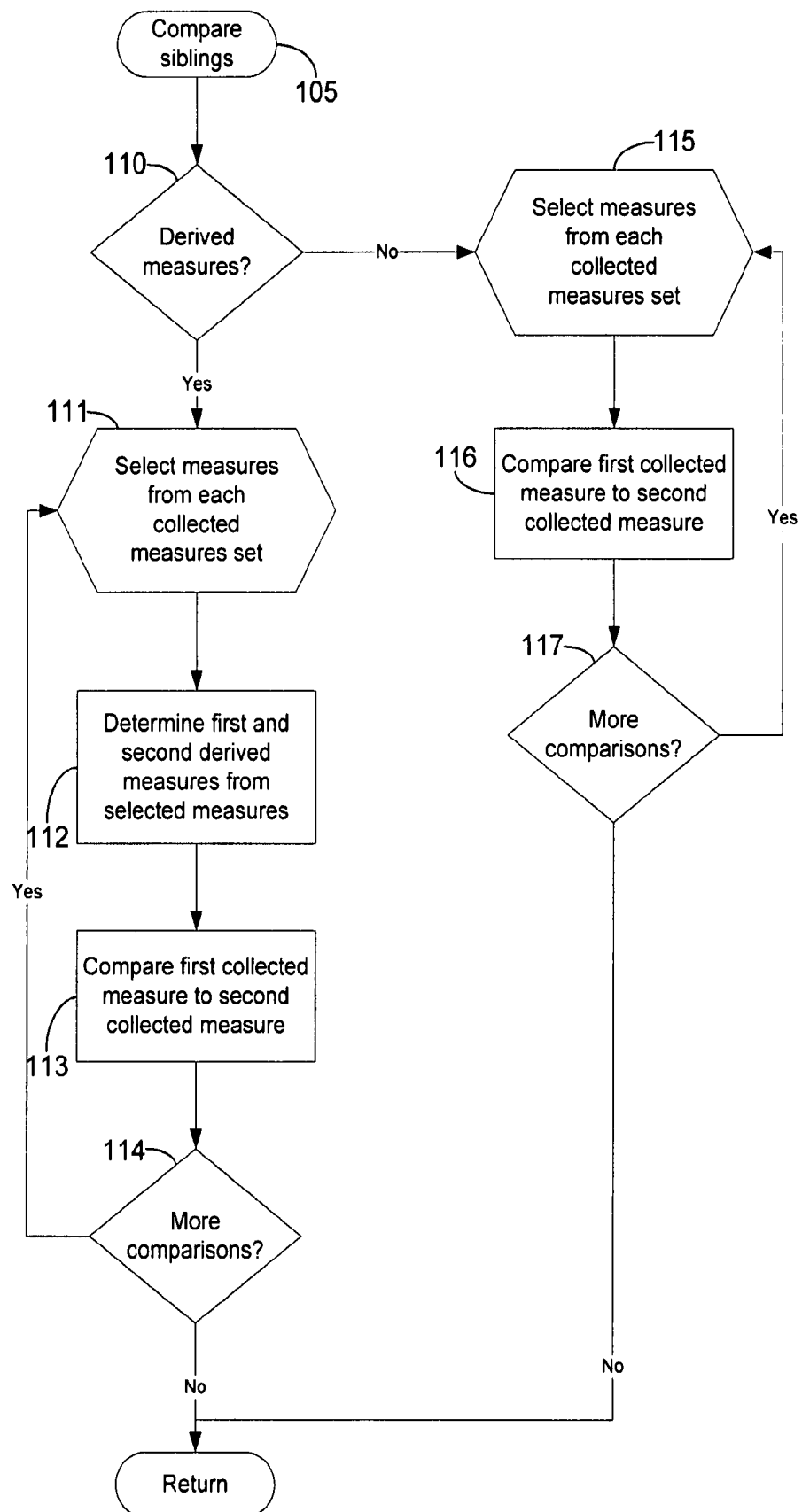
Patient 3

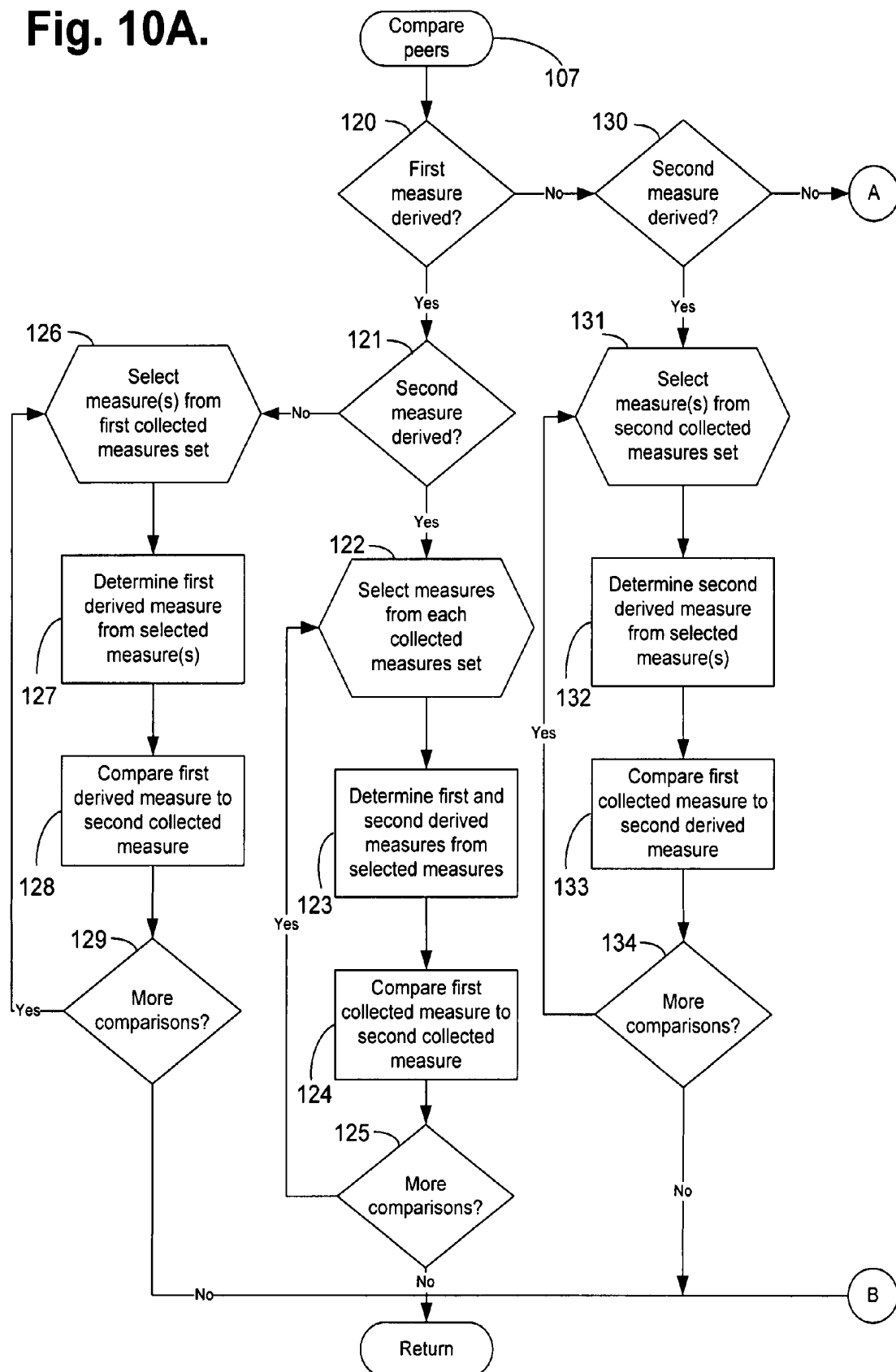
Set 0				Set n-2	Set n-1	Set n
$X_{0''}$	•	•	•	$X_{n-2''}$	$X_{n-1''}$	$X_{n''}$
$Y_{0''}$	•	•	•	$Y_{n-2''}$	$Y_{n-1''}$	$Y_{n''}$
$Z_{0''}$	•	•	•	$Z_{n-2''}$	$Z_{n-1''}$	$Z_{n''}$

