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(54) **PHYSIOLOGICAL OBJECT DISPLAYS**

Publication Classification

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(52) **U.S. Cl. 600/300; 600/483; 600/526; 600/529; 128/200.24**

(57) **ABSTRACT**

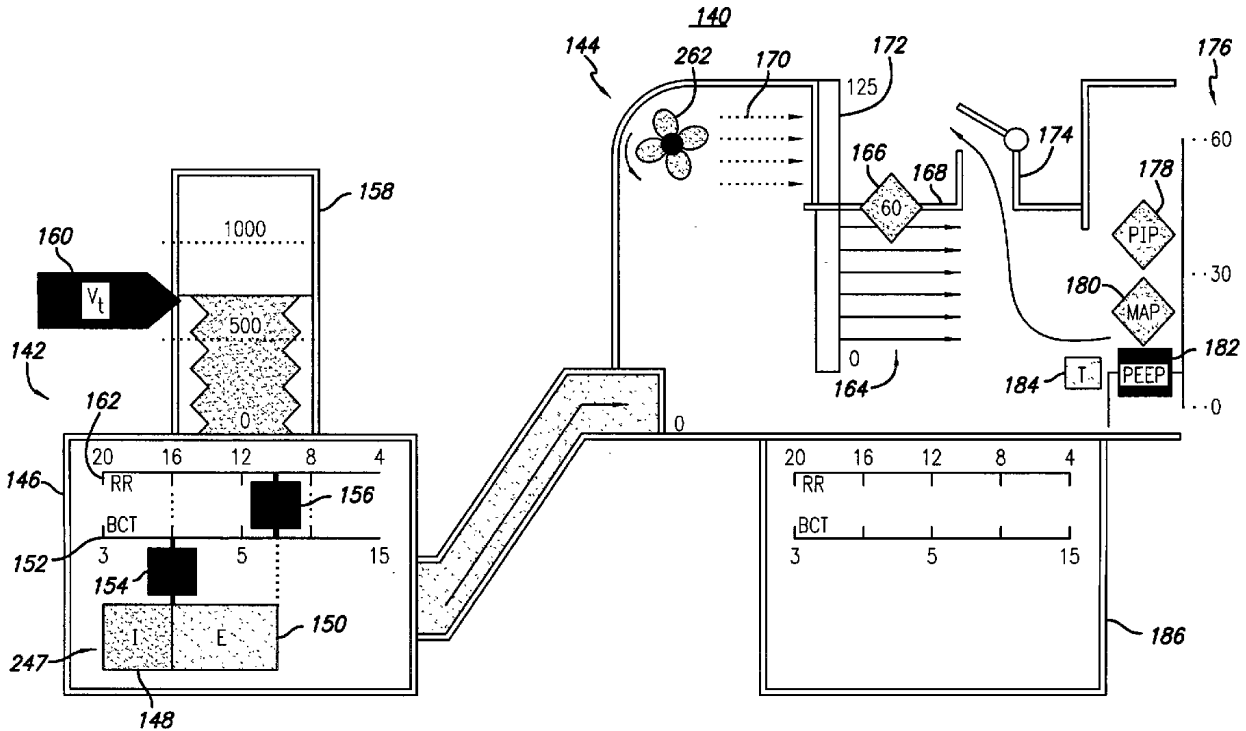
(21) **Appl. No.: 10/054,069**

The disclosed invention relates to systems and methods for obtaining physiological information from patients and displaying that information in an intuitive and logical format to a physician. Object displays are disclosed that are capable of displaying critical information in real time to allow physicians to quickly perceive the importance of changing patient values.

(22) **Filed: Jan. 22, 2002**

Related U.S. Application Data

(60) **Provisional application No. 60/263,861, filed on Jan. 23, 2001.**



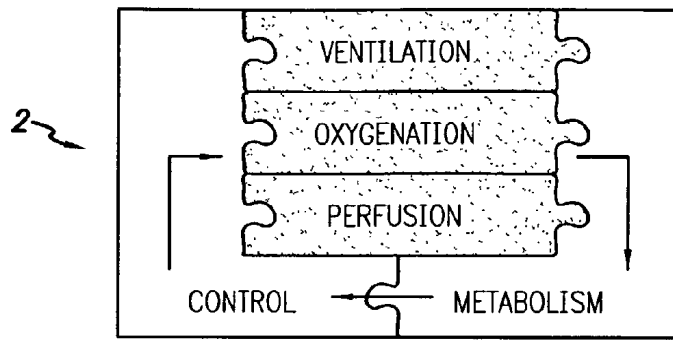


FIG. 1

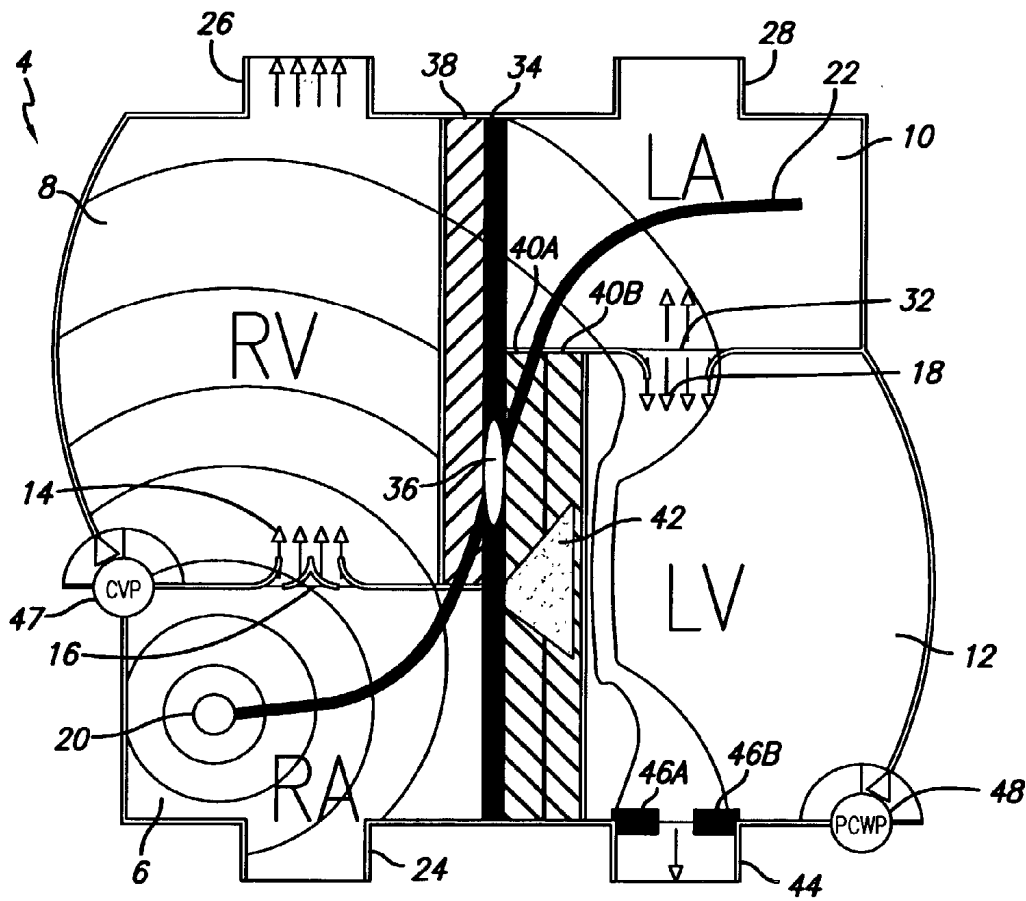


FIG. 2

FIG. 3-1

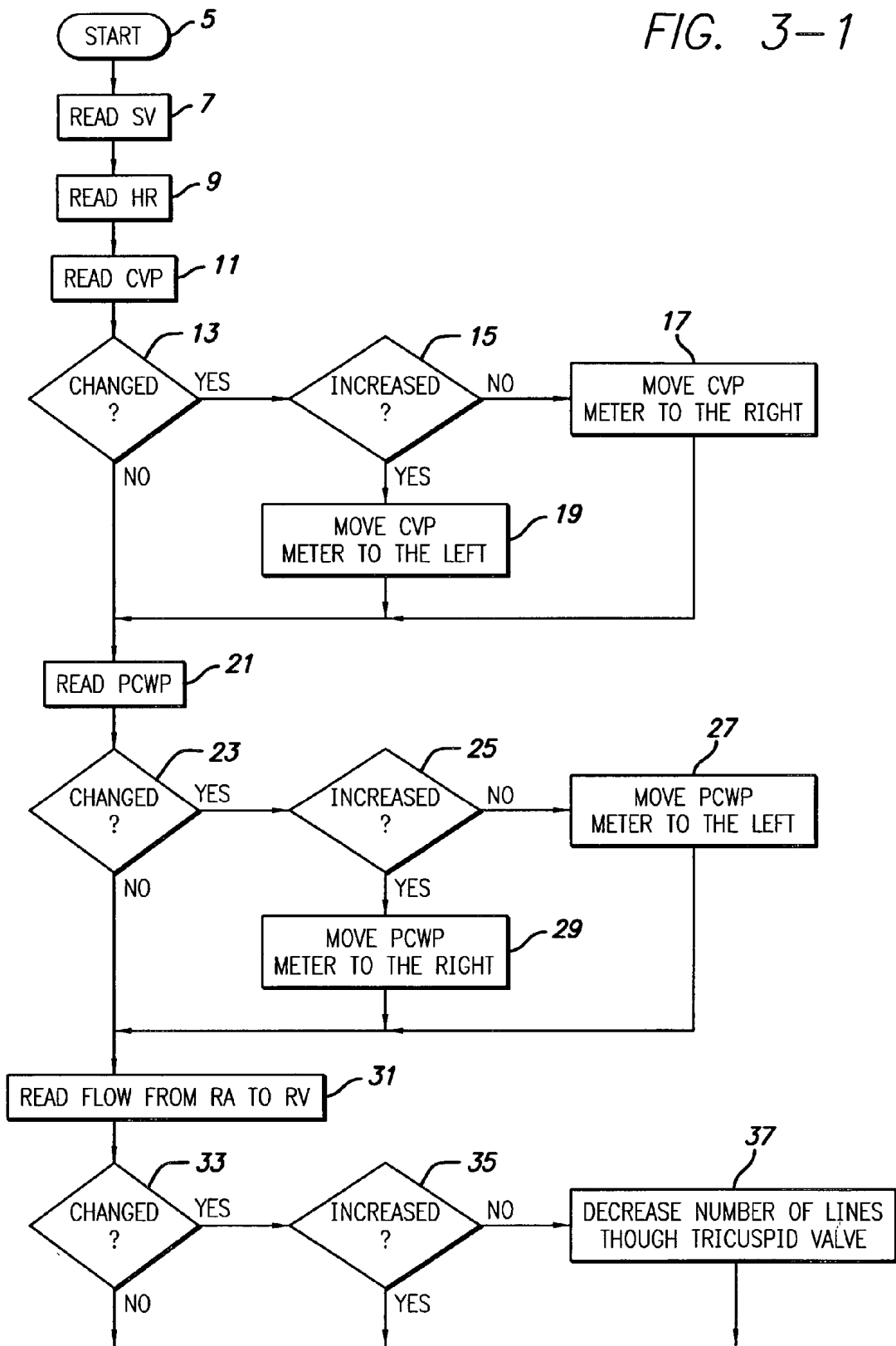
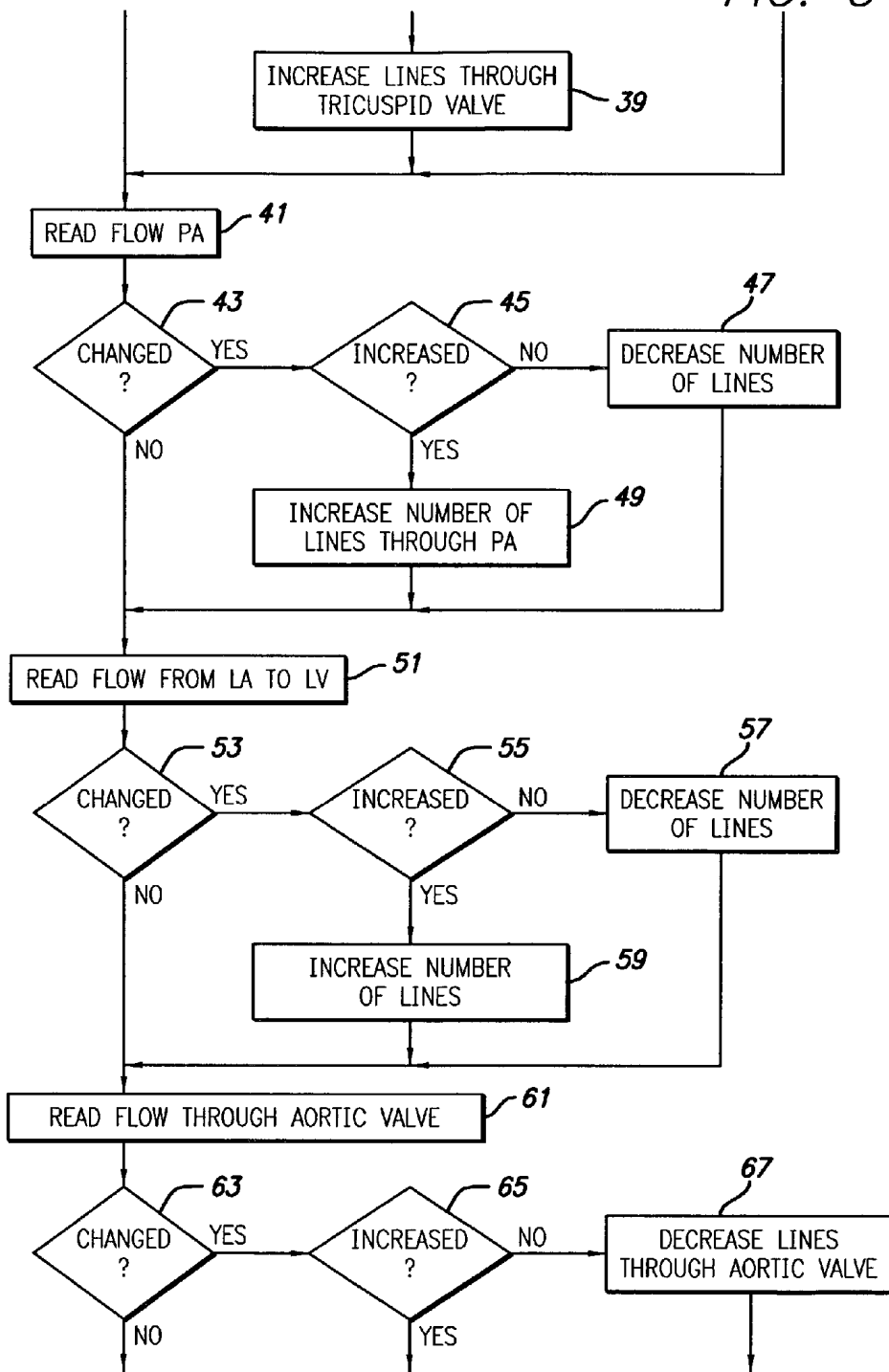