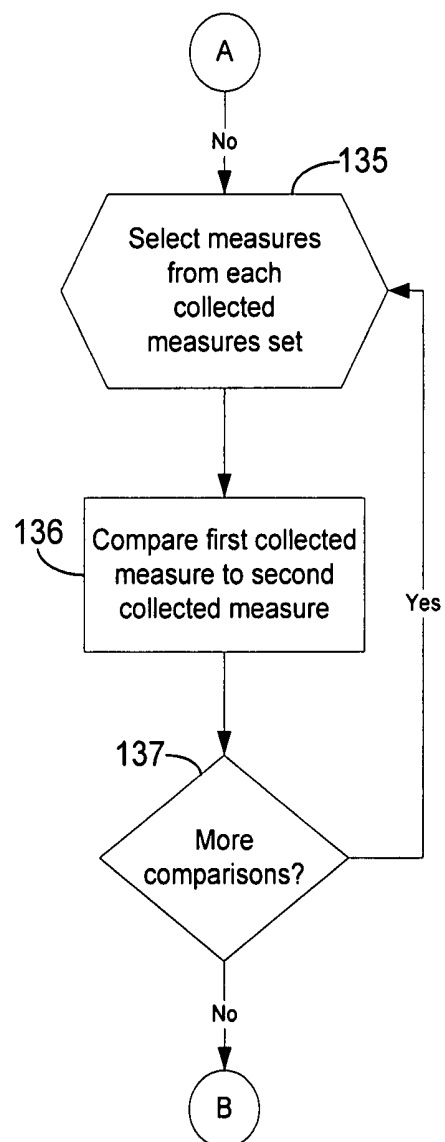
*time* →

**Fig. 7.**

**Fig. 8.**

**Fig. 9.**

**Fig. 10A.**

**Fig. 10B.**

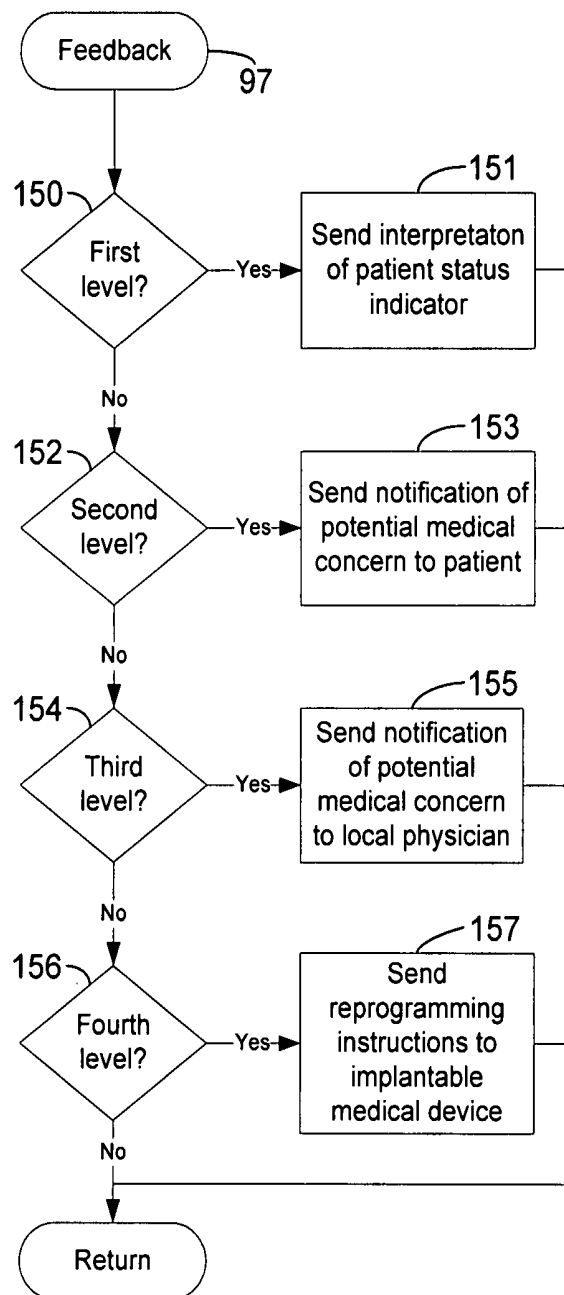
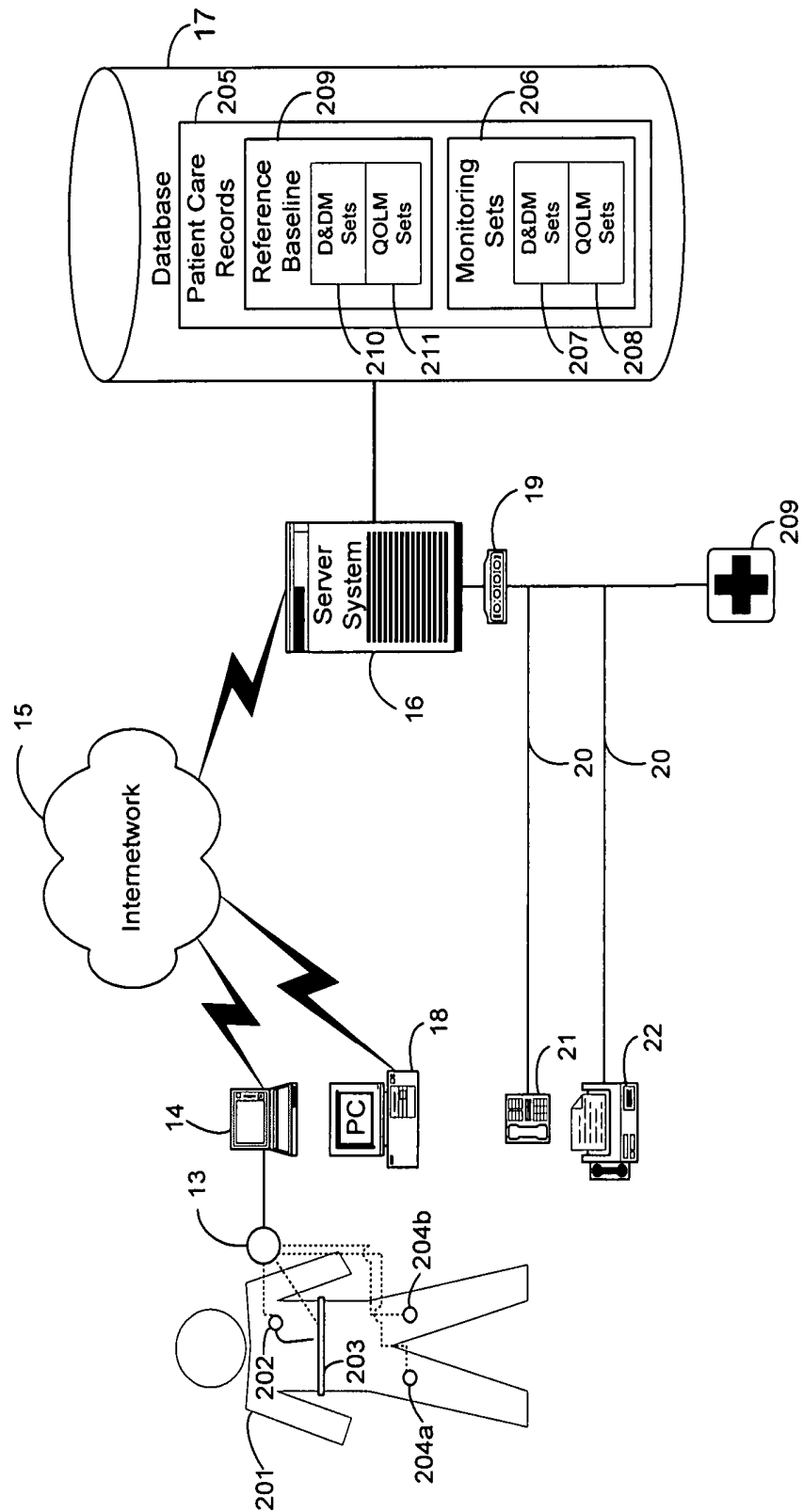
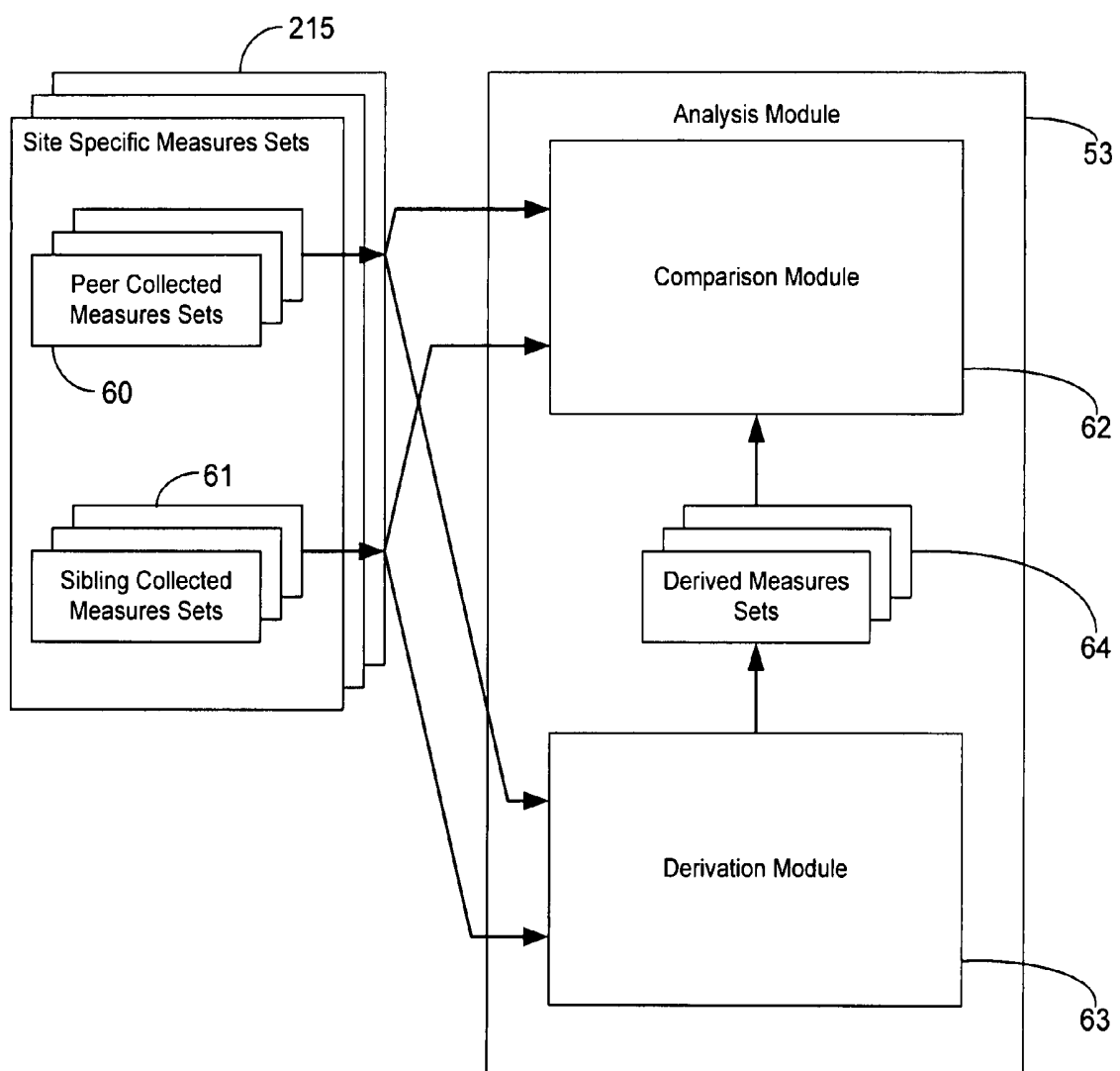
**Fig. 11.**



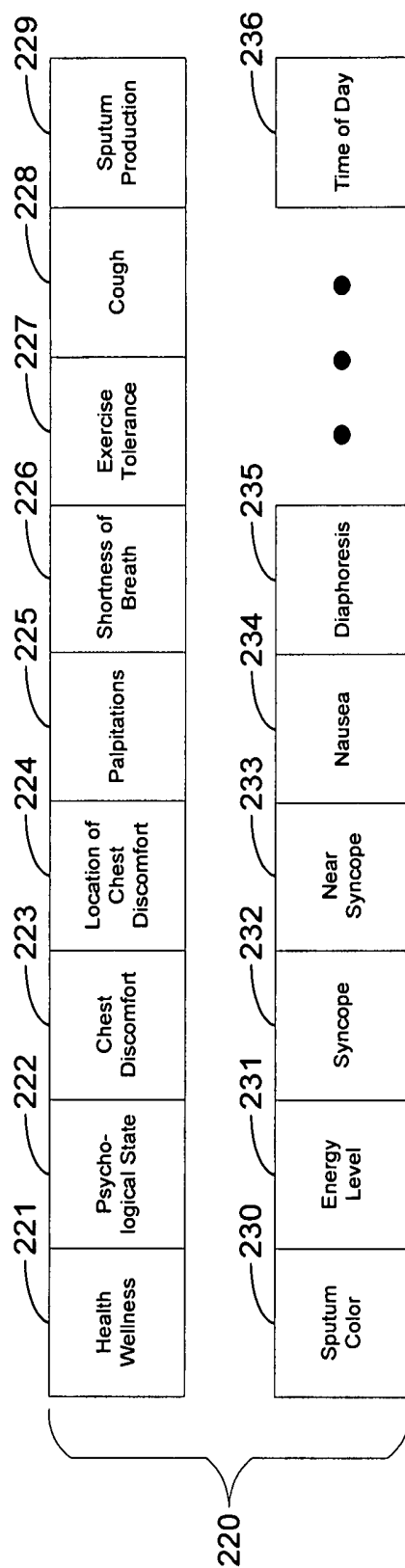
Fig. 12.