FIG. 3-2



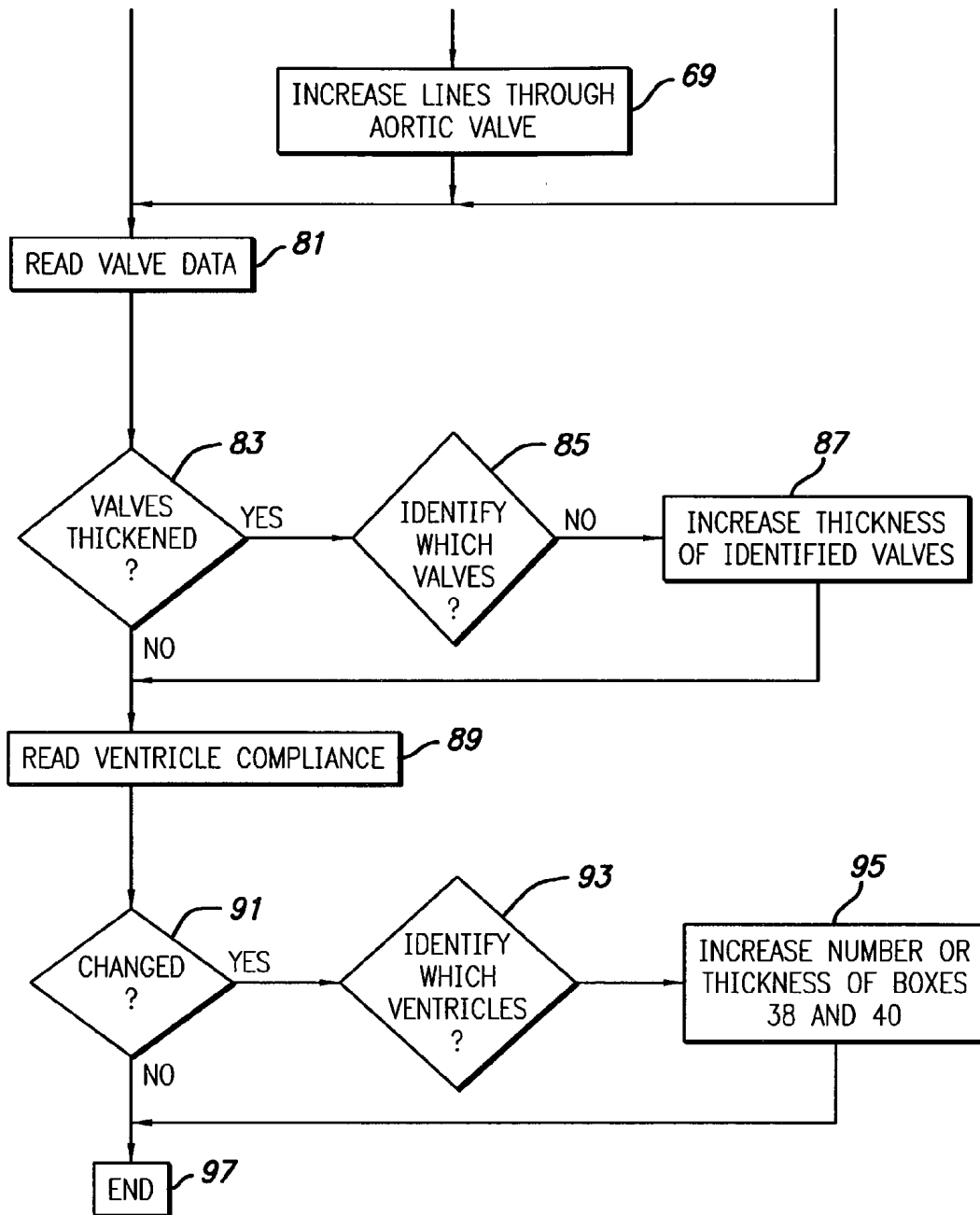


FIG. 3-3

FIG. 4

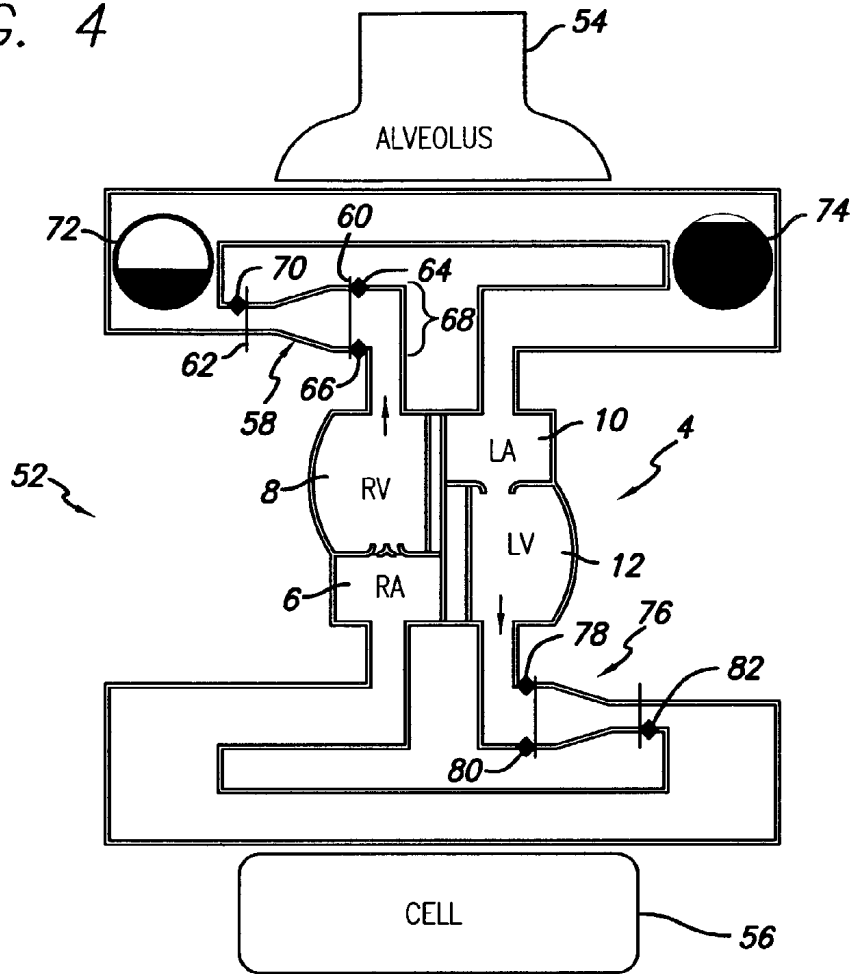


FIG. 5

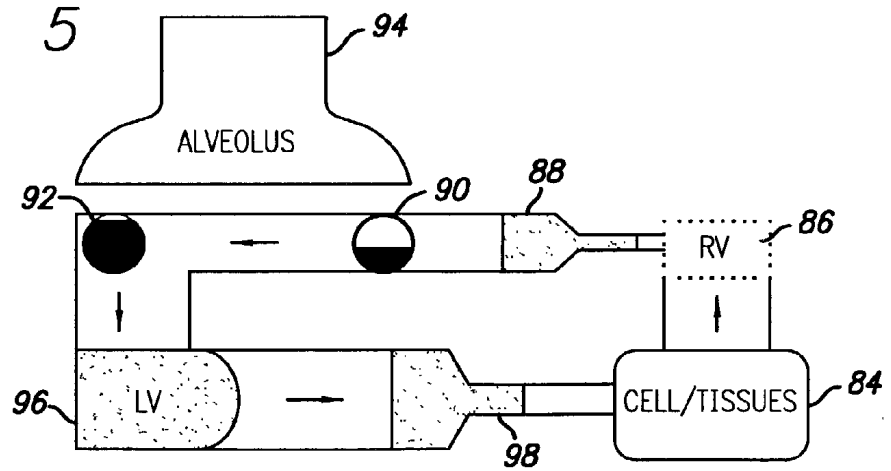
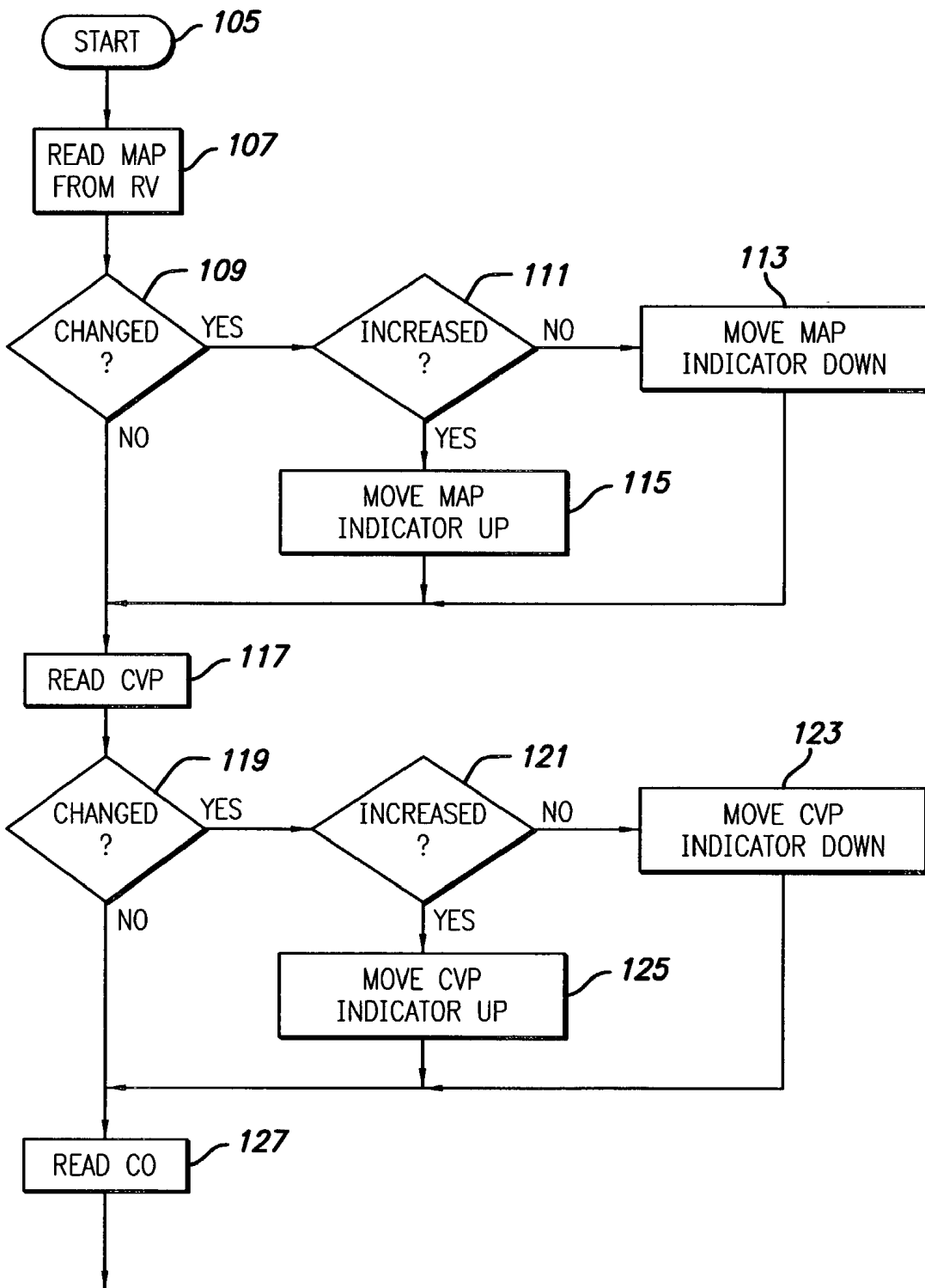


FIG. 6-1



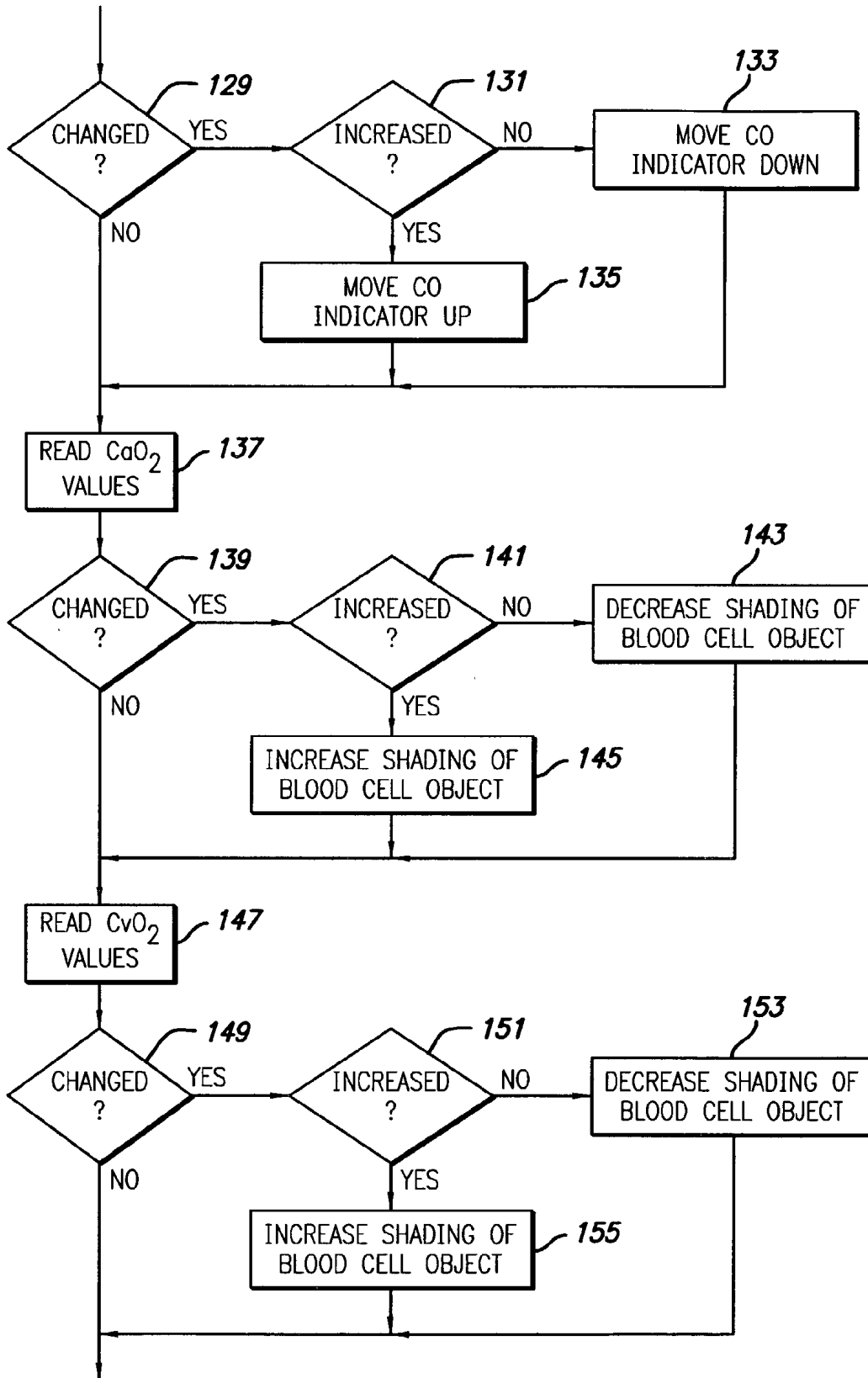


FIG. 6-2

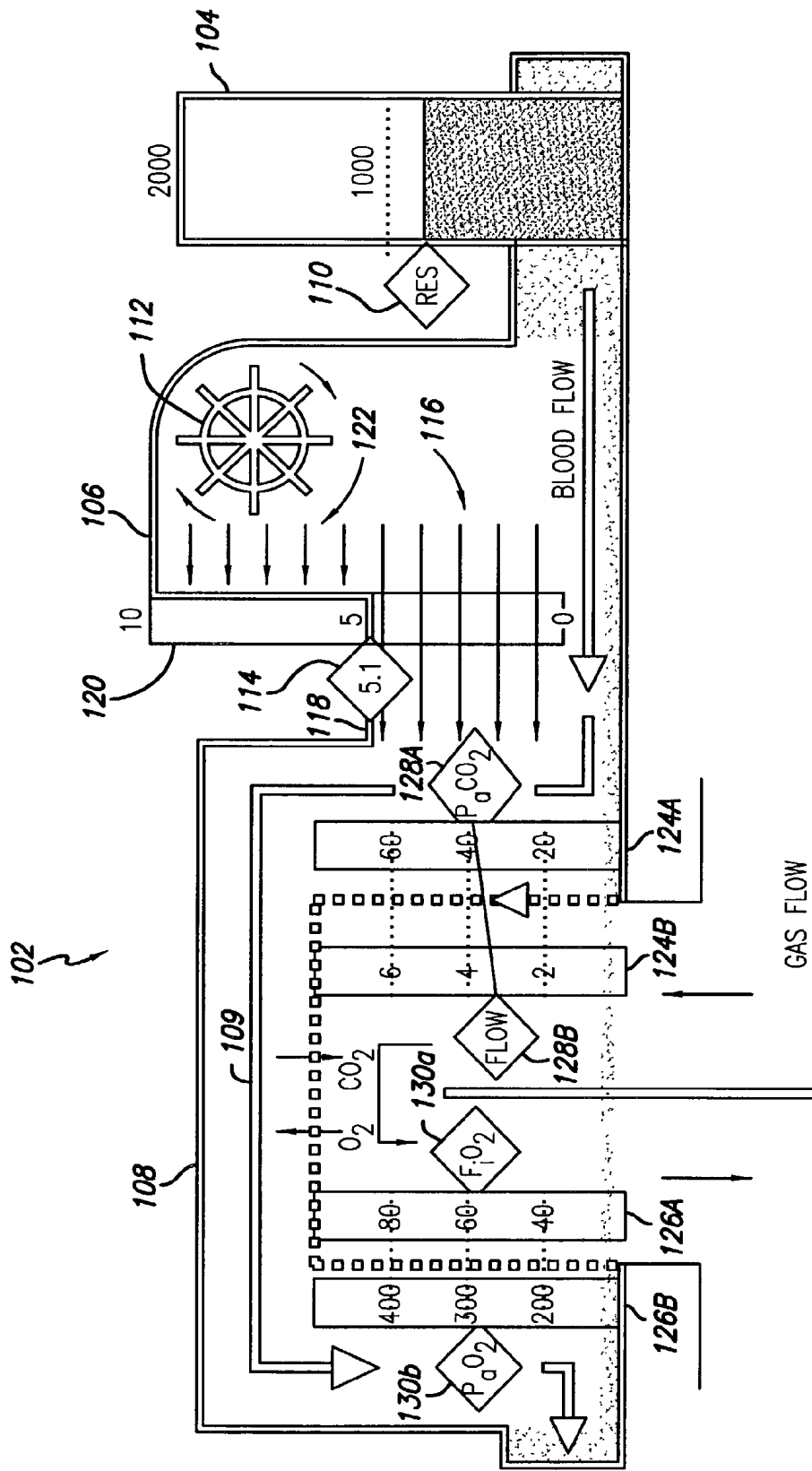
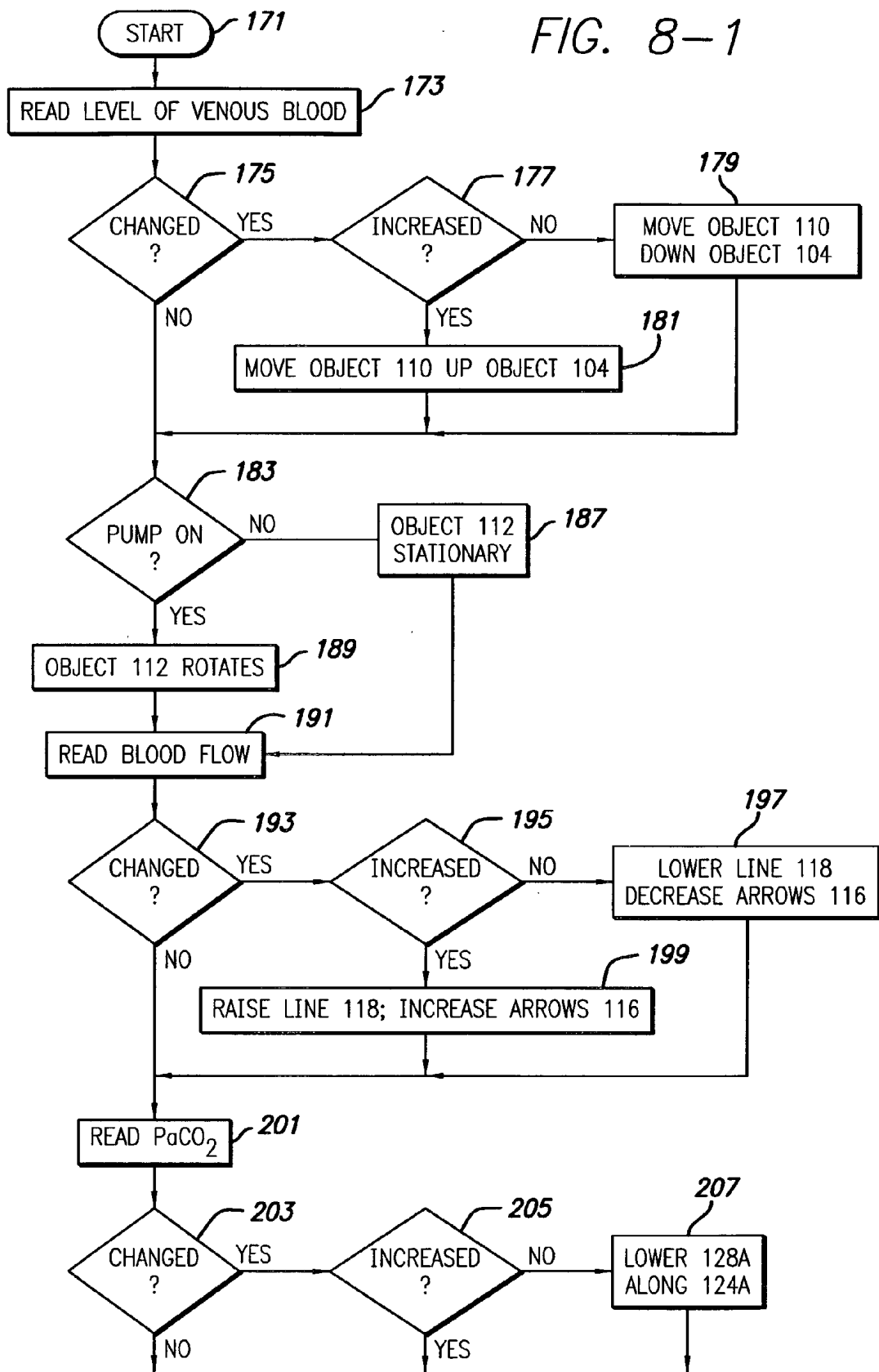