200



**Fig. 13.**

**Fig. 14.**



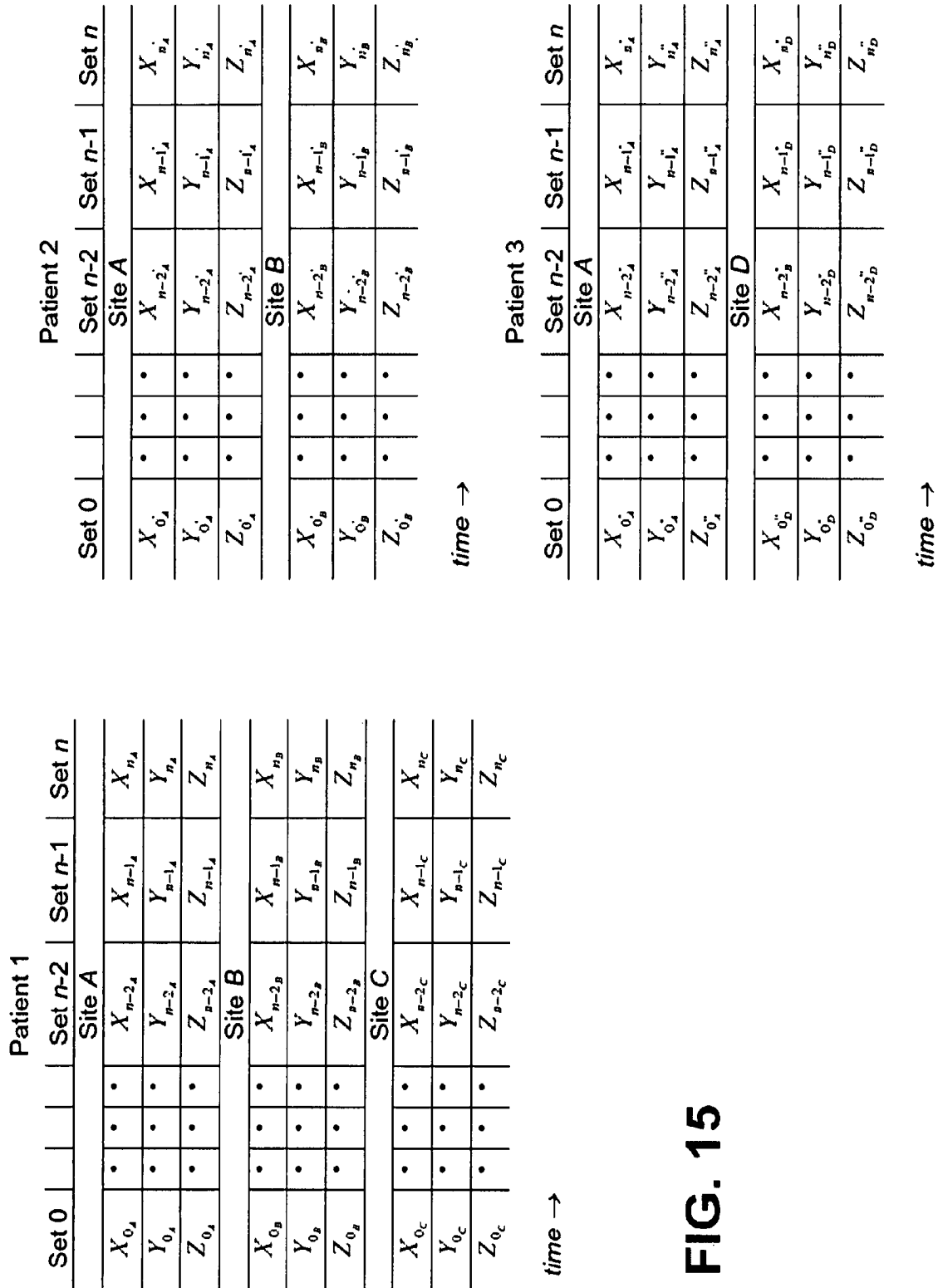
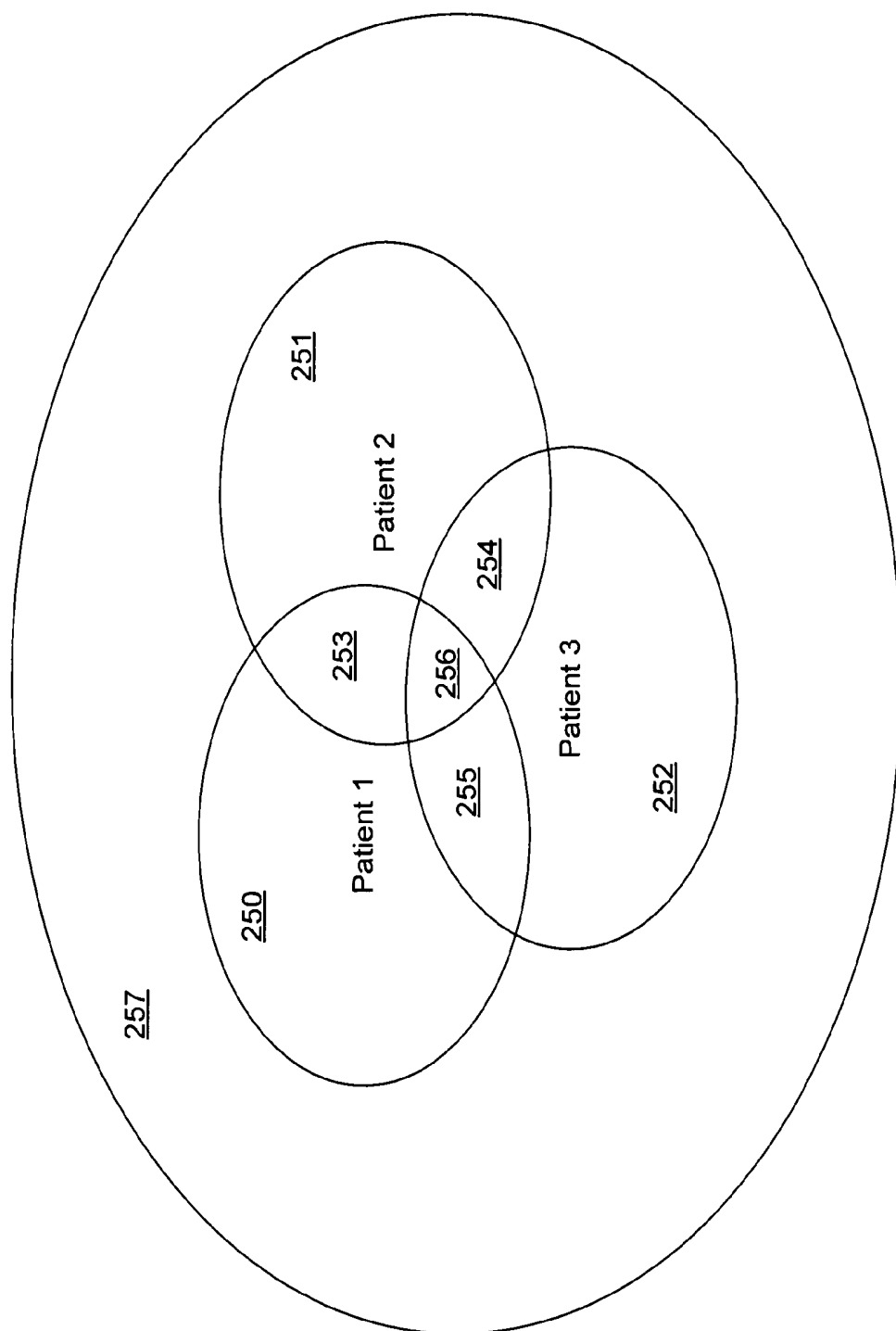
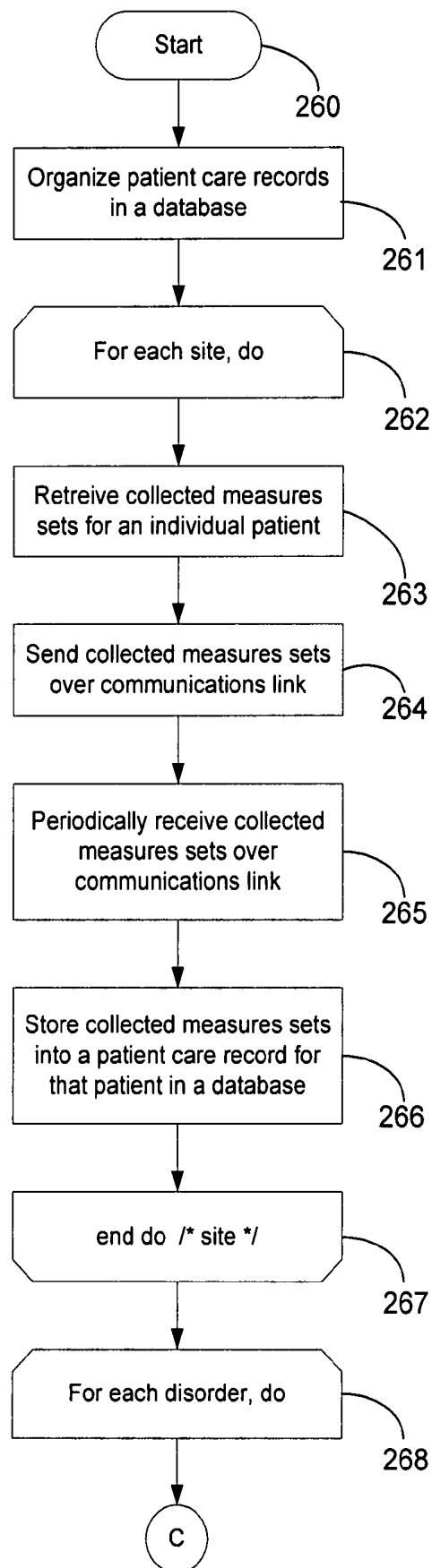
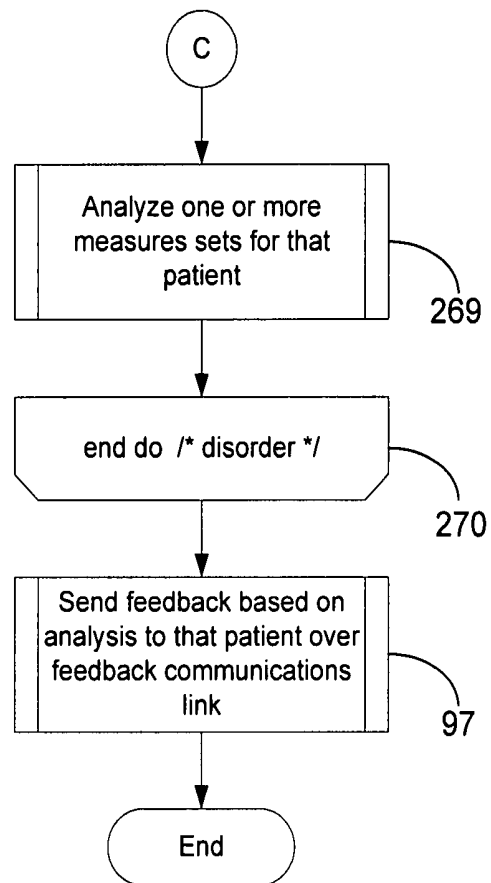
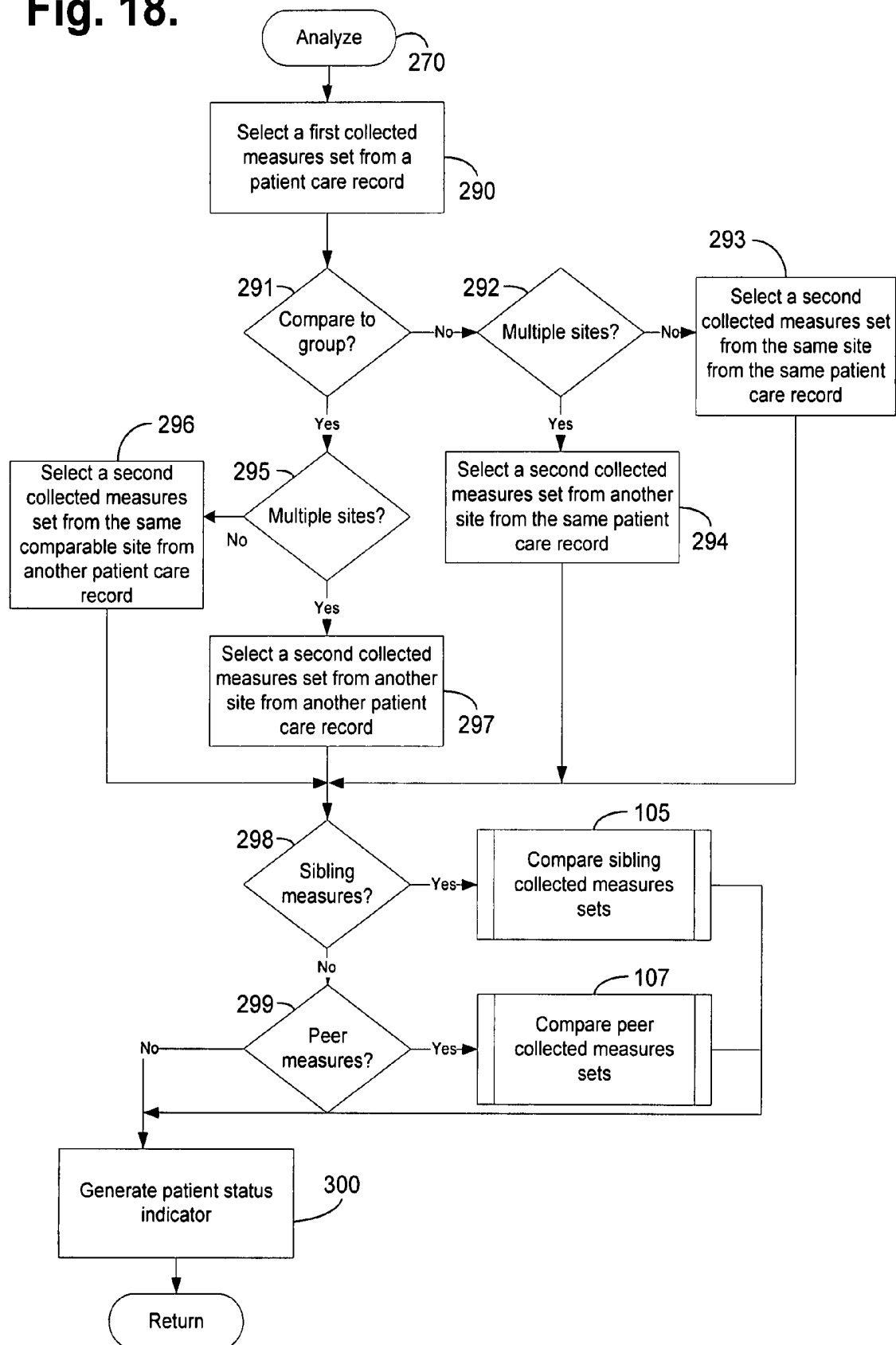


FIG. 15

**Fig. 16.**

**Fig. 17A.**

**Fig. 17B.**

**Fig. 18.**



# SYSTEM AND METHOD FOR EVALUATING A PATIENT STATUS FOR USE IN HEART FAILURE ASSESSMENT

## CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation of U.S. patent application, Ser. No. 11/480,634, filed Jun. 30, 2006, abandoned; which is a continuation of U.S. patent application, Ser. No. 10/422,495 filed Apr. 23, 2003, now U.S. Pat. No. 7,070,562, issued Jul. 4, 2006; which is a divisional of U.S. patent application, Ser. No. 09/860,977 filed May 18, 2001, now U.S. Pat. No. 6,974,413, issued Dec. 13, 2005; which is a continuation of U.S. patent application, Ser. No. 09/476,602 filed Dec. 31, 1999, now U.S. Pat. No. 6,270,457, issued Aug. 7, 2001; which is a continuation-in-part of U.S. patent application, Ser. No. 09/324,894 filed Jun. 3, 1999, now U.S. Pat. No. 6,312,378, issued Nov. 6, 2001, the priority filing dates of which are claimed and the disclosures of which are incorporated by reference.