FIG. 7

FIG. 8-1



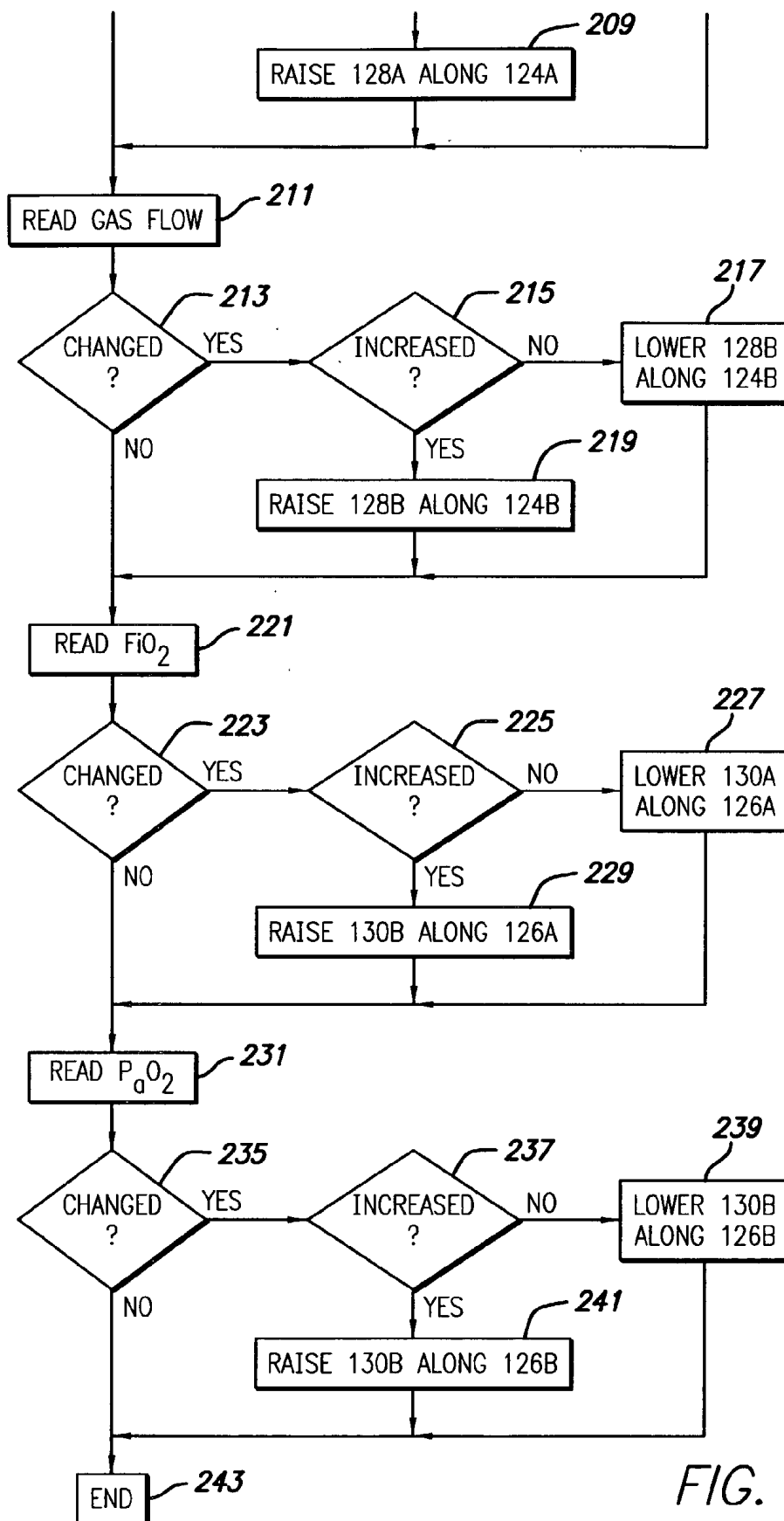


FIG. 8-2

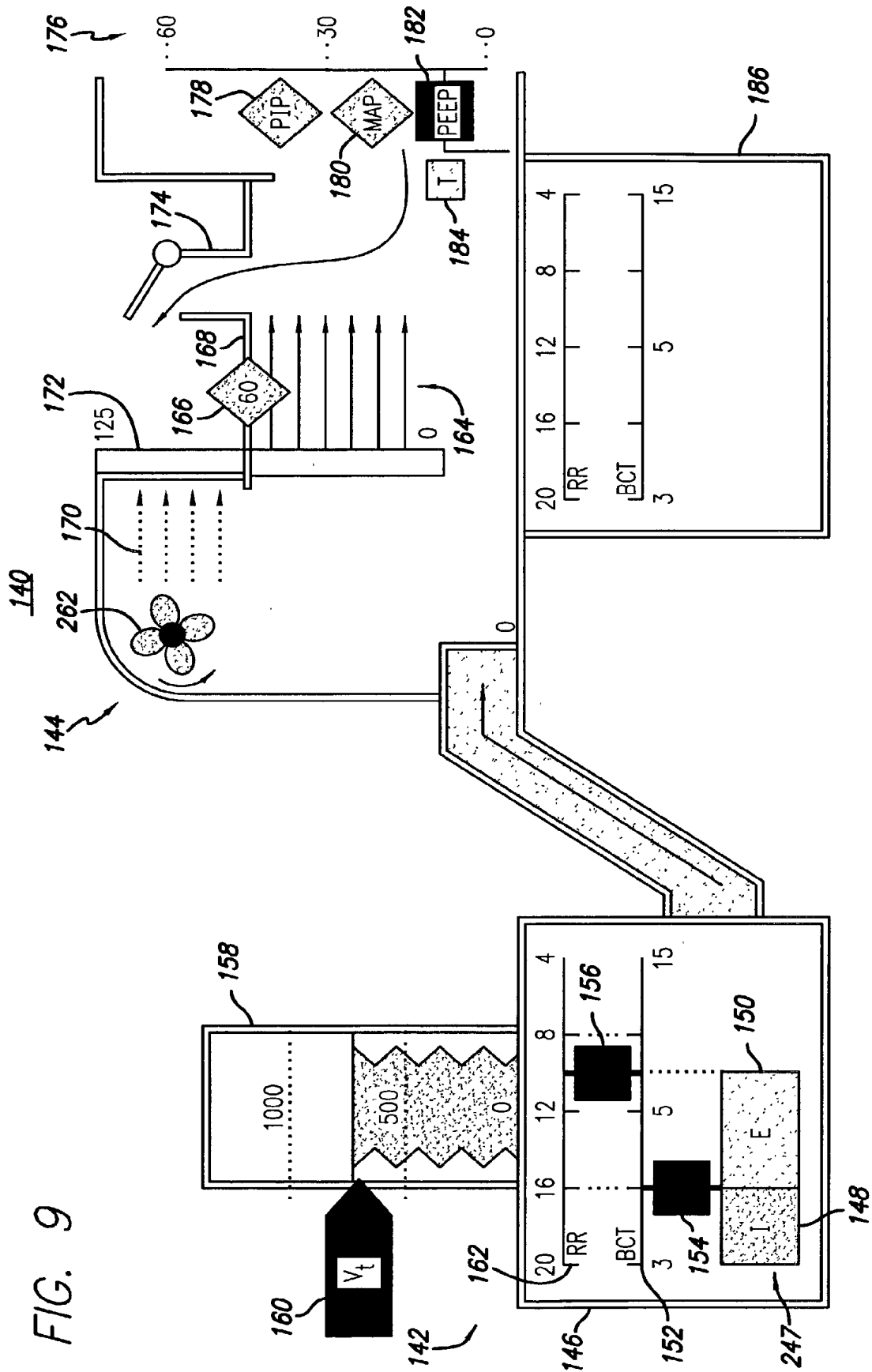


FIG. 10-1

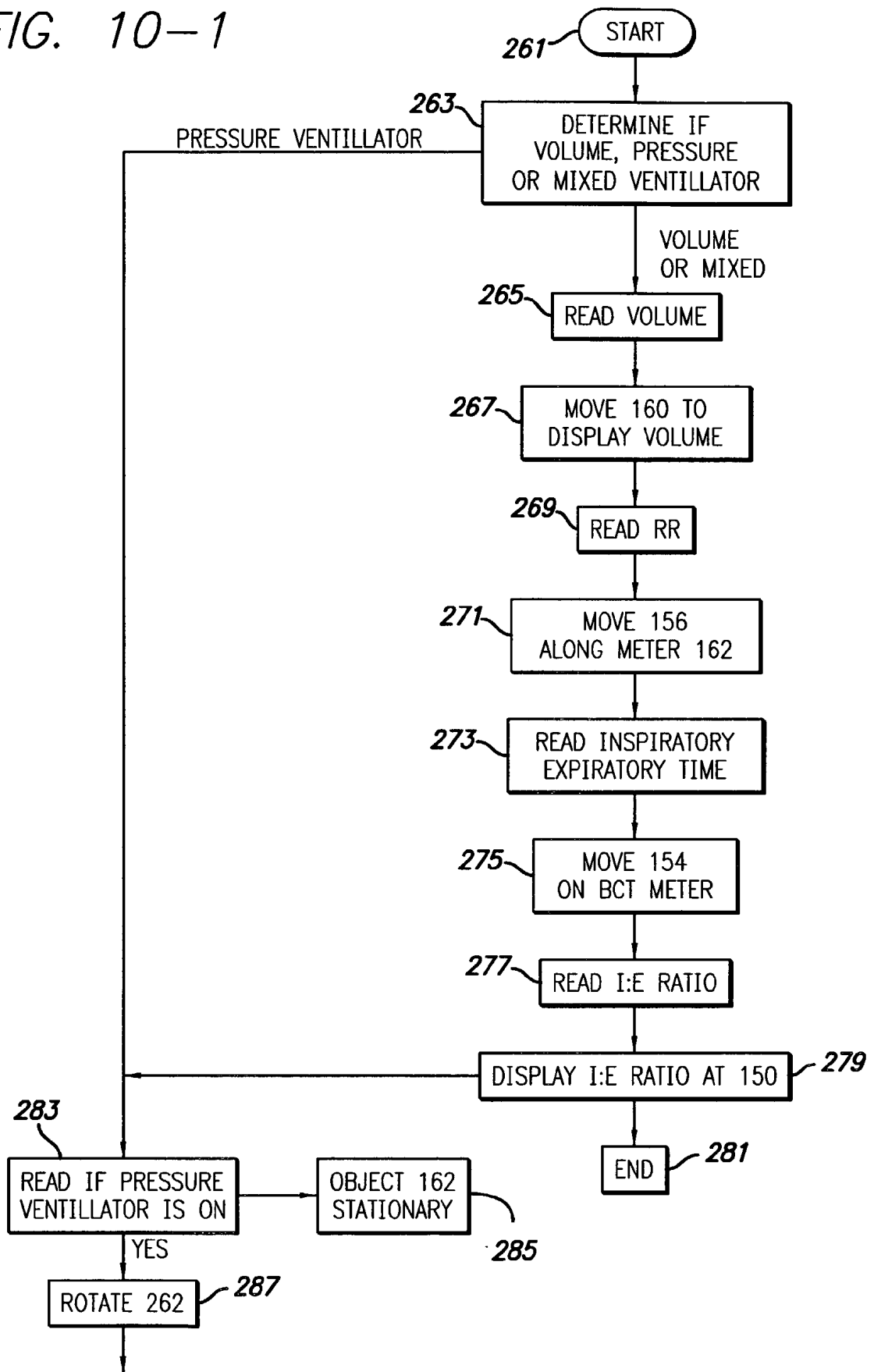
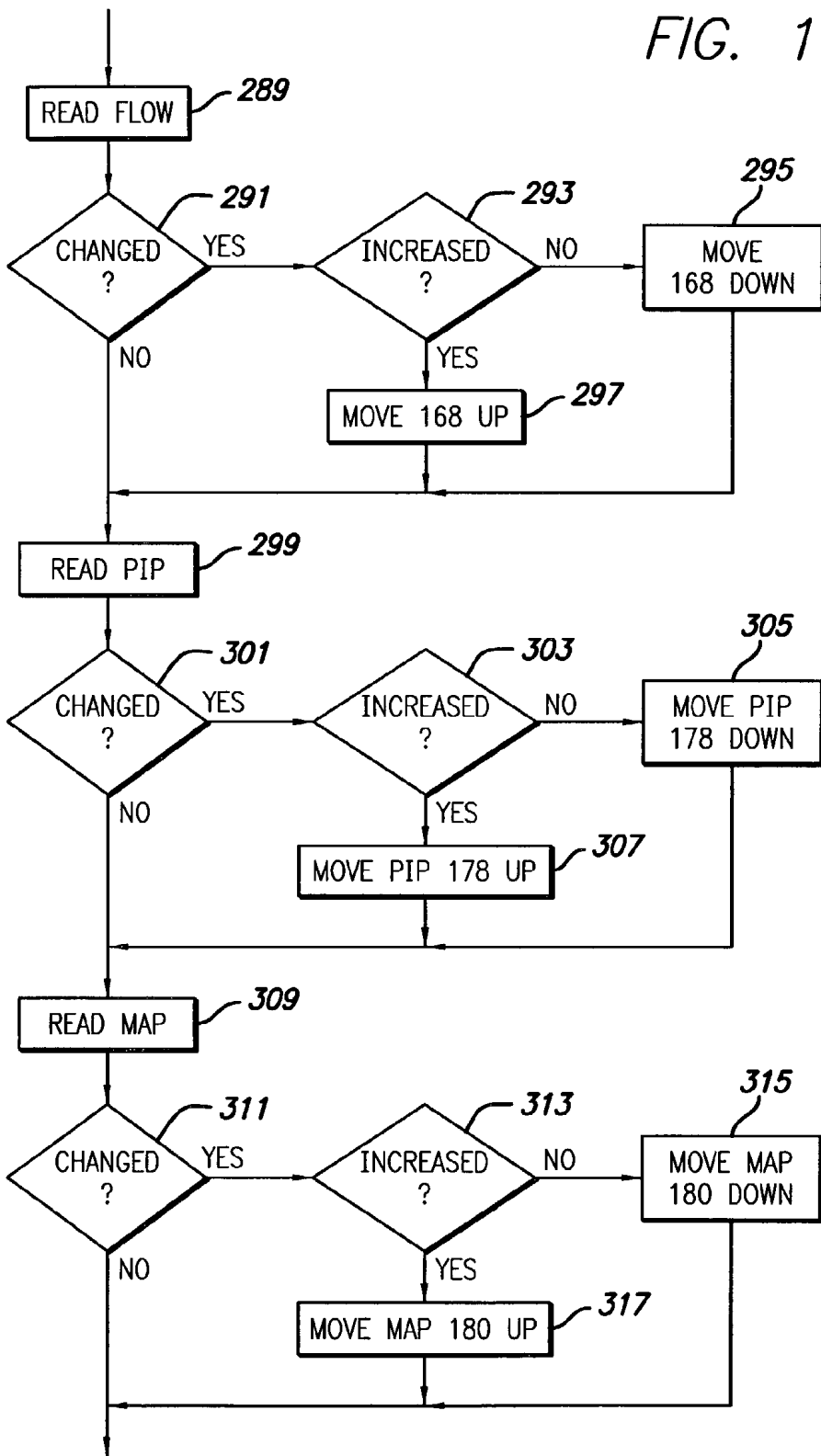