## FIELD

The present invention relates in general to heart failure assessment, and, in particular, to a system and method for evaluating a patient status for use in heart failure assessment.

## BACKGROUND

A broad class of medical subspecialties, including cardiology, endocrinology, hematology, neurology, gastroenterology, urology, ophthalmology, and otolaryngology, to name a few, rely on accurate and timely patient information for use in aiding health care providers in diagnosing and treating diseases and disorders. Often, proper medical diagnosis requires information on physiological events of short duration and sudden onset, yet these types of events are often occur infrequently and with little or no warning. Fortunately, such patient information can be obtained via external, implantable, cutaneous, subcutaneous, and manual medical devices, and combinations thereof. For example, in the area of cardiology, implantable pulse generators (IPGs) are commonly used to treat irregular heartbeats, known as arrhythmias. There are three basic types of IPGs. Cardiac pacemakers are used to manage bradycardia, an abnormally slow or irregular heartbeat. Bradycardia can cause symptoms such as fatigue, dizziness, and fainting. Implantable cardioverter defibrillators (ICDs) are used to treat tachycardia, heart rhythms that are abnormally fast and life threatening. Tachycardia can result in sudden cardiac death (SCD). Finally, implantable cardiovascular monitors and therapeutic devices are used to monitor and treat structural problems of the heart, such as congestive heart failure and rhythm problems.

Pacemakers and ICDs, as well as other types of implantable and external medical devices, are equipped with an on-board, volatile memory in which telemetered signals can be stored for later retrieval and analysis. In addition, a growing class of cardiac medical devices, including implantable heart failure monitors, implantable event monitors, cardiovascular monitors, and therapy devices, are being used to provide similar stored device information. These devices are able to store more than thirty minutes of per heartbeat data. Typically, the telemetered signals can provide patient device information recorded on a per heartbeat, binned average basis, or derived basis from, for example, atrial

electrical activity, ventricular electrical activity, minute ventilation, patient activity score, cardiac output score, mixed venous oxygen score, cardiovascular pressure measures, time of day, and any interventions and the relative success of such interventions. In addition, many such devices can have multiple sensors, or several devices can work together, for monitoring different sites within a patient's body.

Presently, stored device information is retrieved using a proprietary interrogator or programmer, often during a clinic visit or following a device event. The volume of data retrieved from a single device interrogation "snapshot" can be large and proper interpretation and analysis can require significant physician time and detailed subspecialty knowledge, particularly by cardiologists and cardiac electrophysiologists. The sequential logging and analysis of regularly scheduled interrogations can create an opportunity for recognizing subtle and incremental changes in patient condition otherwise undetectable by inspection of a single "snapshot." However, present approaches to data interpretation and understanding and practical limitations on time and physician availability make such analysis impracticable.

A prior art system for collecting and analyzing pacemaker and ICD telemetered signals in a clinical or office setting is the Model 9790 Programmer, manufactured by Medtronic, Inc., Minneapolis, Minn. This programmer can be used to retrieve data, such as patient electrocardiogram and any measured physiological conditions, collected by the IPG for recordation, display and printing. The retrieved data is displayed in chronological order and analyzed by a physician. Comparable prior art systems are available from other IPG manufacturers, such as the Model 2901 Programmer Recorder Monitor, manufactured by Guidant Corporation, Indianapolis, Ind., which includes a removable floppy diskette mechanism for patient data storage. These prior art systems lack remote communications facilities and must be operated with the patient present. These systems present a limited analysis of the collected data based on a single device interrogation and lack the capability to recognize trends in the data spanning multiple episodes over time or relative to a disease specific peer group.

A prior art system for locating and communicating with a remote medical device implanted in an ambulatory patient is disclosed in U.S. Pat. No. 5,752,976 ('976). The implanted device includes a telemetry transceiver for communicating data and operating instructions between the implanted device and an external patient communications device. The communications device includes a communication link to a remote medical support network, a global positioning satellite receiver, and a patient activated link for permitting patient initiated communication with the medical support network.

Related prior art systems for remotely communicating with and receiving telemetered signals from a medical device are disclosed in U.S. Pat. Nos. 5,113,869 ('869) and 5,336,245 ('245). In the '869 patent, an implanted AECG monitor can be automatically interrogated at preset times of day to telemeter out accumulated data to a telephonic communicator or a full disclosure recorder. The communicator can be automatically triggered to establish a telephonic communication link and transmit the accumulated data to an office or clinic through a modem. In the '245 patent, telemetered data is downloaded to a larger capacity, external data recorder and is forwarded to a clinic using an auto-dialer and fax modem operating in a personal computer-based programmer/interrogator. However, the '976 telemetry transceiver, '869 communicator, and '245 programmer/interrogator are limited to facilitating communication and

transferal of downloaded patient data and do not include an ability to automatically track, recognize, and analyze trends in the data itself.

In addition, the uses of multiple sensors situated within a patient's body at multiple sites are disclosed in U.S. Pat. No. 5,040,536 ('536) and U.S. Pat. No. 5,987,352 ('352). In the '536 patent, an intravascular pressure posture detector includes at least two pressure sensors implanted in different places in the cardiovascular system, such that differences in pressure with changes in posture are differentially measurable. However, the physiological measurements are used locally within the device, or in conjunction with any implantable device, to effect a therapeutic treatment. In the '352 patent, an event monitor can include additional sensors for monitoring and recording physiological signals during arrhythmia and syncopal events. The recorded signals can be used for diagnosis, research or therapeutic study, although no systematic approach to analyzing these signals, particularly with respect to peer and general population groups, is presented.

Thus, there is a need for a system and method for providing continuous retrieval, transferal, and automated analysis of retrieved medical device information, such as telemetered signals, retrieved in general from a broad class of implantable and external medical devices. Preferably, the automated analysis would include recognizing a trend indicating disease absence, onset, progression, regression, and status quo and determining whether medical intervention is necessary.

There is a further need for a system and method that would allow consideration of sets of collected measures, both actual and derived, from multiple device interrogations. These collected measures sets could then be compared and analyzed against short and long term periods of observation.

There is a further need for a system and method that would enable the measures sets for an individual patient to be self-referenced and cross-referenced to similar or dissimilar patients and to the general patient population. Preferably, the historical collected measures sets of an individual patient could be compared and analyzed against those of other patients in general or of a disease specific peer group in particular.

### SUMMARY

The present invention provides a system and method for automated collection and analysis of patient information retrieved from an implantable medical device for remote patient care. The patient device information relates to individual measures recorded by and retrieved from implantable medical devices, such as IPGs and monitors. The patient device information is received on a regular, e.g., daily, basis as sets of collected measures, which are stored along with other patient records in a database. The information can be analyzed in an automated fashion and feedback provided to the patient at any time and in any location.

An embodiment provides a system and method for evaluating a patient status for use in heart failure assessment. Physiological measures, which were directly recorded as data on a substantially continuous basis by a medical device for a patient or indirectly derived from the data are assembled. A status is determined for the patient through sampling and analysis of the physiological measures over a plurality of data assembly points. The physiological measures relative to the patient status are evaluated by analyzing

any trend, including one of a status quo and a change in cardiac performance and comparing the trend to cardiac decompensation indications.

A further embodiment provides a system and method for evaluating a patient status from sampled physiometry for use in heart failure assessment. Physiological measures, including at least one of direct measures regularly recorded on a substantially continuous basis by a medical device for a patient and measures derived from the direct measures are stored. At least one of those of the physiological measures, which each relate to a same type of physiometry, and those of the physiological measures, which each relate to a different type of physiometry are sampled. A status is determined for the patient through analysis of those sampled physiological measures assembled from a plurality of recording points. The sampled physiological measures are evaluated. Trends that are indicated by the patient status, including one of a status quo and a change, which might affect cardiac performance of the patient, are identified. Each trend is compared to cardiac decompensation indications to generate a notification of parameter violations.

Still other embodiments of the present invention will become readily apparent to those skilled in the art from the following detailed description, wherein is described embodiments of the invention by way of illustrating the best mode contemplated for carrying out the invention. As will be realized, the invention is capable of other and different embodiments and its several details are capable of modifications in various obvious respects, all without departing from the spirit and the scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing a system for automated collection and analysis of patient information retrieved from an implantable medical device for remote patient care in accordance with the present invention;

FIG. 2 is a block diagram showing the hardware components of the server system of the system of FIG. 1;

FIG. 3 is a block diagram showing the software modules of the server system of the system of FIG. 1;

FIG. 4 is a block diagram showing the analysis module of the server system of FIG. 3;

FIG. 5 is a database schema showing, by way of example, the organization of a cardiac patient care record stored in the database of the system of FIG. 1;

FIG. 6 is a record view showing, by way of example, a set of partial cardiac patient care records stored in the database of the system of FIG. 1;

FIG. 7 is a flow diagram showing a method for automated collection and analysis of patient information retrieved from an implantable medical device for remote patient care in accordance with the present invention;

FIG. 8 is a flow diagram showing a routine for analyzing collected measures sets for use in the method of FIG. 7;

FIG. 9 is a flow diagram showing a routine for comparing sibling collected measures sets for use in the routine of FIG. 8;

FIGS. 10A and 10B are flow diagrams showing a routine for comparing peer collected measures sets for use in the routine of FIG. 8; and

FIG. 11 is a flow diagram showing a routine for providing feedback for use in the method of FIG. 7;

FIG. 12 is a block diagram showing a system for automated collection and analysis of regularly retrieved patient

information for remote patient care in accordance with a further embodiment of the present invention;

FIG. 13 is a block diagram showing the analysis module of the server system of FIG. 12;

FIG. 14 is a database schema showing, by way of example, the organization of a quality of life and symptom measures set record for care of patients stored as part of a patient care record in the database of the system of FIG. 12;

FIG. 15 is a record view showing, by way of example, a set of partial cardiac patient care records stored in the database of the system of FIG. 12;

FIG. 16 is a Venn diagram showing, by way of example, peer group overlap between the partial patient care records of FIG. 15;

FIGS. 17A-17B are flow diagrams showing a method for automated collection and analysis of regularly retrieved patient information for remote patient care in accordance with a further embodiment of the present invention; and

FIG. 18 is a flow diagram showing a routine for analyzing collected measures sets for use in the method of FIGS. 17A-17B.

#### DETAILED DESCRIPTION

Presently, congestive heart failure is one of the leading causes of cardiovascular disease-related deaths in the world. Clinically, congestive heart failure involves circulatory congestion caused by heart disorders that are primarily characterized by abnormalities of left ventricular function and neurohormonal regulation. Congestive heart failure occurs when these abnormalities cause the heart to fail to pump blood at a rate required by the metabolizing tissues. The effects of congestive heart failure range from impairment during physical exertion to a complete failure of cardiac pumping function at any level of activity. Clinical manifestations of congestive heart failure include respiratory distress, such as shortness of breath and fatigue, and reduced exercise capacity or tolerance.

Several factors make the early diagnosis and prevention of congestive heart failure, as well as the monitoring of the progression of congestive heart failure, relatively difficult. First, the onset of congestive heart failure is generally subtle and erratic. Often, the symptoms are ignored and the patient compensates by changing his or her daily activities. As a result, many congestive heart failure conditions or deteriorations in congestive heart failure remain undiagnosed until more serious problems arise, such as pulmonary edema or cardiac arrest. Moreover, the susceptibility to suffer from congestive heart failure depends upon the patient's age, sex, physical condition, and other factors, such as diabetes, lung disease, high blood pressure, and kidney function. No one factor is dispositive. Finally, annual or even monthly check-ups provide, at best, a "snapshot" of patient wellness and the incremental and subtle clinicophysiological changes which portend the onset or progression of congestive heart failure often go unnoticed, even with regular health care. Documentation of subtle improvements following therapy, that can guide and refine further evaluation and therapy, can be equally elusive.

Nevertheless, taking advantage of frequently and regularly measured physiological measures, such as recorded manually by a patient, via an external monitoring or therapeutic device, or via implantable device technologies, can provide a degree of detection and prevention heretofore unknown. For instance, patients already suffering from some form of treatable heart disease often receive an implantable pulse generator (IPG), cardiovascular or heart failure moni-

tor, therapeutic device, or similar external wearable device, with which rhythm and structural problems of the heart can be monitored and treated. These types of devices are useful for detecting physiological changes in patient conditions through the retrieval and analysis of telemetered signals stored in an on-board, volatile memory.