FIG. 10-2



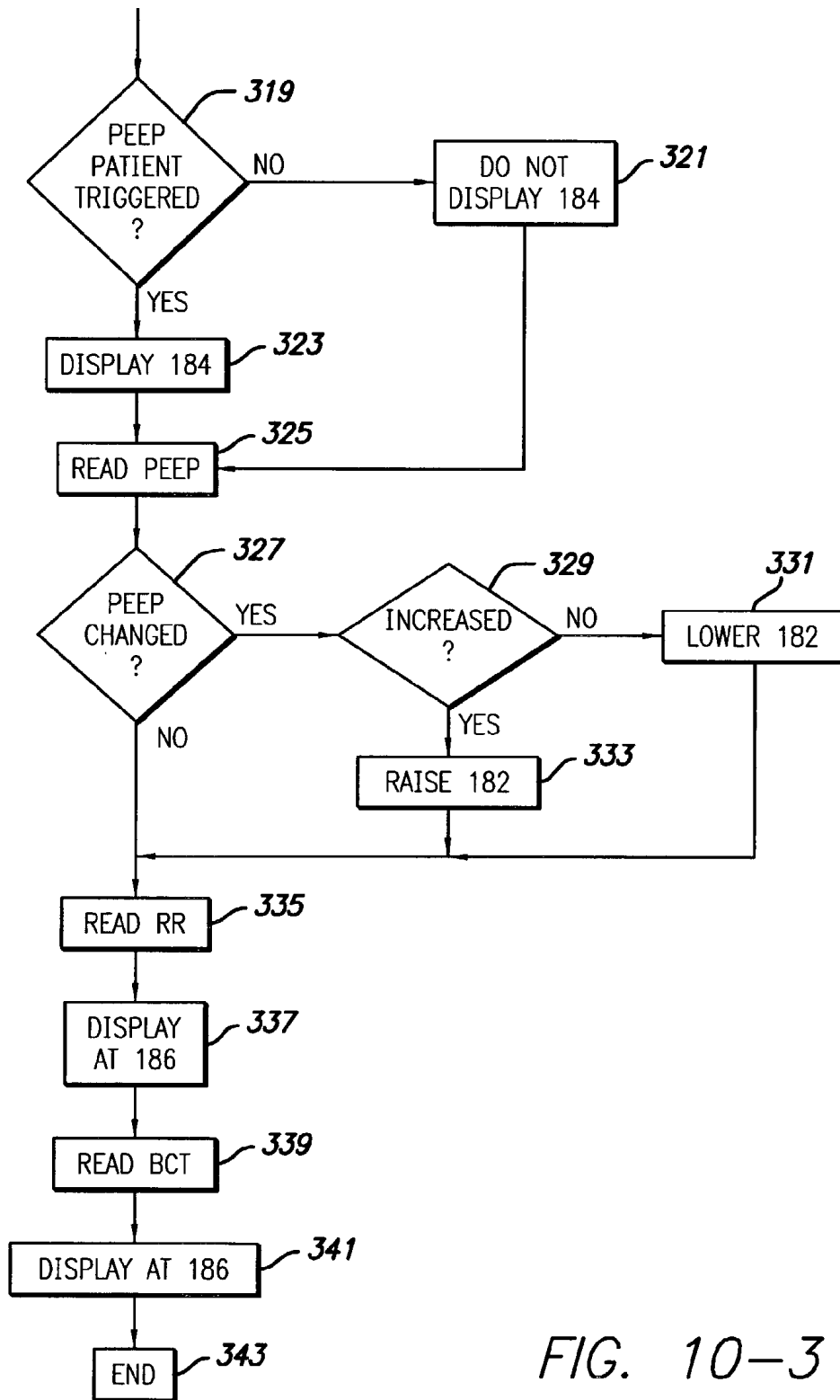


FIG. 10-3

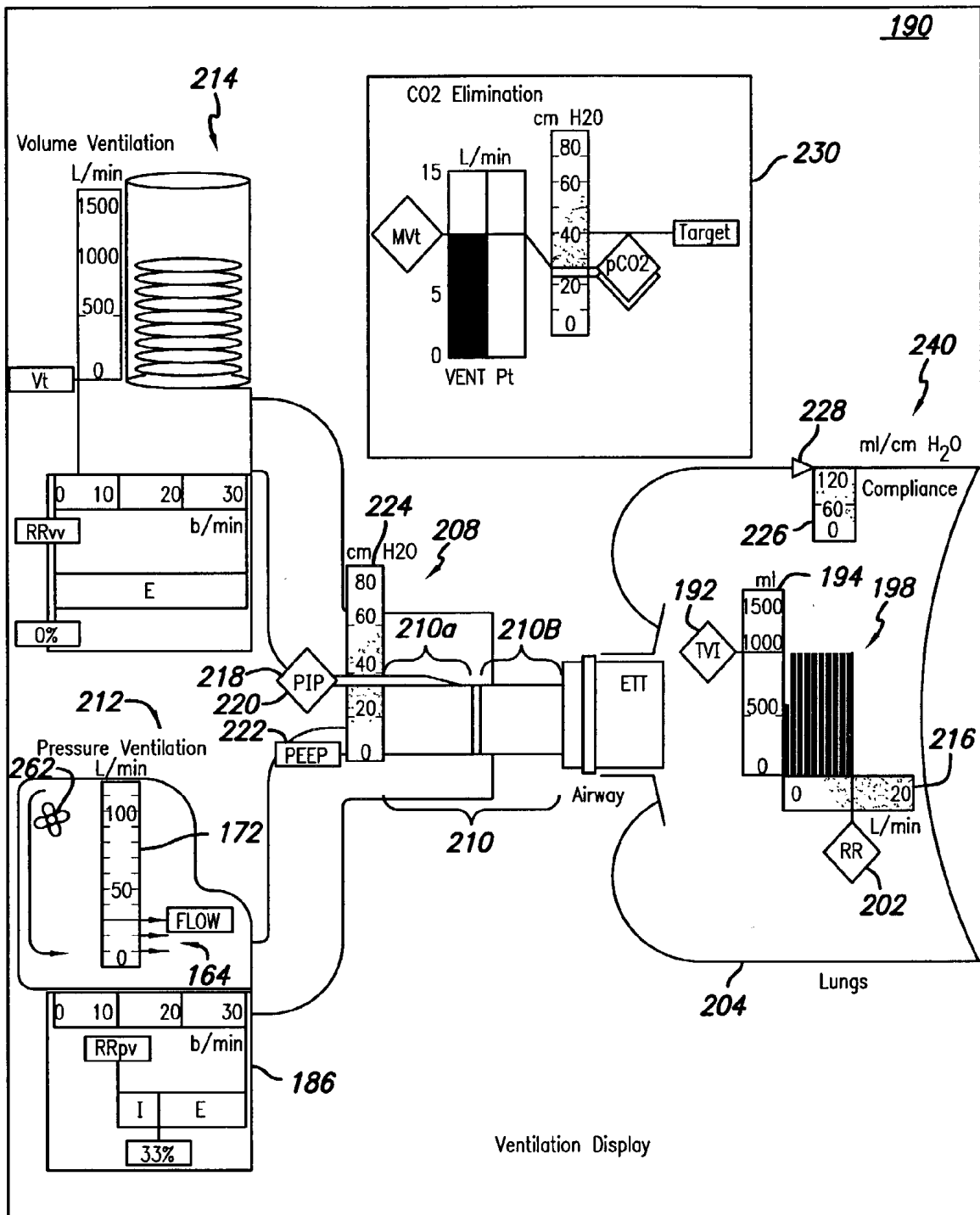


FIG. 11

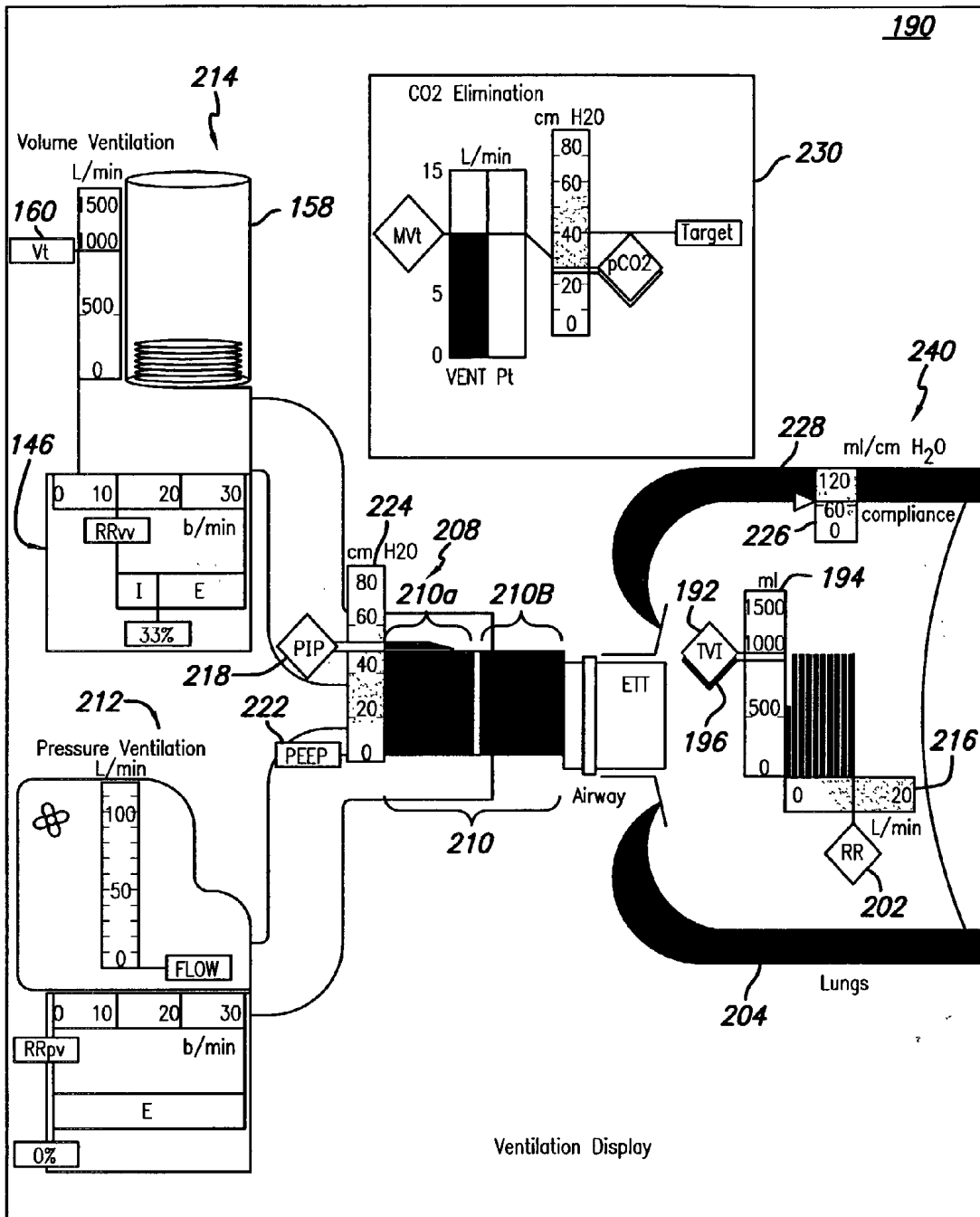


FIG. 12

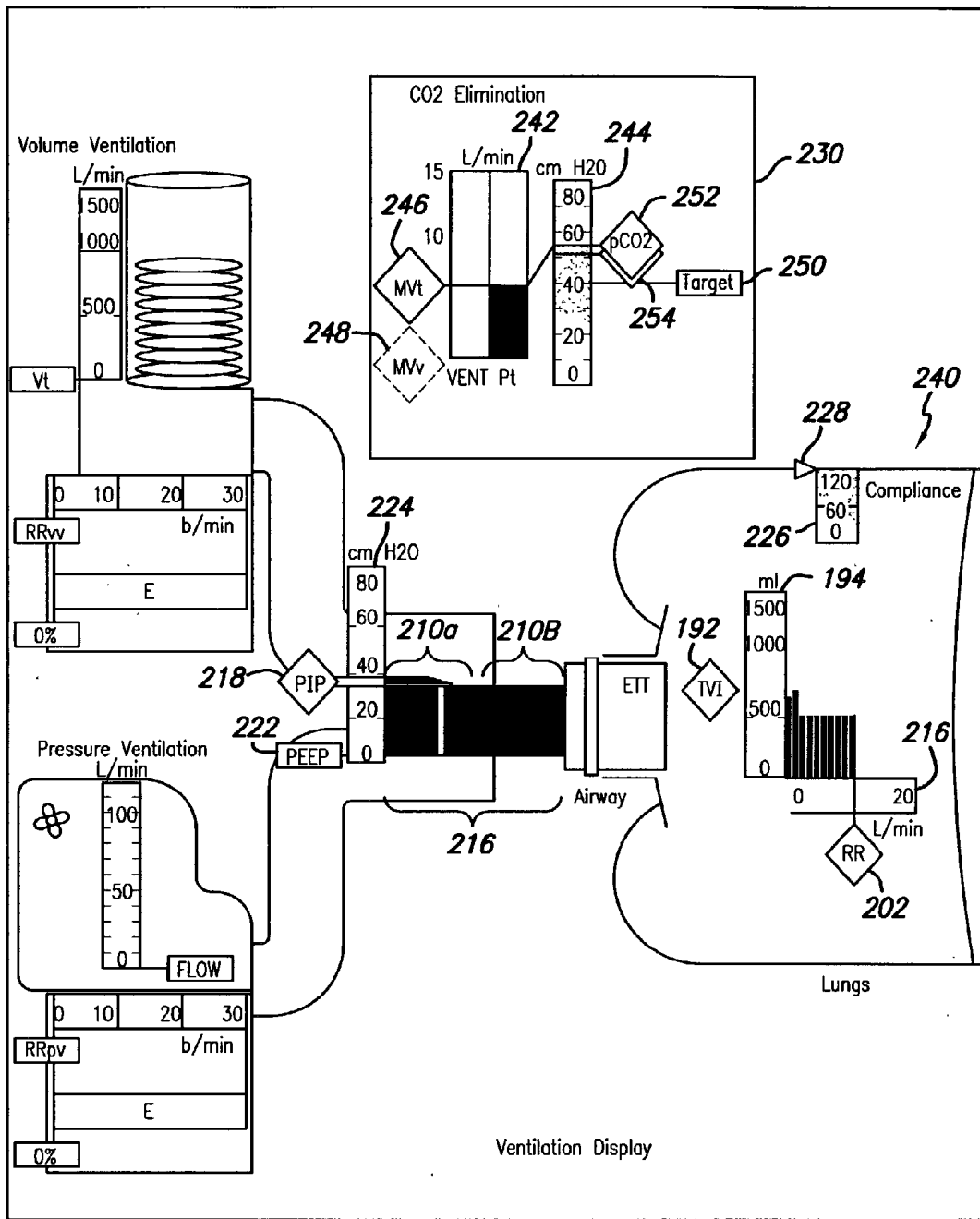


FIG. 13

FIG. 14-1

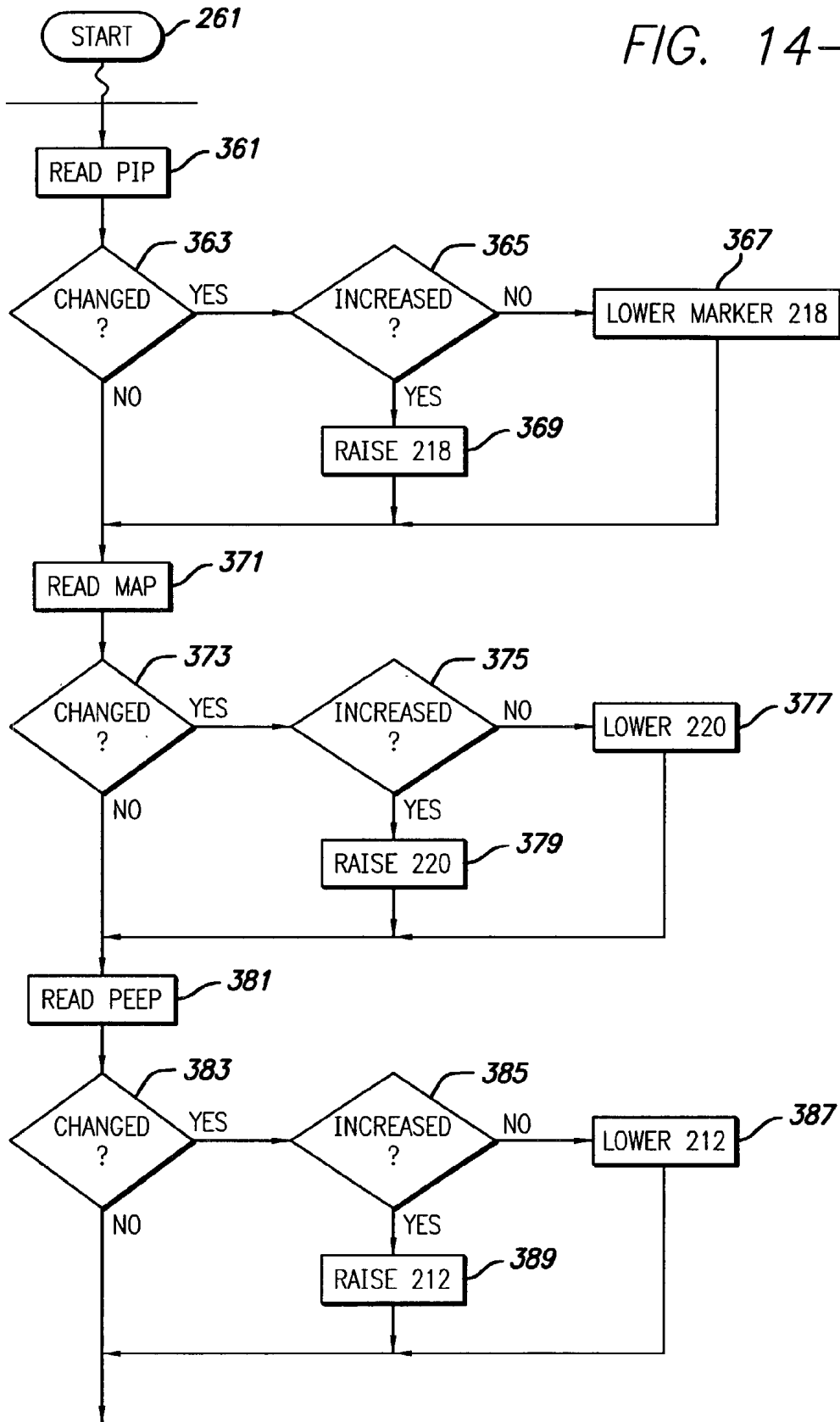
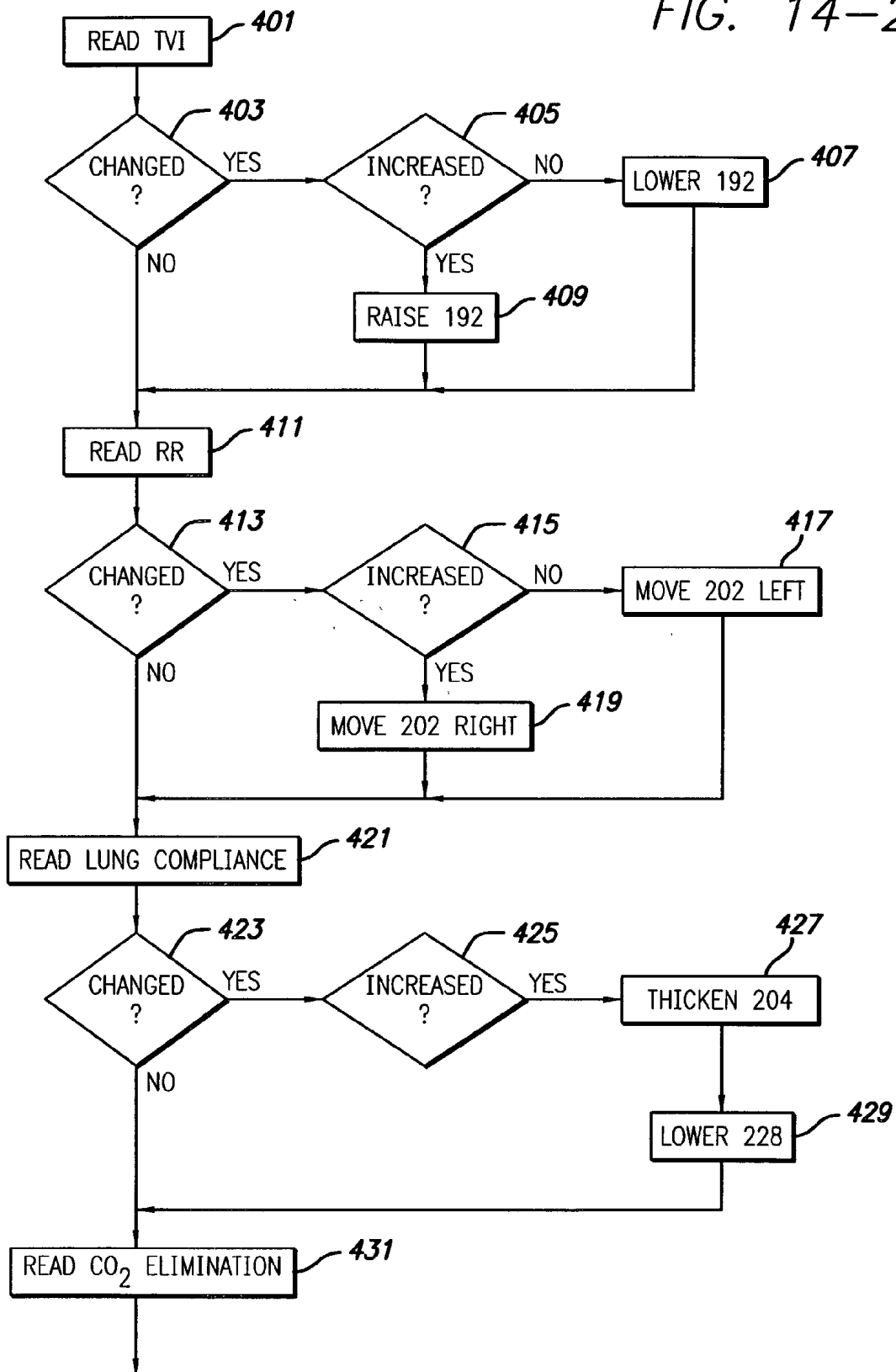


FIG. 14-2



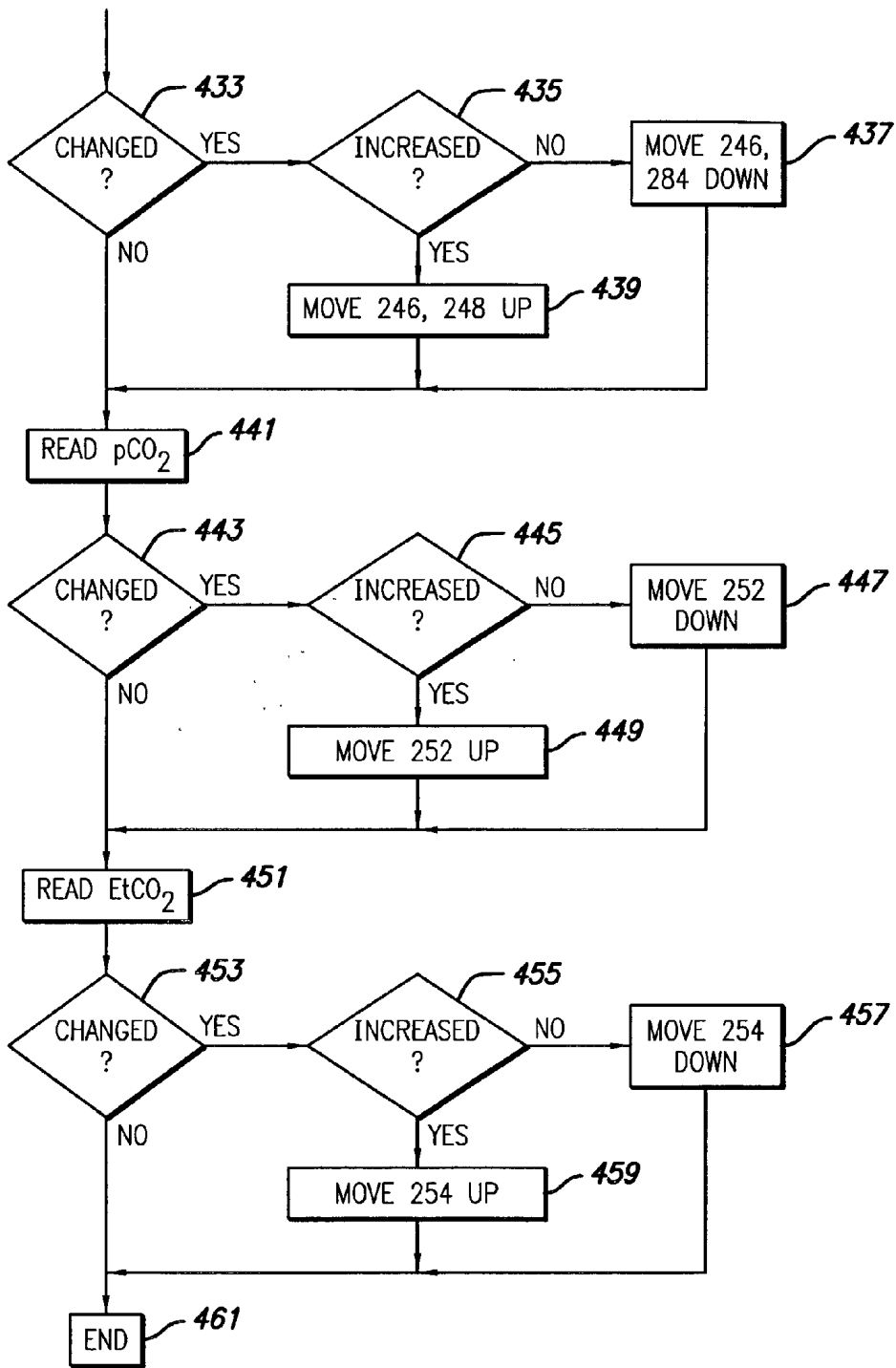


FIG. 14-3

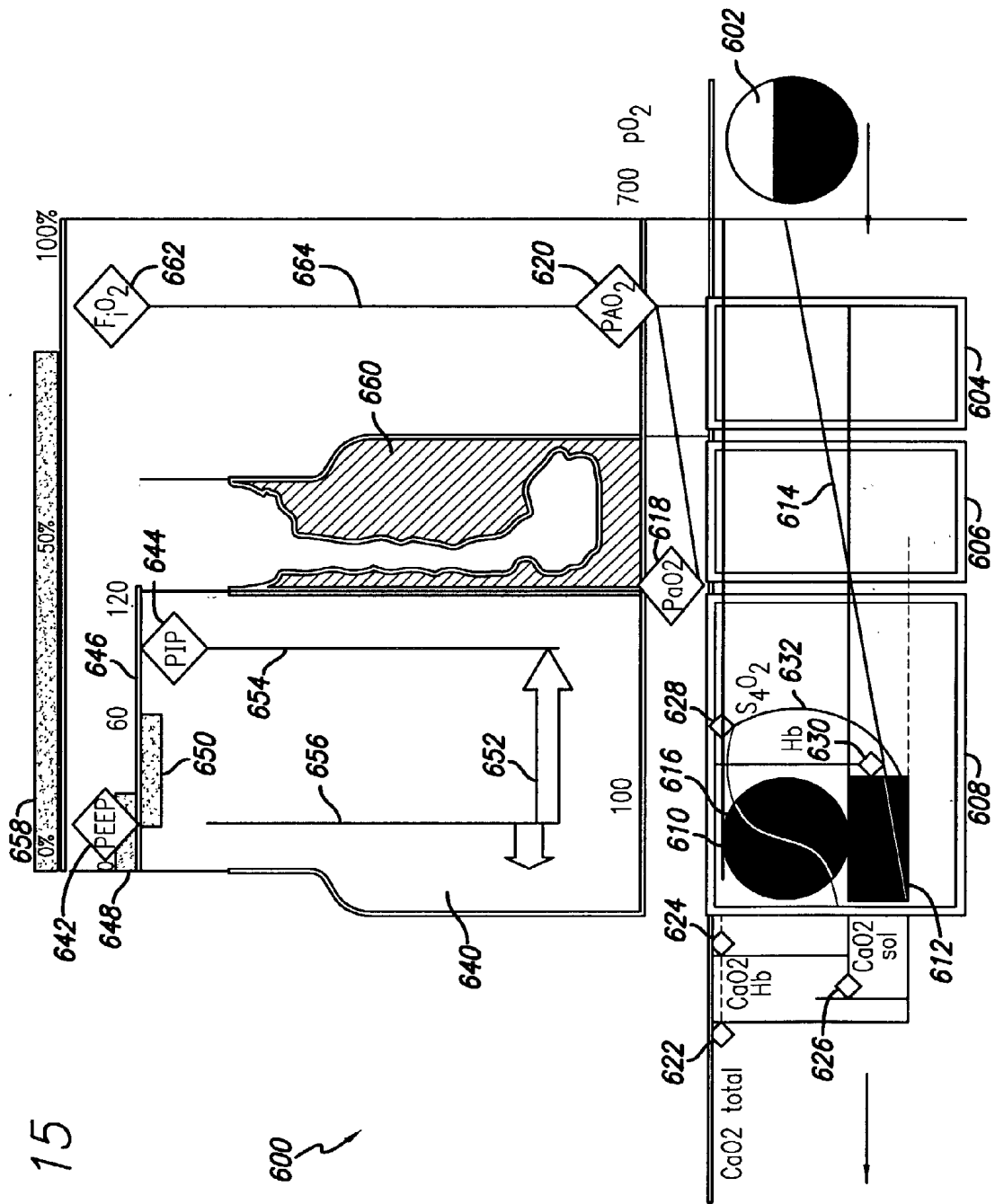
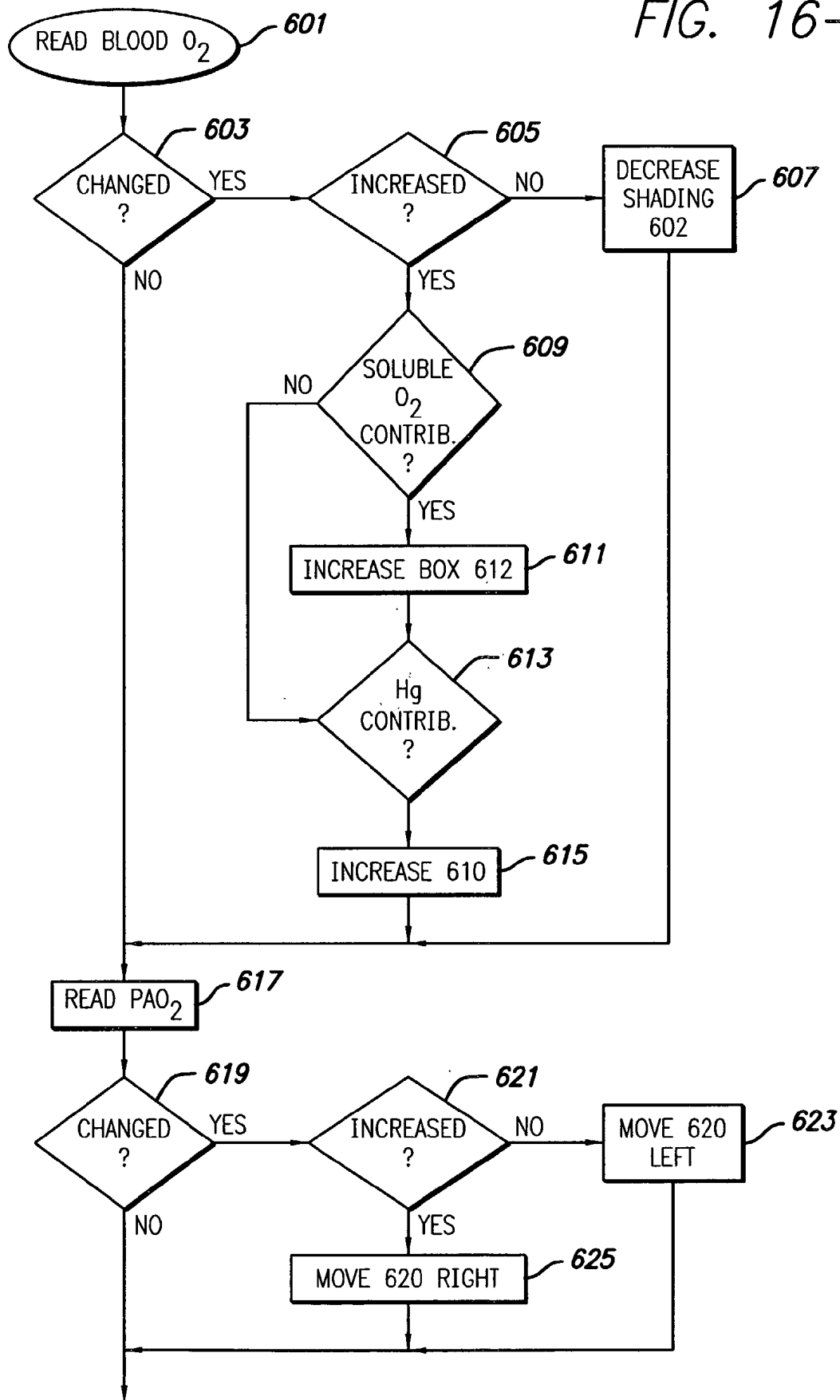