FIG. 1 is a block diagram showing a system 10 for automated collection and analysis of patient information retrieved from an implantable medical device for remote patient care in accordance with the present invention. A patient 11 is a recipient of an implantable medical device 12, such as, by way of example, an IPG or a heart failure or event monitor, with a set of leads extending into his or her heart. The implantable medical device 12 includes circuitry for recording into a short-term, volatile memory telemetered signals, which are stored as a set of collected measures for later retrieval.

For an exemplary cardiac implantable medical device, the telemetered signals non-exclusively present patient information relating to: atrial electrical activity, ventricular electrical activity, time of day, activity level, cardiac output, oxygen level, cardiovascular pressure measures, the number and types of interventions made, and the relative success of any interventions made on a per heartbeat or binned average basis, plus the status of the batteries and programmed settings. Examples of pacemakers suitable for use in the present invention include the Discovery line of pacemakers, manufactured by Guidant Corporation, Indianapolis, Ind. Examples of ICDs suitable for use in the present invention include the Ventak line of ICDs, also manufactured by Guidant Corporation, Indianapolis, Ind.

In the described embodiment, the patient 11 has a cardiac implantable medical device. However, a wide range of related implantable medical devices are used in other areas of medicine and a growing number of these devices are also capable of measuring and recording patient information for later retrieval. These implantable medical devices include monitoring and therapeutic devices for use in metabolism, endocrinology, hematology, neurology, muscularology, gastro-intestinalogy, genital-urology, ocular, auditory, and similar medical subspecialties. One skilled in the art would readily recognize the applicability of the present invention to these related implantable medical devices.

On a regular basis, the telemetered signals stored in the implantable medical device 12 are retrieved. By way of example, a programmer 14 can be used to retrieve the telemetered signals. However, any form of programmer, interrogator, recorder, monitor, or telemetered signals transceiver suitable for communicating with an implantable medical device 12 could be used, as is known in the art. In addition, a personal computer or digital data processor could be interfaced to the implantable medical device 12, either directly or via a telemetered signals transceiver configured to communicate with the implantable medical device 12.

Using the programmer 14, a magnetized reed switch (not shown) within the implantable medical device 12 closes in response to the placement of a wand 13 over the location of the implantable medical device 12. The programmer 14 communicates with the implantable medical device 12 via RF signals exchanged through the wand 14. Programming or interrogating instructions are sent to the implantable medical device 12 and the stored telemetered signals are downloaded into the programmer 14. Once downloaded, the telemetered signals are sent via an internetwork 15, such as the Internet, to a server system 16 which periodically receives and stores the telemetered signals in a database 17, as further described below with reference to FIG. 2.

An example of a programmer **14** suitable for use in the present invention is the Model 2901 Programmer Recorder Monitor, manufactured by Guidant Corporation, Indianapolis, Ind., which includes the capability to store retrieved telemetered signals on a proprietary removable floppy diskette. The telemetered signals could later be electronically transferred using a personal computer or similar processing device to the internetwork **15**, as is known in the art.

Other alternate telemetered signals transfer means could also be employed. For instance, the stored telemetered signals could be retrieved from the implantable medical device **12** and electronically transferred to the internetwork **15** using the combination of a remote external programmer and analyzer and a remote telephonic communicator, such as described in U.S. Pat. No. 5,113,869, the disclosure of which is incorporated herein by reference. Similarly, the stored telemetered signals could be retrieved and remotely downloaded to the server system **16** using a world-wide patient location and data telemetry system, such as described in U.S. Pat. No. 5,752,976, the disclosure of which is incorporated herein by reference.

The received telemetered signals are analyzed by the server system **16**, which generates a patient status indicator. The feedback is then provided back to the patient **11** through a variety of means. By way of example, the feedback can be sent as an electronic mail message generated automatically by the server system **16** for transmission over the internetwork **15**. The electronic mail message is received by personal computer **18** (PC) situated for local access by the patient **11**. Alternatively, the feedback can be sent through a telephone interface device **19** as an automated voice mail message to a telephone **21** or as an automated facsimile message to a facsimile machine **22**, both also situated for local access by the patient **11**. In addition to a personal computer **18**, telephone **21**, and facsimile machine **22**, feedback could be sent to other related devices, including a network computer, wireless computer, personal data assistant, television, or digital data processor. Preferably, the feedback is provided in a tiered fashion, as further described below with reference to FIG. 3.

FIG. 2 is a block diagram showing the hardware components of the server system **16** of the system **10** of FIG. 1. The server system **16** consists of three individual servers: network server **31**, database server **34**, and application server **35**. These servers are interconnected via an intranetwork **33**. In the described embodiment, the functionality of the server system **16** is distributed among these three servers for efficiency and processing speed, although the functionality could also be performed by a single server or cluster of servers. The network server **31** is the primary interface of the server system **16** onto the internetwork **15**. The network server **31** periodically receives the collected telemetered signals sent by remote implantable medical devices over the internetwork **15**. The network server **31** is interfaced to the internetwork **15** through a router **32**. To ensure reliable data exchange, the network server **31** implements a TCP/IP protocol stack, although other forms of network protocol stacks are suitable.

The database server **34** organizes the patient care records in the database **17** and provides storage of and access to information held in those records. A high volume of data in the form of collected measures sets from individual patients is received. The database server **34** frees the network server **31** from having to categorize and store the individual collected measures sets in the appropriate patient care record.

The application server **35** operates management applications and performs data analysis of the patient care records, as further described below with reference to FIG. 3. The application server **35** communicates feedback to the individual patients either through electronic mail sent back over the internetwork **15** via the network server **31** or as automated voice mail or facsimile messages through the telephone interface device **19**.

The server system **16** also includes a plurality of individual workstations **36** (WS) interconnected to the intranetwork **33**, some of which can include peripheral devices, such as a printer **37**. The workstations **36** are for use by the data management and programming staff, nursing staff, office staff, and other consultants and authorized personnel.

The database **17** consists of a high-capacity storage medium configured to store individual patient care records and related health care information. Preferably, the database **17** is configured as a set of high-speed, high capacity hard drives, such as organized into a Redundant Array of Inexpensive Disks (RAID) volume. However, any form of volatile storage, non-volatile storage, removable storage, fixed storage, random access storage, sequential access storage, permanent storage, erasable storage, and the like would be equally suitable. The organization of the database **17** is further described below with reference to FIG. 3.

The individual servers and workstations are general purpose, programmed digital computing devices consisting of a central processing unit (CPU), random access memory (RAM), non-volatile secondary storage, such as a hard drive or CD ROM drive, network interfaces, and peripheral devices, including user interfacing means, such as a keyboard and display. Program code, including software programs, and data are loaded into the RAM for execution and processing by the CPU and results are generated for display, output, transmittal, or storage. In the described embodiment, the individual servers are Intel Pentium-based server systems, such as available from Dell Computers, Austin, Tex., or Compaq Computers, Houston, Tex. Each system is preferably equipped with 128 MB RAM, 100 GB hard drive capacity, data backup facilities, and related hardware for interconnection to the intranetwork **33** and internetwork **15**. In addition, the workstations **36** are also Intel Pentium-based personal computer or workstation systems, also available from Dell Computers, Austin, Tex., or Compaq Computers, Houston, Tex. Each workstation is preferably equipped with 64 MB RAM, 10 GB hard drive capacity, and related hardware for interconnection to the intranetwork **33**. Other types of server and workstation systems, including personal computers, minicomputers, mainframe computers, supercomputers, parallel computers, workstations, digital data processors and the like would be equally suitable, as is known in the art.

The telemetered signals are communicated over an internetwork **15**, such as the Internet. However, any type of electronic communications link could be used, including an intranetwork link, serial link, data telephone link, satellite link, radio-frequency link, infrared link, fiber optic link, coaxial cable link, television link, and the like, as is known in the art. Also, the network server **31** is interfaced to the internetwork **15** using a T-1 network router **32**, such as manufactured by Cisco Systems, Inc., San Jose, Calif. However, any type of interfacing device suitable for interconnecting a server to a network could be used, including a data modem, cable modem, network interface, serial connection, data port, hub, frame relay, digital PBX, and the like, as is known in the art.

FIG. 3 is a block diagram showing the software modules of the server system 16 of the system 10 of FIG. 1. Each module is a computer program written as source code in a conventional programming language, such as the C or Java programming languages, and is presented for execution by the CPU as object or byte code, as is known in the arts. The various implementations of the source code and object and byte codes can be held on a computer-readable storage medium or embodied on a transmission medium in a carrier wave. There are three basic software modules, which functionally define the primary operations performed by the server system 16: database module 51, analysis module 53, and feedback module 55. In the described embodiment, these modules are executed in a distributed computing environment, although a single server or a cluster of servers could also perform the functionality of the modules. The module functions are further described below in more detail beginning with reference to FIG. 7.

For each patient being provided remote patient care, the server system 16 periodically receives a collected measures set 50 which is forwarded to the database module 51 for processing. The database module 51 organizes the individual patient care records stored in the database 52 and provides the facilities for efficiently storing and accessing the collected measures sets 50 and patient data maintained in those records. An exemplary database schema for use in storing collected measures sets 50 in a patient care record is described below, by way of example, with reference to FIG. 5. The database server 34 (shown in FIG. 2) performs the functionality of the database module 51. Any type of database organization could be utilized, including a flat file system, hierarchical database, relational database, or distributed database, such as provided by database vendors, such as Oracle Corporation, Redwood Shores, Calif.

The analysis module 53 analyzes the collected measures sets 50 stored in the patient care records in the database 52. The analysis module 53 makes an automated determination of patient wellness in the form of a patient status indicator 54. Collected measures sets 50 are periodically received from implantable medical devices and maintained by the database module 51 in the database 52. Through the use of this collected information, the analysis module 53 can continuously follow the medical well being of a patient and can recognize any trends in the collected information that might warrant medical intervention. The analysis module 53 compares individual measures and derived measures obtained from both the care records for the individual patient and the care records for a disease specific group of patients or the patient population in general. The analytic operations performed by the analysis module 53 are further described below with reference to FIG. 4. The application server 35 (shown in FIG. 2) performs the functionality of the analysis module 53.

The feedback module 55 provides automated feedback to the individual patient based, in part, on the patient status indicator 54. As described above, the feedback could be by electronic mail or by automated voice mail or facsimile. Preferably, the feedback is provided in a tiered manner. In the described embodiment, four levels of automated feedback are provided. At a first level, an interpretation of the patient status indicator 54 is provided. At a second level, a notification of potential medical concern based on the patient status indicator 54 is provided. This feedback level could also be coupled with human contact by specially trained technicians or medical personnel. At a third level, the notification of potential medical concern is forwarded to medical practitioners located in the patient's geographic

area. Finally, at a fourth level, a set of reprogramming instructions based on the patient status indicator 54 could be transmitted directly to the implantable medical device to modify the programming instructions contained therein. As is customary in the medical arts, the basic tiered feedback scheme would be modified in the event of bona fide medical emergency. The application server 35 (shown in FIG. 2) performs the functionality of the feedback module 55.

FIG. 4 is a block diagram showing the analysis module 53 of the server system 16 of FIG. 3. The analysis module 53 contains two functional submodules: comparison module 62 and derivation module 63. The purpose of the comparison module 62 is to compare two or more individual measures, either collected or derived. The purpose of the derivation module 63 is to determine a derived measure based on one or more collected measures which is then used by the comparison module 62. For instance, a new and improved indicator of impending heart failure could be derived based on the exemplary cardiac collected measures set described with reference to FIG. 5. The analysis module 53 can operate either in a batch mode of operation wherein patient status indicators are generated for a set of individual patients or in a dynamic mode wherein a patient status indicator is generated on the fly for an individual patient.

The comparison module 62 receives as inputs from the database 17 two input sets functionally defined as peer collected measures sets 60 and sibling collected measures sets 61, although in practice, the collected measures sets are stored on a per sampling basis. Peer collected measures sets 60 contain individual collected measures sets that all relate to the same type of patient information, for instance, atrial electrical activity, but which have been periodically collected over time. Sibling collected measures sets 61 contain individual collected measures sets that relate to different types of patient information, but which may have been collected at the same time or different times. In practice, the collected measures sets are not separately stored as "peer" and "sibling" measures. Rather, each individual patient care record stores multiple sets of sibling collected measures. The distinction between peer collected measures sets 60 and sibling collected measures sets 61 is further described below with reference to FIG. 6.

The derivation module 63 determines derived measures sets 64 on an as-needed basis in response to requests from the comparison module 62. The derived measures 64 are determined by performing linear and non-linear mathematical operations on selected peer measures 60 and sibling measures 61, as is known in the art.