FIG. 15

FIG. 16-1



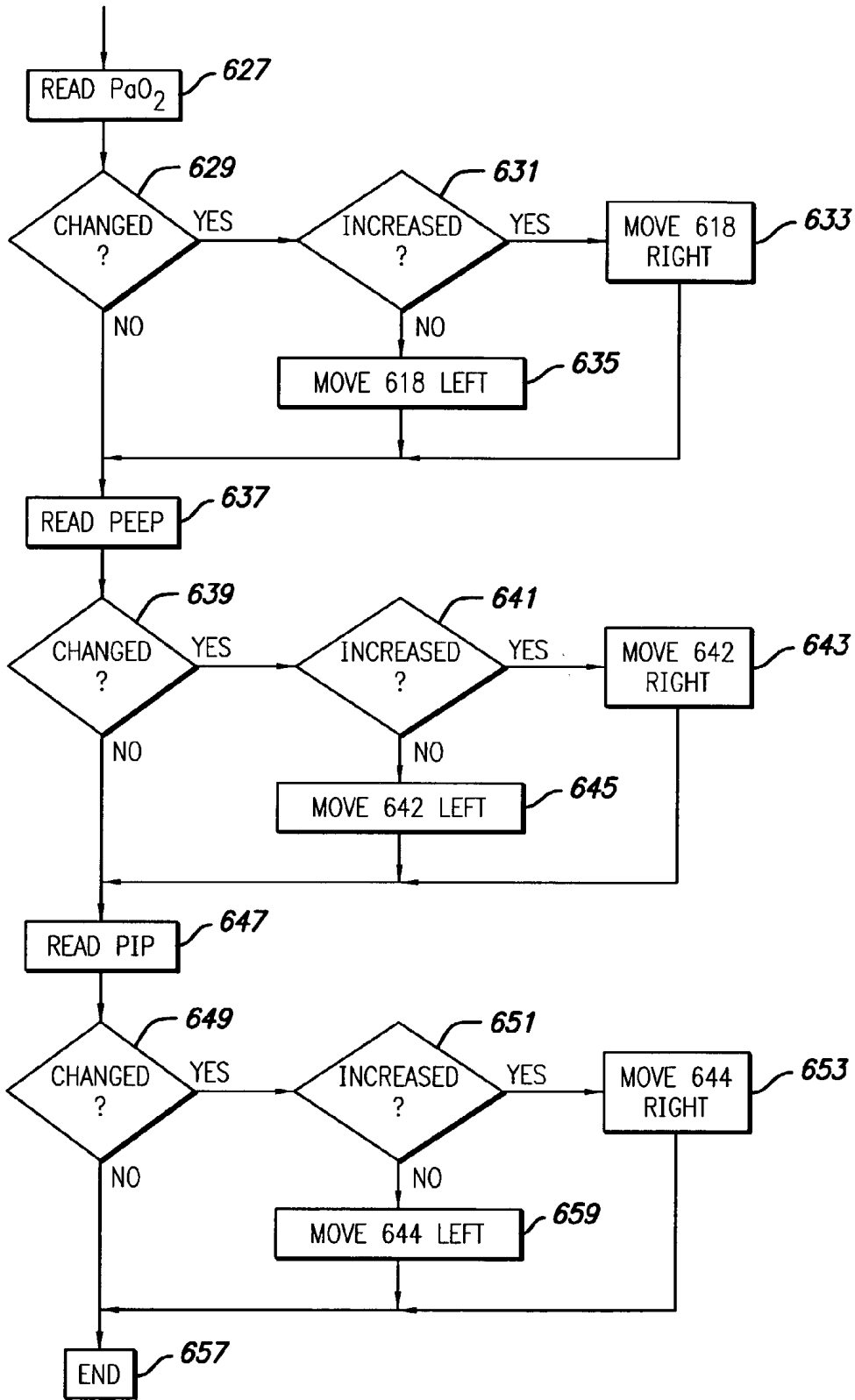


FIG. 16-2

FIG. 17

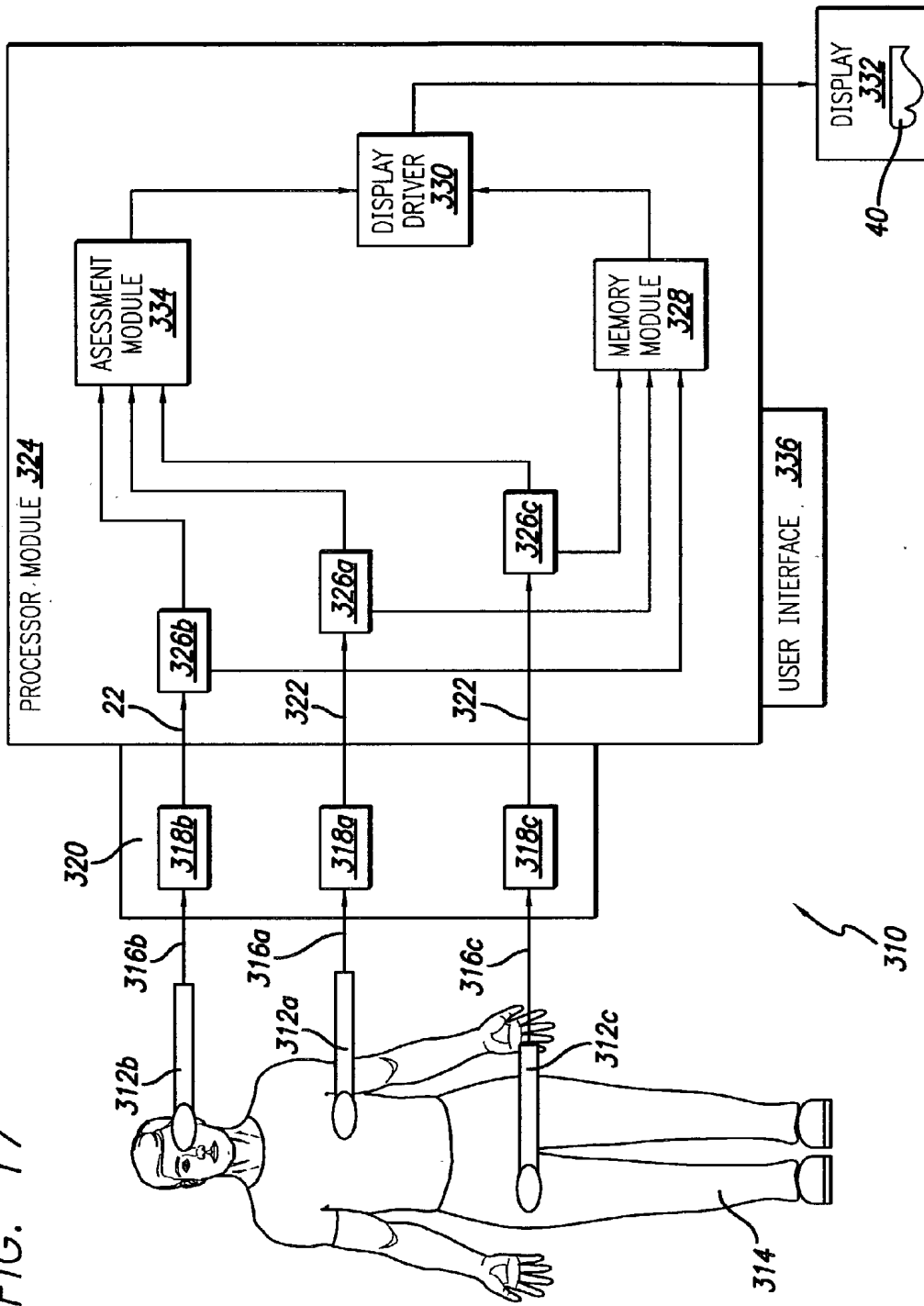


FIG. 18

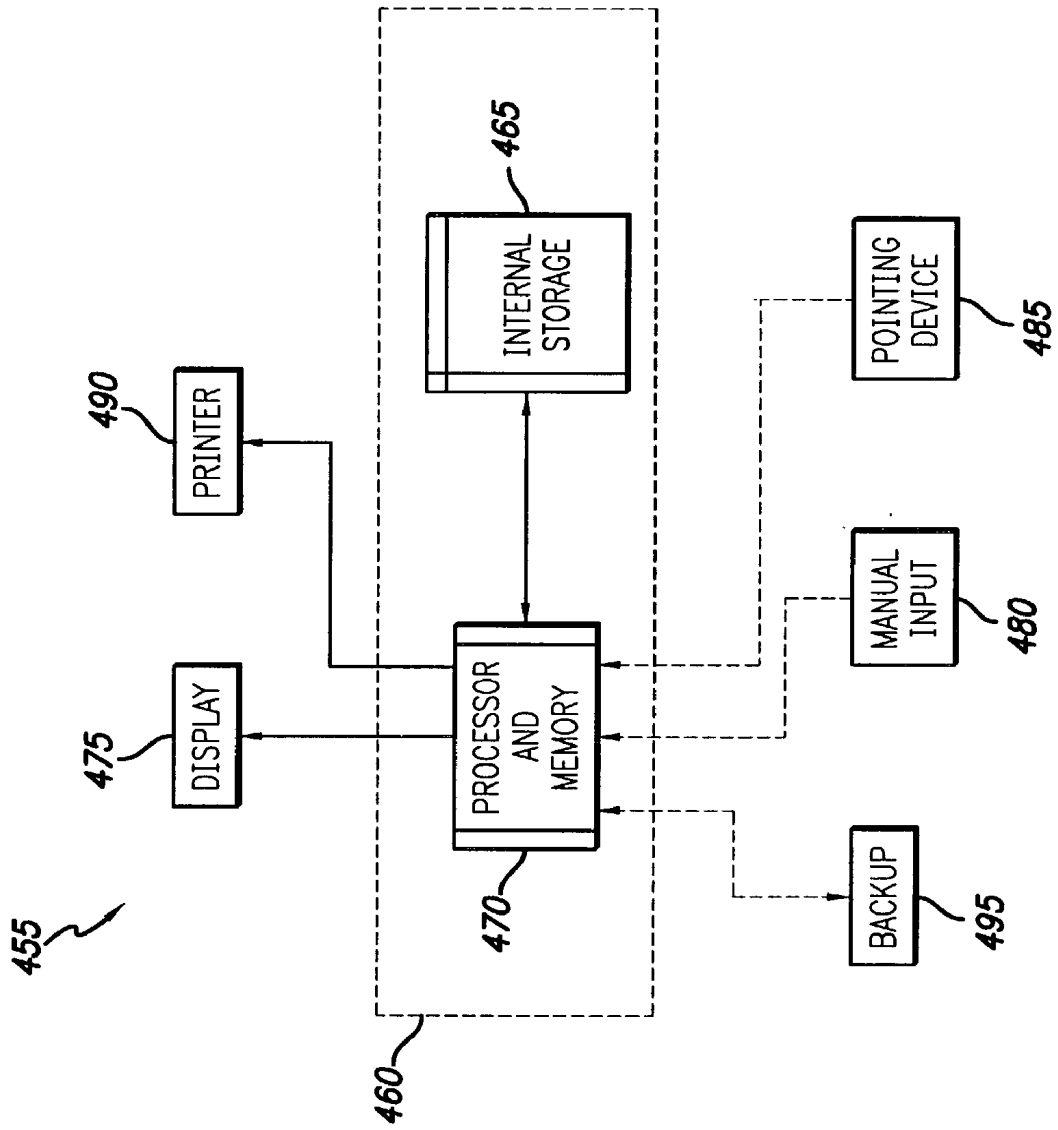
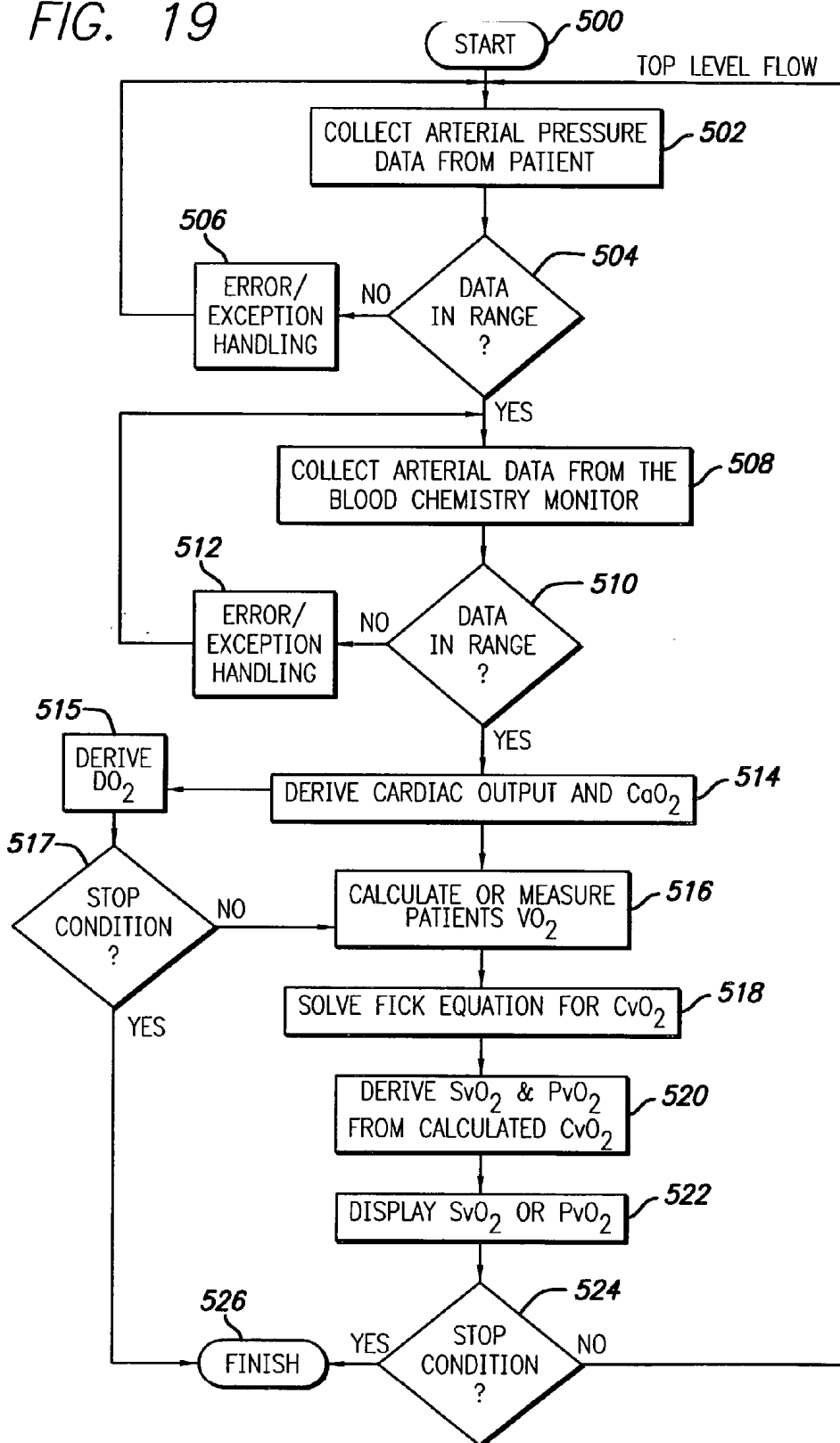


FIG. 19



PHYSIOLOGICAL OBJECT DISPLAYS

[0001] This application claims priority under 35 U.S.C. §120 to provisional patent application serial No. 60/263,861 filed on Jan. 19, 2000.

FIELD OF THE INVENTION

[0002] This invention relates to display systems for displaying complex medical information to a physician. More specifically, the invention relates to hardware, software and object displays for displaying complex physiological information to physicians in unique graphical display formats in real time.

BACKGROUND OF THE INVENTION

[0003] Medical display systems provide information to physicians in a clinical setting. Typical display systems provide data in the form of numbers and one-dimensional signal waveforms that must be assessed, in real time, by the attending physician. Alarms are sometimes included with such systems to warn the physician of an unsafe condition, e.g., a number exceeds a recommended value. In the field of anesthesiology, for example, the anesthesiologist must monitor the patient's condition and at the same time (i) recognize problems, (ii) identify the cause of the problems, and (iii) take corrective action during the administration of the anesthesia. An error in judgment can be fatal.

[0004] Physiologic data displays of the patient's condition play a central role in allowing surgeons and anesthesiologists to observe problem states in their patients and deduce the most likely causes of the problem state during surgery, thus allowing expeditious treatment. As one might predict, 63 percent of the reported incidents in the Australian Incident Monitoring Study (AIMS) database were considered detectable with standard data monitors and potentially avoidable. Others have attempted to address these problems, but with only limited success.

[0005] For example, Cole, et. al. has developed a set of objects to display the respiratory physiology of intensive care unit (ICU) patients on ventilators. This set of displays integrates information from the patient, the ventilator, rate of breathing, volume of breathing, and percent oxygen inspired. Using information from object displays, ICU physicians made faster and more accurate interpretations of data than when they used alphanumeric displays. Cole published one study that compared how physicians performed data interpretation using tabular data vs. printed graphical data. However, Cole's work did not utilize all of the methods being leveraged in aviation and nuclear power to involve a system for receiving analog data channels and driving real-time graphical displays on a medical monitor.

[0006] Ohmeda, a company that makes anesthesia machines, manufactures the Modulus CD machine which has an option for displaying data in a graphical way. The display has been referred to as a glyph. Physiologic data is mapped onto the shape of a hexagon. Six data channels generate the six sides of the hexagon. Although this display is graphical, the alphanumeric information of the display predominates. There is no obvious rationale for why the physiologic data is assigned a side of the hexagon. Moreover, symmetric changes to the different signs of this geometric shape are very hard for individuals to differentiate.

Overall, information displays that show the quantitative (data value), qualitative (high, low, normal zones for the parameter), temporal (trending and change over time), and relational (manner in which multiple parameters relate to disease states that need treatment) information that clinicians need in an intuitive manner are lacking.

[0007] The physiologic parameters that relate to oxygen transportation are central to medical assessment of any patient's well being. A review of the physiological parameters of interest and their importance in medical decision making that are represented in the informational display of this application, follows:

[0008] Blood adequacy:

[0009] In the surgical and postoperative settings, decisions regarding the need for blood transfusion normally are guided by hemoglobin (Hb) or hematocrit levels (Hct). Hematocrit is typically defined as the percentage by volume of packed red blood cells following centrifugation of a blood sample. If the hemoglobin level per deciliter of blood in the patient is high, the physician can infer that the patient has sufficient capacity to carry oxygen to the tissue. During an operation this value is often used as a trigger; i.e. if the value falls below a certain point, additional blood is given to the patient. While these parameters provide an indication of the arterial oxygen content of the blood, they provide no information on the total amount of oxygen transported (or "offered") to the tissues, or on the oxygen content of blood coming from the tissues.

[0010] For example, it has been shown that low postoperative hematocrit may be associated with postoperative ischemia in patients with generalized atherosclerosis. Though a number of researchers have attempted to define a critical Hct level, most authorities would agree that an empirical automatic transfusion trigger, whether based on Hb or Hct, should be avoided and that red cell transfusions should be tailored to the individual patient. The transfusion trigger, therefore, should be activated by the patient's own response to anemia rather than any predetermined value.

[0011] Tissue oxygenation:

[0012] This is, in part, due to the fact that a number of parameters are important in determining how well the patient's tissues are actually oxygenated. In this regard, the patient's cardiac output is also an important factor in correlating hemoglobin levels with tissue oxygenation states. Cardiac output or CO is defined as the volume of blood ejected by the left ventricle of the heart into the aorta per unit of time (ml/min) and can be measured with thermodilution techniques. For example, if a patient has internal bleeding, the concentration of hemoglobin in the blood might be normal, but the total volume of blood will be low. Accordingly, simply measuring the amount of hemoglobin in the blood without measuring other parameters such as cardiac output is not always sufficient for estimating the actual oxygenation state of the patient.