FIG. 5 is a database schema showing, by way of example, the organization of a cardiac patient care record stored 70 in the database 17 of the system 10 of FIG. 1. Only the information pertaining to collected measures sets are shown. Each patient care record would also contain normal identifying and treatment profile information, as well as medical history and other pertinent data (not shown). Each patient care record stores a multitude of collected measures sets for an individual patient. Each individual set represents a recorded snapshot of telemetered signals data which was recorded, for instance, per heartbeat or binned average basis by the implantable medical device 12. For example, for a cardiac patient, the following information would be recorded as a collected measures set: atrial electrical activity 71, ventricular electrical activity 72, time of day 73, activity level 74, cardiac output 75, oxygen level 76, cardiovascular pressure measures 77, pulmonary measures 78, interventions made by the implantable medical device 78, and the relative success of any interventions made 80. In addition,

the implantable medical device **12** would also communicate device specific information, including battery status **81** and program settings **82**. Other types of collected measures are possible. In addition, a well-documented set of derived measures can be determined based on the collected measures, as is known in the art.

FIG. **6** is a record view showing, by way of example, a set of partial cardiac patient care records stored in the database **17** of the system **10** of FIG. **1**. Three patient care records are shown for Patient **1**, Patient **2**, and Patient **3**. For each patient, three sets of measures are shown, X, Y, and Z. The measures are organized into sets with Set **0** representing sibling measures made at a reference time  $t=0$ . Similarly, Set  $n-2$ , Set  $n-1$  and Set  $n$  each represent sibling measures made at later reference times  $t=n-2$ ,  $t=n-1$  and  $t=n$ , respectively.

For a given patient, for instance, Patient **1**, all measures representing the same type of patient information, such as measure X, are peer measures. These are measures, which are monitored over time in a disease-matched peer group. All measures representing different types of patient information, such as measures X, Y, and Z, are sibling measures. These are measures which are also measured over time, but which might have medically significant meaning when compared to each other within a single set. Each of the measures, X, Y, and Z could be either collected or derived measures.

The analysis module **53** (shown in FIG. **4**) performs two basic forms of comparison. First, individual measures for a given patient can be compared to other individual measures for that same patient. These comparisons might be peer-to-peer measures projected over time, for instance,  $X_n, X_{n-1}, X_{n-2}, \dots, X_0$ , or sibling-to-sibling measures for a single snapshot, for instance,  $X_n, Y_n$ , and  $Z_n$ , or projected over time, for instance,  $X_n, Y_n, Z_n, X_{n-1}, Y_{n-1}, Z_{n-1}, X_{n-2}, Y_{n-2}, Z_{n-2}, \dots, X_0, Y_0, Z_0$ . Second, individual measures for a given patient can be compared to other individual measures for a group of other patients sharing the same disease-specific characteristics or to the patient population in general. Again, these comparisons might be peer-to-peer measures projected over time, for instance,  $X_n, X_n', X_n'', X_{n-1}, X_{n-1}', X_{n-1}'', X_{n-2}, X_{n-2}', X_{n-2}'', \dots, X_0, X_0', X_0''$ , or comparing the individual patient's measures to an average from the group. Similarly, these comparisons might be sibling-to-sibling measures for single snapshots, for instance,  $X_n, X_n', X_n'', Y_n, Y_n', Y_n'',$  and  $Z_n, Z_n', Z_n''$ , or projected over time, for instance,  $X_n, X_n', X_n'', Y_n, Y_n', Y_n'', Z_n, Z_n', Z_n'', X_{n-1}, X_{n-1}', X_{n-1}'', Y_{n-1}, Y_{n-1}', Y_{n-1}'', Z_{n-1}, Z_{n-1}', Z_{n-1}'', X_{n-2}, X_{n-2}', X_{n-2}'', Y_{n-2}, Y_{n-2}', Y_{n-2}'', Z_{n-2}, Z_{n-2}', Z_{n-2}'', \dots, X_0, X_0', X_0'', Y_0, Y_0', Y_0'',$  and  $Z_0, Z_0', Z_0''$ . Other forms of comparisons are feasible.

FIG. **7** is a flow diagram showing a method **90** for automated collection and analysis of patient information retrieved from an implantable medical device **12** for remote patient care in accordance with the present invention. The method **90** is implemented as a conventional computer program for execution by the server system **16** (shown in FIG. **1**). As a preparatory step, the patient care records are organized in the database **17** with a unique patient care record assigned to each individual patient (block **91**). Next, the collected measures sets for an individual patient are retrieved from the implantable medical device **12** (block **92**) using a programmer, interrogator, telemetered signals transceiver, and the like. The retrieved collected measures sets are sent, on a substantially regular basis, over the internetwork **15** or similar communications link (block **93**) and periodically received by the server system **16** (block **94**). The collected measures sets are stored into the patient care record in the database **17** for that individual patient (block **95**). One or more of the collected measures sets for that

patient are analyzed (block **96**), as further described below with reference to FIG. **8**. Finally, feedback based on the analysis is sent to that patient over the internetwork **15** as an email message, via telephone line as an automated voice mail or facsimile message, or by similar feedback communications link (block **97**), as further described below with reference to FIG. **11**.

FIG. **8** is a flow diagram showing the routine for analyzing collected measures sets **96** for use in the method of FIG. **7**. The purpose of this routine is to make a determination of general patient wellness based on comparisons and heuristic trends analyses of the measures, both collected and derived, in the patient care records in the database **17**. A first collected measures set is selected from a patient care record in the database **17** (block **100**). If the measures comparison is to be made to other measures originating from the patient care record for the same individual patient (block **101**), a second collected measures set is selected from that patient care record (block **102**). Otherwise, a group measures comparison is being made (block **101**) and a second collected measures set is selected from another patient care record in the database **17** (block **103**). Note the second collected measures set could also contain averaged measures for a group of disease specific patients or for the patient population in general.

Next, if a sibling measures comparison is to be made (block **104**), a routine for comparing sibling collected measures sets is performed (block **105**), as further described below with reference to FIG. **9**. Similarly, if a peer measures comparison is to be made (block **106**), a routine for comparing sibling collected measures sets is performed (block **107**), as further described below with reference to FIGS. **10A** and **10B**.

Finally, a patient status indicator is generated (block **108**). By way of example, cardiac output could ordinarily be approximately 5.0 liters per minute with a standard deviation of  $\pm 1.0$ . An actionable medical phenomenon could occur when the cardiac output of a patient is  $\pm 3.0$ -4.0 standard deviations out of the norm. A comparison of the cardiac output measures **75** (shown in FIG. **5**) for an individual patient against previous cardiac output measures **75** would establish the presence of any type of downward health trend as to the particular patient. A comparison of the cardiac output measures **75** of the particular patient to the cardiac output measures **75** of a group of patients would establish whether the patient is trending out of the norm. From this type of analysis, the analysis module **53** generates a patient status indicator **54** and other metrics of patient wellness, as is known in the art.

FIG. **9** is a flow diagram showing the routine for comparing sibling collected measures sets **105** for use in the routine of FIG. **8**. Sibling measures originate from the patient care records for an individual patient. The purpose of this routine is either to compare sibling derived measures to sibling derived measures (blocks **111-113**) or sibling collected measures to sibling collected measures (blocks **115-117**). Thus, if derived measures are being compared (block **110**), measures are selected from each collected measures set (block **111**). First and second derived measures are derived from the selected measures (block **112**) using the derivation module **63** (shown in FIG. **4**). The first and second derived measures are then compared (block **113**) using the comparison module **62** (also shown in FIG. **4**). The steps of selecting, determining, and comparing (blocks **111-113**) are repeated until no further comparisons are required (block **114**), whereupon the routine returns.

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If collected measures are being compared (block 110), measures are selected from each collected measures set (block 115). The first and second collected measures are then compared (block 116) using the comparison module 62 (also shown in FIG. 4). The steps of selecting and comparing (blocks 115-116) are repeated until no further comparisons are required (block 117), whereupon the routine returns.

FIGS. 10A and 10B are a flow diagram showing the routine for comparing peer collected measures sets 107 for use in the routine of FIG. 8. Peer measures originate from patient care records for different patients, including groups of disease specific patients or the patient population in general. The purpose of this routine is to compare peer derived measures to peer derived measures (blocks 122-125), peer derived measures to peer collected measures (blocks 126-129), peer collected measures to peer derived measures (block 131-134), or peer collected measures to peer collected measures (blocks 135-137). Thus, if the first measure being compared is a derived measure (block 120) and the second measure being compared is also a derived measure (block 121), measures are selected from each collected measures set (block 122). First and second derived measures are derived from the selected measures (block 123) using the derivation module 63 (shown in FIG. 4). The first and second derived measures are then compared (block 124) using the comparison module 62 (also shown in FIG. 4). The steps of selecting, determining, and comparing (blocks 122-124) are repeated until no further comparisons are required (block 115), whereupon the routine returns.

If the first measure being compared is a derived measure (block 120) but the second measure being compared is a collected measure (block 121), a first measure is selected from the first collected measures set (block 126). A first derived measure is derived from the first selected measure (block 127) using the derivation module 63 (shown in FIG. 4). The first derived and second collected measures are then compared (block 128) using the comparison module 62 (also shown in FIG. 4). The steps of selecting, determining, and comparing (blocks 126-128) are repeated until no further comparisons are required (block 129), whereupon the routine returns.

If the first measure being compared is a collected measure (block 120) but the second measure being compared is a derived measure (block 130), a second measure is selected from the second collected measures set (block 131). A second derived measure is derived from the second selected measure (block 132) using the derivation module 63 (shown in FIG. 4). The first collected and second derived measures are then compared (block 133) using the comparison module 62 (also shown in FIG. 4). The steps of selecting, determining, and comparing (blocks 131-133) are repeated until no further comparisons are required (block 134), whereupon the routine returns.

If the first measure being compared is a collected measure (block 120) and the second measure being compared is also a collected measure (block 130), measures are selected from each collected measures set (block 135). The first and second collected measures are then compared (block 136) using the comparison module 62 (also shown in FIG. 4). The steps of selecting and comparing (blocks 135-136) are repeated until no further comparisons are required (block 137), whereupon the routine returns.

FIG. 11 is a flow diagram showing the routine for providing feedback 97 for use in the method of FIG. 7. The purpose of this routine is to provide tiered feedback based on the patient status indicator. Four levels of feedback are provided with increasing levels of patient involvement and

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medical care intervention. At a first level (block 150), an interpretation of the patient status indicator 54, preferably phrased in lay terminology, and related health care information is sent to the individual patient (block 151) using the feedback module 55 (shown in FIG. 3). At a second level (block 152), a notification of potential medical concern, based on the analysis and heuristic trends analysis, is sent to the individual patient (block 153) using the feedback module 55. At a third level (block 154), the notification of potential medical concern is forwarded to the physician responsible for the individual patient or similar health care professionals (block 155) using the feedback module 55. Finally, at a fourth level (block 156), reprogramming instructions are sent to the implantable medical device 12 (block 157) using the feedback module 55.

Therefore, through the use of the collected measures sets, the present invention makes possible immediate access to expert medical care at any time and in any place. For example, after establishing and registering for each patient an appropriate baseline set of measures, the database server could contain a virtually up-to-date patient history, which is available to medical providers for the remote diagnosis and prevention of serious illness regardless of the relative location of the patient or time of day.

Moreover, the gathering and storage of multiple sets of critical patient information obtained on a routine basis makes possible treatment methodologies based on an algorithmic analysis of the collected data sets. Each successive introduction of a new collected measures set into the database server would help to continually improve the accuracy and effectiveness of the algorithms used. In addition, the present invention potentially enables the detection, prevention, and cure of previously unknown forms of disorders based on a trends analysis and by a cross-referencing approach to create continuously improving peer-group reference databases.

Finally, the present invention makes possible the provision of tiered patient feedback based on the automated analysis of the collected measures sets. This type of feedback system is suitable for use in, for example, a subscription based health care service. At a basic level, informational feedback can be provided by way of a simple interpretation of the collected data. The feedback could be built up to provide a graduated response to the patient, for example, to notify the patient that he or she is trending into a potential trouble zone. Human interaction could be introduced, both by remotely situated and local medical practitioners. Finally, the feedback could include direct interventive measures, such as remotely reprogramming a patient's IPG.

FIG. 12 is a block diagram showing a system for automated collection and analysis of regularly retrieved patient information for remote patient care 200 in accordance with a further embodiment of the present invention. The system 200 provides remote patient care in a manner similar to the system 10 of FIG. 1, but with additional functionality for diagnosing and monitoring multiple sites within a patient's body using a variety of patient sensors for diagnosing one or more disorder. The patient 201 can be the recipient of an implantable medical device 202, as described above, or have an external medical device 203 attached, such as a Holter monitor-like device for monitoring electrocardiograms. In addition, one or more sites in or around the patient's body can be monitored using multiple sensors 204a, 204b, such as described in U.S. Pat. Nos. 4,987,897; 5,040,536; 5,113,859; and 5,987,352, the disclosures of which are incorporated herein by reference. Other types of devices with physiological measure sensors, both heterogeneous and homogenous,



could be used, either within the same device or working in conjunction with each other, as is known in the art.

As part of the system 200, the database 17 stores patient care records 205 for each individual patient to whom remote patient care is being provided. Each patient care record 205 contains normal patient identification and treatment profile information, as well as medical history, medications taken, height and weight, and other pertinent data (not shown). The patient care records 205 consist primarily of monitoring sets 206 storing device and derived measures (D&DM) sets 207 and quality of life and symptom measures (QOLM) sets 208 recorded and determined thereafter on a regular, continuous basis. The organization of the device and derived measures sets 205 for an exemplary cardiac patient care record is described above with reference to FIG. 5. The organization of the quality of life and symptom measures sets 208 is further described below with reference to FIG. 14.

Optionally, the patient care records 205 can further include a reference baseline 209 storing a special set of device and derived reference measures sets 210 and quality of life and symptom measures sets 211 recorded and determined during an initial observation period, such as described in the related, commonly-owned U.S. Pat. No. 6,280,380, issued Aug. 28, 2001, the disclosure of which is incorporated herein by reference. Other forms of database organization are feasible.

Finally, simultaneous notifications can also be delivered to the patient's physician, hospital, or emergency medical services provider 212 using feedback means similar to that used to notify the patient. As described above, the feedback could be by electronic mail or by automated voice mail or facsimile. The feedback can also include normalized voice feedback, such as described in the related, commonly-owned U.S. Pat. No. 6,261,230, issued Jul. 17, 2001, the disclosure of which is incorporated herein by reference.

FIG. 13 is a block diagram showing the analysis module 53 of the server system 16 of FIG. 12. The peer collected measures sets 60 and sibling collected measures sets 61 can be organized into site specific groupings based on the sensor from which they originate, that is, implantable medical device 202, external medical device 203, or multiple sensors 204a, 204b. The functionality of the analysis module 53 is augmented to iterate through a plurality of site specific measures sets 215 and one or more disorders.

As an adjunct to remote patient care through the monitoring of measured physiological data via implantable medical device 202, external medical device 203 and multiple sensors 204a, 204b, quality of life and symptom measures sets 208 can also be stored in the database 17 as part of the monitoring sets 206. A quality of life measure is a semi-quantitative self-assessment of an individual patient's physical and emotional well-being and a record of symptoms, such as provided by the Duke Activities Status Indicator. These scoring systems can be provided for use by the patient 11 on the personal computer 18 (shown in FIG. 1) to record his or her quality of life scores for both initial and periodic download to the server system 16. FIG. 14 is a database schema showing, by way of example, the organization of a quality of life and symptom measures set record 220 for care of patients stored as part of a patient care record 205 in the database 17 of the system 200 of FIG. 12. The following exemplary information is recorded for a patient: overall health wellness 221, psychological state 222, chest discomfort 223, location of chest discomfort 224, palpitations 225, shortness of breath 226, exercise tolerance 227, cough 228, sputum production 229, sputum color 230, energy level 231, syncope 232, near syncope 233, nausea 234, diaphoresis

235, time of day 91, and other quality of life and symptom measures as would be known to one skilled in the art.

Other types of quality of life and symptom measures are possible, such as those indicated by responses to the Minnesota Living with Heart Failure Questionnaire described in E. Braunwald, ed., "Heart Disease—A Textbook of Cardiovascular Medicine," pp. 452-454, W. B. Saunders Co. (1997), the disclosure of which is incorporated herein by reference. Similarly, functional classifications based on the relationship between symptoms and the amount of effort required to provoke them can serve as quality of life and symptom measures, such as the New York Heart Association (NYHA) classifications I, II, III and IV, also described in *Ibid*.

The patient may also add non-device quantitative measures, such as the six-minute walk distance, as complementary data to the device and derived measures sets 207 and the symptoms during the six-minute walk to quality of life and symptom measures sets 208.

FIG. 15 is a record view showing, by way of example, a set of partial cardiac patient care records stored in the database 17 of the system 200 of FIG. 12. Three patient care records are again shown for Patient 1, Patient 2, and Patient 3 with each of these records containing site specific measures sets 215, grouped as follows. First, the patient care record for Patient 1 includes three site specific measures sets A, B and C, corresponding to three sites on Patient 1's body. Similarly, the patient care record for Patient 2 includes two site specific measures sets A and B, corresponding to two sites, both of which are in the same relative positions on Patient 2's body as the sites for Patient 1. Finally, the patient care record for Patient 3 includes two site specific measures sets A and D, also corresponding to two medical device sensors, only one of which, Site A, is in the same relative position as Site A for Patient 1 and Patient 2.

The analysis module 53 (shown in FIG. 13) performs two further forms of comparison in addition to comparing the individual measures for a given patient to other individual measures for that same patient or to other individual measures for a group of other patients sharing the same disease-specific characteristics or to the patient population in general. First, the individual measures corresponding to each body site for an individual patient can be compared to other individual measures for that same patient, a peer group or a general patient population. Again, these comparisons might be peer-to-peer measures projected over time, for instance, comparing measures for each site, A, B and C, for Patient 1,  $X_{n,A}, X_{n',A}, X_{n'',A}, X_{n-1,A}, X_{n-1',A}, X_{n-1'',A}, X_{n-2,A}, X_{n-2',A}, X_{n-2'',A}, \dots$   $X_{0,A}, X_{0',A}, X_{0'',A}; X_{n,B}, X_{n',B}, X_{n'',B}, X_{n-1,B}, X_{n-1',B}, X_{n-1'',B}, X_{n-2,B}, X_{n-2',B}, X_{n-2'',B}, \dots X_{0,B}, X_{0',B}, X_{0'',B}; X_{n,C}, X_{n',C}, X_{n'',C}, X_{n-1,C}, X_{n-1',C}, X_{n-1'',C}, X_{n-2,C}, X_{n-2',C}, X_{n-2'',C}, \dots X_{0,C}, X_{0',C}, X_{0'',C}$ ; comparing comparable measures for Site A for the three patients,  $X_{n,A}, X_{n',A}, X_{n'',A}, X_{n-1,A}, X_{n-1',A}, X_{n-1'',A}, X_{n-2,A}, X_{n-2',A}, X_{n-2'',A}, \dots X_{0,A}, X_{0',A}, X_{0'',A}$ ; or comparing the individual patient's measures to an average from the group. Similarly, these comparisons might be sibling-to-sibling measures for single snapshots, for instance, comparing comparable measures for Site A for the three patients,  $X_{n,A}, X_{n',A}, X_{n'',A}$  and  $Z_{n,A}, Z_{n',A}, Z_{n'',A}$ , or comparing those same comparable measures for Site A projected over time, for instance,  $X_{n,A}, X_{n',A}, X_{n'',A}, Y_{n,A}, Y_{n',A}, Y_{n'',A}, Z_{n,A}, Z_{n',A}, Z_{n'',A}, X_{n-1,A}, X_{n-1',A}, X_{n-1'',A}, Y_{n-1,A}, Y_{n-1',A}, Y_{n-1'',A}, Z_{n-1,A}, Z_{n-1',A}, Z_{n-1'',A}, X_{n-2,A}, X_{n-2',A}, X_{n-2'',A}, Y_{n-2,A}, Y_{n-2',A}, Y_{n-2'',A}, Z_{n-2,A}, Z_{n-2',A}, Z_{n-2'',A}, \dots X_{0,A}, X_{0',A}, X_{0'',A}, Y_{0,A}, Y_{0',A}, Y_{0'',A}$  and  $Z_{0,A}, Z_{0',A}, Z_{0'',A}$ . Other forms of site-specific comparisons, including comparisons between individual measures from non-comparable sites between patients, are feasible.



Second, the individual measures can be compared on a disorder specific basis. The individual measures stored in each cardiac patient record can be logically grouped into measures relating to specific disorders and diseases, for instance, congestive heart failure, myocardial infarction, respiratory distress, and atrial fibrillation. The foregoing comparison operations performed by the analysis module 53 are further described below with reference to FIGS. 17A-17B.

FIG. 16 is a Venn diagram showing, by way of example, peer group overlap between the partial patient care records 205 of FIG. 15. Each patient care record 205 includes characteristics data 250, 251, 252, including personal traits, demographics, medical history, and related personal data, for patients 1, 2 and 3, respectively. For example, the characteristics data 250 for patient 1 might include personal traits which include gender and age, such as male and an age between 40-45; a demographic of resident of New York City; and a medical history consisting of anterior myocardial infarction, congestive heart failure and diabetes. Similarly, the characteristics data 251 for patient 2 might include identical personal traits, thereby resulting in partial overlap 253 of characteristics data 250 and 251. Similar characteristics overlap 254, 255, 256 can exist between each respective patient. The overall patient population 257 would include the universe of all characteristics data. As the monitoring population grows, the number of patients with personal traits matching those of the monitored patient will grow, increasing the value of peer group referencing. Large peer groups, well matched across all monitored measures, will result in a well known natural history of disease and will allow for more accurate prediction of the clinical course of the patient being monitored. If the population of patients is relatively small, only some traits 256 will be uniformly present in any particular peer group. Eventually, peer groups, for instance, composed of 100 or more patients each, would evolve under conditions in which there would be complete overlap of substantially all salient data, thereby forming a powerful core reference group for any new patient being monitored.

FIGS. 17A-17B are flow diagrams showing a method for automated collection and analysis of regularly retrieved patient information for remote patient care 260 in accordance with a further embodiment of the present invention. As with the method 90 of FIG. 7, this method is also implemented as a conventional computer program and performs the same set of steps as described with reference to FIG. 7 with the following additional functionality. As before, the patient care records are organized in the database 17 with a unique patient care record assigned to each individual patient (block 261). Next, the individual measures for each site are iteratively obtained in a first processing loop (blocks 262-267) and each disorder is iteratively analyzed in a second processing loop (blocks 268-270). Other forms of flow control are feasible, including recursive processing.

During each iteration of the first processing loop (blocks 262-267), the collected measures sets for an individual patient are retrieved from the medical device or sensor located at the current site (block 263) using a programmer, interrogator, telemetered signals transceiver, and the like. The retrieved collected measures sets are sent, on a substantially regular basis, over the internetwork 15 or similar communications link (block 264) and periodically received by the server system 16 (block 265). The collected measures sets are stored into the patient care record 205 in the database 17 for that individual patient (block 266).

During each iteration of the second processing loop (blocks 268-270), one or more of the collected measures sets for that patient are analyzed for the current disorder (block 269), as further described below with reference to FIG. 18. Finally, feedback based on the analysis is sent to that patient over the internetwork 15 as an email message, via telephone line as an automated voice mail or facsimile message, or by similar feedback communications link (block 97), as further described above with reference to FIG. 11.

FIG. 18 is a flow diagram showing a routine for analyzing collected measures sets 270 for use in the method 260 of FIGS. 17A-17B. The purpose of this routine is to make a determination of general patient wellness based on comparisons and heuristic trends analyses of the device and derived measures and quality of life and symptom measures in the patient care records 205 in the database 17. A first collected measures set is selected from a patient care record in the database 17 (block 290). The selected measures set can either be compared to other measures originating from the patient care record for the same individual patient or to measures from a peer group of disease specific patients or for the patient population in general (block 291). If the first collected measures set is being compared within an individual patient care record (block 291), the selected measures set can either be compared to measures from the same site or from another site (block 292). If from the same site (block 292), a second collected measures set is selected for the current site from that patient care record (block 293). Otherwise, a second collected measures set is selected for another site from that patient care record (block 294). Similarly, if the first collected measures set is being compared within a group (block 291), the selected measures set can either be compared to measures from the same comparable site or from another site (block 295). If from the same comparable site (block 295), a second collected measures set is selected for a comparable site from another patient care record (block 296). Otherwise, a second collected measures set is selected for another site from another patient care record (block 297). Note the second collected measures set could also contain averaged measures for a group of disease specific patients or for the patient population in general.

Next, if a sibling measures comparison is to be made (block 298), the routine for comparing sibling collected measures sets is performed (block 105), as further described above with reference to FIG. 9. Similarly, if a peer measures comparison is to be made (block 299), the routine for comparing sibling collected measures sets is performed (block 107), as further described above with reference to FIGS. 10A and 10B.

Finally, a patient status indicator is generated (block 300), as described above with reference to FIG. 8. In addition, the measures sets can be further evaluated and matched to diagnose specific medical disorders, such as congestive heart failure, myocardial infarction, respiratory distress, and atrial fibrillation, as described in related, commonly-owned U.S. Pat. No. 6,336,903, issued Jan. 8, 2002; U.S. Pat. No. 6,368,284, issued Apr. 9, 2002; U.S. Pat. No. 6,398,728, issued Jun. 4, 2002; and U.S. Pat. No. 6,411,840, issued Jun. 25, 2002, the disclosures of which are incorporated herein by reference. In addition, multiple near-simultaneous disorders can be ordered and prioritized as part of the patient status indicator as described in the related, commonly-owned U.S. Pat. No. 6,440,066, issued Aug. 27, 2002, the disclosure of which is incorporated herein by reference.

While the invention has been particularly shown and described as referenced to the embodiments thereof, those skilled in the art will understand that the foregoing and other

changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A computer-implemented system for evaluating a patient status for use in heart failure assessment, comprising:
  - a data module configured to assemble physiological measures which were electronically stored in a memory and directly recorded as data on a substantially continuous basis by medical device for a patient or indirectly derived from the data, wherein the physiological measures comprise measures for the patient and one or more of measures for a peer group of disease specific patients and measures for an overall patient population;
  - a status module configured to sample the physiological measures over a plurality of data assembly points;
  - an evaluation module configured to evaluate and match at each data assembly point the sampled physiological measures to determine a patient status indicator;
  - a diagnosis module configured to determine one of a status quo and a change in cardiac performance of the patient and compare the change in the cardiac performance to worsening heart failure indications;
  - a quality of life module configured to query the patient on a regular basis and collect quality of life measures and to chronicle the quality of life measures with the physiological measures; and
  - a feedback module configured to provide tiered feedback based on the patient status indicator comprising:
    - a first level module configured to communicate, at a first level, an interpretation of the change in the cardiac performance;
    - a second level module configured to communicate, at a second level, a notification of potential medical concern based on the change in the cardiac performance to the patient;
    - a third level module configured to communicate, at a third level, a notification of potential medical concern based on the change in the cardiac performance to medical personnel; and
    - a fourth level module configured to communicate to a patient medical device of the patient, at a fourth level, a set of reprogramming instructions based on the change in the cardiac performance;

wherein the tiered feedback has increasing levels of patient involvement and medical care intervention.
2. A system according to claim 1, wherein the change in cardiac performance is selected from the group comprising an onset, progression, and regression of a cardiac performance parameter.
3. A system according to claim 1, wherein the worsening heart failure indications are selected from the group comprising pulmonary artery pressure, left atrial pressure, dyspnea, orthopnea, pulmonary edema, peripheral edema, and fatigue.
4. A system according to claim 1, further comprising:
  - a measurement module configured to measure one or more of pulmonary artery pressure, heart rate, heart sounds, intrathoracic impedance, respiration, posture, lung fluid, activity, weight, and physiological response to activity.
5. A system according to claim 1, further comprising:
  - a reprogramming module configured to reprogram the patient medical device based on the patient status indicator.
6. A system according to claim 5, wherein the worsening heart failure indications are factored into the reprogramming of the patient medical device.

7. A system according to claim 1, wherein respiration rate is tracked through the patient medical device, further comprising:

a notification module configured to generate a notification triggered by a parameter assigned to the respiration rate.

8. A system according to claim 7, wherein the parameter comprises one or more of an upper limit parameter applied over a short term and a counter parameter applied over a long term.

9. A system according to claim 1, wherein the medical device comprises one of an implantable medical device and an external medical device.

10. A computer-implemented method for evaluating a patient status for use in heart failure assessment, comprising:
 

- assembling physiological measures electronically stored in a memory and directly recorded as data on a substantially continuous basis by a medical device for a patient or indirectly derived from the data, wherein the physiological measures comprise measures for the patient and one or more of measures for a peer group of disease specific patients and measures for an overall patient population;
- sampling the physiological measures over a plurality of data assembly points;
- at each data assembly point, evaluating and matching the sampled physiological measures to form a patient status indicator;
- determining one of a status quo and a change in cardiac performance of the patient and comparing the change in the cardiac performance to worsening heart failure indications;
- querying the patient on a regular basis to collect quality of life measures;
- chronicling the quality of life measures with the physiological measures; and
- providing tiered feedback based on the patient status indicator comprising:
  - at a first level, communicating an interpretation of the change in the cardiac performance;
  - at a second level, communicating a notification of potential medical concern based on the change in the cardiac performance to the patient;
  - at a third level, communicating a notification of potential medical concern based on the change in the cardiac performance to medical personnel; and
  - at a fourth level, communicating to a patient medical device a set of reprogramming instructions based on the change in the cardiac performance;

wherein the tiered feedback has increasing levels of patient involvement and medical care intervention.

11. A method according to claim 10, wherein the change in cardiac performance is selected from the group comprising an onset, progression, and regression of a cardiac performance parameter.

12. A method according to claim 10, wherein the worsening heart failure indications are selected from the group comprising pulmonary artery pressure, left atrial pressure, dyspnea, orthopnea, pulmonary edema, peripheral edema, and fatigue.

13. A method according to claim 10, further comprising:
 

- measuring one or more of pulmonary artery pressure, heart rate, heart sounds, intrathoracic impedance, respiration, posture, lung fluid, activity, weight, and physiological response to activity.

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14. A method according to claim 10, further comprising: reprogramming the patient medical device based on the patient status indicator.
15. A method according to claim 14, further comprising: factoring the worsening heart failure indications into the reprogramming of the patient medical device.
16. A method according to claim 10, further comprising: tracking respiration rate through the patient medical device; and generating a notification triggered by a parameter assigned to the respiration rate.
17. A method according to claim 16, wherein the parameter comprises one or more of an upper limit parameter applied over a short term and a counter parameter applied over a long term.
18. A method according to claim 10, wherein the medical device comprise one of an implantable medical device and an external medical device.
19. A computer-implemented system for evaluating a patient status indicator from sampled physiometry for use in heart failure assessment, comprising:
- a storage module configured to electronically store physiological measures in a memory, the physiological measures comprising at least one of direct measures regularly recorded on a substantially continuous basis by a medical device for a patient and measures derived from the direct measures, wherein the physiological measures comprise measures for the patient and one or more of measures for a peer group of disease specific patients and measures for an overall patient population;
  - a sampling module configured to sample at least one of those of the physiological measures, which each relate to a same type of physiometry, and those of the physiological measures, which each relate to a different type of physiometry;
  - a status module configured to analyze the sampled physiological measures assembled from a plurality of recordation points;
  - an evaluation module configured to evaluate each of a status quo and a change in the sampled physiological measures affecting cardiac performance of the patient;
  - a diagnostic module configured to determine one of a status quo and a change in cardiac performance of the patient and compare the change in the cardiac performance to worsening heart failure indications;
  - a quality of life module configured to query the patient on a regular basis and collect quality of life measures and to chronicle the quality of life measures with the physiological measures; and
  - a feedback module configured to provide tiered feedback based on the change in cardiac performance comprising:
    - a first level module configured to communicate, at a first level, an interpretation of the change in the sampled physiological measures affecting cardiac performance;
    - a second level module configured to communicate, at a second level, a notification of potential medical concern based on the change in the sampled physiological measures affecting cardiac performance to the patient;
    - a third level module configured to communicate, at a third level, a notification of potential medical concern based on the change in the sampled physiological measures affecting cardiac performance to medical personnel; and

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- a fourth level module configured to communicate to a patient medical device, at a fourth level, a set of reprogramming instructions based on the change in the sampled physiological measures affecting cardiac performance;
  - wherein the tiered feedback has increasing levels of patient involvement and medical care intervention; and
  - an alerting module configured to generate a notification of parameter violations by the change in the sampled physiological measures affecting at least one of pulmonary artery pressure, left atrial pressure, dyspnea, orthopnea, pulmonary edema, peripheral edema, and fatigue.
20. A system according to claim 19, further comprising: a reprogramming module configured to reprogram the patient medical device based on extended evaluation of the direct measures and the derived measures.
21. A system according to claim 19, further comprising: a tracking module configured to track respiration rate of the patient on a regular basis through the medical device; and a notification module configured to generate a notification triggered by one or more of an upper limit parameter applied over a short term and a counter parameter applied over a long term.
22. A computer-implemented method for evaluating a patient status indicator from sampled physiometry for use in heart failure assessment, comprising:
- electronically storing physiological measures in a memory, the physiological measures comprising at least one of direct measures regularly recorded on a substantially continuous basis by a medical device for a patient and measures derived from the direct measures, wherein the physiological measures comprise measures for the patient and one or more of measures for a peer group of disease specific patients and measures for an overall patient population;
  - sampling at least one of those of the physiological measures, which each relate to a same type of physiometry, and those of the physiological measures, which each relate to a different type of physiometry;
  - matching the sampled physiological measures assembled from a plurality of recordation points;
  - evaluating each of a status quo and a change in the sampled physiological measures affecting cardiac performance of the patient;
  - determining one of a status quo and a change in cardiac performance of the patient and comparing the change in the cardiac performance to worsening heart failure indications;
  - querying the patient on a regular basis to collect quality of life measures;
  - chronicling the quality of life measures with the physiological measures; and
  - providing tiered feedback based on the change in the cardiac performance comprising:
    - at a first level, communicating an interpretation of the change in the sampled physiological measures affecting cardiac performance;
    - at a second level, communicating a notification of potential medical concern based on the change in the sampled physiological measures affecting cardiac performance to the patient;
    - at a third level, communicating a notification of potential medical concern based on the change in the

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sampled physiological measures affecting cardiac performance to medical personnel; and  
at a fourth level, communicating to a patient medical device a set of reprogramming instructions based on the change in the sampled physiological measures 5 affecting cardiac performance;  
wherein the tiered feedback has increasing levels of patient involvement and medical care intervention; and  
generating a notification of parameter violations by the 10 change in the sampled physiological measures affecting at least one of pulmonary artery pressure, left atrial pressure, dyspnea, orthopnea, pulmonary edema, peripheral edema, and fatigue.

23. A method according to claim 22, further comprising: 15 reprogramming the patient medical device based on extended evaluation of the direct measures and the derived measures.

24. A method according to claim 22, further comprising: tracking respiration rate of the patient on a regular basis 20 through the patient medical device; and  
generating a notification triggered by one or more of an upper limit parameter applied over a short term and a counter parameter applied over a long term.

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专利名称(译)	用于评估患者状态以用于心力衰竭评估的系统和方法		
公开(公告)号	<a href="#">US9526456</a>	公开(公告)日	2016-12-27
申请号	US11/894281	申请日	2007-08-20
[标]申请(专利权)人(译)	BARDY GUST ^ h		
申请(专利权)人(译)	BARDY GUST ^ h		
当前申请(专利权)人(译)	心脏起搏器，INC.		
[标]发明人	BARDY GUST H		
发明人	BARDY, GUST H.		
IPC分类号	A61N5/00 A61B5/0205 G06F19/00 A61B5/00 A61N1/39 A61B7/02 A61B5/11 A61B5/021 G06Q50/24 A61B5/02 A61N1/372 A61B5/145 A61B5/08 A61B5/0215 A61B5/0432 G16H10/60		
CPC分类号	A61B5/7275 A61B5/0002 A61B5/0006 A61B5/0022 A61B5/0031 A61B5/021 A61B5/0205 A61B5/02028 A61B5/1116 A61B5/1118 A61B5/4878 A61B5/686 A61B5/7246 A61B5/746 A61B7/02 A61N1/37258 A61N1/3962 G06F19/322 G06F19/345 G06F19/3418 G06F19/3431 G06F19/3487 G06Q50/24 A61B5/0215 A61B5/0432 A61B5/0826 A61B5/145 A61N1/37282 Y10S128/92 A61N1/39622 G16H10/60 G16H15/00 G16H40/67 G16H50/20 G16H50/30		
优先权	10/422495 2006-07-04 US 09/860977 2005-12-13 US 09/476602 2001-08-07 US 09/324894 2001-11-06 US		
其他公开文献	US20070293738A1		
外部链接	<a href="#">Espacenet</a> <a href="#">USPTO</a>		

# 摘要(译)

提出了一种用于从采样的健康测量中评估患者状态以用于心力衰竭评估的系统和方法。存储生理措施，包括由医疗装置基本上连续地定期记录的直接措施和从直接措施得到的措施中的至少一种。对与相同类型的生理测量相关的那些生理测量中的至少一个和与不同类型的生理测量相关的生理测量中的至少一个进行采样。通过分析从多个记录点组装的那些采样测量值来确定患者的状态。评估采样的措施。识别由患者状态指示的趋势，包括可能影响患者的心脏性能的现状和变化之一。将每种趋势与恶化的心力衰竭指征进行比较，以生成参数违规的通知。