[0013] More specifically the oxygenation status of the tissues is reflected by the oxygen supply/demand relationship of those tissues i.e., the relationship of total oxygen transport (DO_2) to total oxygen consumption (VO_2). Hemoglobin is oxygenated to oxyhemoglobin in the pulmonary capillaries and then carried by the cardiac output to the tissues, where the oxygen is consumed. As oxyhemoglobin

releases oxygen to the tissues, the partial pressure of oxygen (PO_2) decreases until sufficient oxygen has been released to meet the oxygen consumption (VO_2). Although there have been advances in methods of determining the oxygenation status of certain organ beds (e.g., gut tonometry; near infrared spectroscopy) these methods are difficult to apply in the clinical setting. Therefore, the use of parameters that reflect the oxygenation status of the blood coming from the tissues i.e., the partial pressure of oxygen in the mixed venous blood (PvO_2 ; also known as the mixed venous blood oxygen tension) or mixed venous blood oxyhemoglobin saturation (SvO_2) has become a generally accepted practice for evaluating the global oxygenation status of the tissues.

[0014] Unfortunately, relatively invasive techniques are necessary to provide more accurate tissue oxygenation levels. In this respect, direct measurement of the oxygenation state of a patient's mixed venous blood during surgery may be made using pulmonary artery catheterization. To fully assess whole body oxygen transport and delivery, one catheter (a flow directed pulmonary artery [PA] catheter) is placed in the patient's pulmonary artery and another in a peripheral artery. Blood samples are then drawn from each catheter to determine the pulmonary artery and arterial blood oxygen levels. As previously discussed, cardiac output may also be determined using the PA catheter. The physician then infers how well the patient's tissue is oxygenated directly from the measured oxygen content of the blood samples.

[0015] While these procedures have proven to be relatively accurate, they are also extremely invasive. For example, use of devices such as the Swan-Ganz® thermodilution catheter (Baxter International, Santa Ana, Calif.) can lead to an increased risk of infection, pulmonary artery bleeding, pneumothorax and other complications. Further, because of the risk and cost associated with PA catheters, their use in surgical patients is restricted to high-risk or high-blood-loss procedures (e.g., cardiac surgery, liver transplant, radical surgery for malignancies) and high-risk patients (e.g., patients who are elderly, diabetic, or have atherosclerotic disease).

[0016] Among other variables, determination of the oxygenation status of the tissues should include assessment of the amount of blood being pumped toward the tissues (CO) and the oxygen content of that (arterial) blood (CaO_2). The product of these variables may then be used to provide a measure of total oxygen transport (DO_2). Currently, assessment of DO_2 requires the use of the invasive monitoring equipment described above. Accordingly, determination of DO_2 is not possible in the majority of surgical cases. However, in the intensive care unit (ICU), invasive monitoring tends to be a part of the routine management of patients; thus, DO_2 determinations are obtained more readily in this population.

[0017] Partial pressure of oxygen in the mixed venous blood or mixed venous blood oxygen tension (PvO_2) is another important parameter that may be determined using a PA catheter. Because of the equilibrium that exists between the partial pressure of oxygen (PO_2) in the venous blood and tissue, a physician can infer the tissue oxygenation state of the patient. More specifically, as arterial blood passes through the tissues, a partial pressure gradient exists between the PO_2 of the blood in the arteriole passing through the tissue and the tissue itself. Due to this oxygen pressure

gradient, oxygen is released from hemoglobin in the red blood cells and also from solution in the plasma; the released O_2 then diffuses into the tissue. The PO_2 of the blood issuing from the venous end of the capillary cylinder (PvO_2) will generally be a close reflection of the PO_2 at the distal (venous) end of the tissue through which the capillary passes.

[0018] Closely related to the mixed venous blood oxygen tension (PvO_2) is the mixed venous blood oxyhemoglobin saturation (SvO_2) which is expressed as the percentage of the available hemoglobin bound to oxygen. Typically, oxyhemoglobin disassociation curves are plotted using SO_2 values vs. PO_2 values. As the partial pressure of oxygen (PO_2) decreases in the blood (i.e. as it goes through a capillary) there is a corresponding decrease in the oxygen saturation of hemoglobin (SO_2). While arterial values of PO_2 and SO_2 are in the neighborhood of 95 mm Hg and 97% respectively, mixed venous oxygen values (PvO_2 , SvO_2) are on the order of 45 mm Hg and 75% respectively. As such SvO_2 , like PvO_2 , is indicative of the global tissue oxygenation status. Unfortunately, like PvO_2 , it is only measurable using relatively invasive measures.

[0019] Another rather informative parameter with respect to patient oxygenation is deliverable oxygen (dDO_2). dDO_2 is the amount of the oxygen transported to the tissues (DO_2) that is able to be delivered to the tissues (i.e. consumed by the tissues) before the PvO_2 (and by implication the global tissue oxygen tension) falls below a certain value. For instance the $dDO_2(40)$ is the amount of oxygen that can be delivered to the tissues (consumed by the tissues) before PvO_2 is 40 mm Hg while $dDO_2(35)$ is the amount consumed before the PvO_2 falls to 35 mm Hg.)

[0020] Additional relevant parameters may be determined non-invasively. For instance, whole body oxygen consumption (VO_2) can be calculated from the difference between inspired and mixed expired oxygen and the minute volume of ventilation. Cardiac output may also be non-invasively inferred by measuring arterial blood pressure instead of relying on thermodilution catheters. For example, Kraiden et al. (U.S. Pat. No. 5,183,051, incorporated herein by reference) use a blood pressure monitor to continuously measure arterial blood pressure. These data are then converted into a pulse contour curve waveform. From this waveform, Kraiden et al. calculate the patient's cardiac output.

[0021] Regardless of how individual parameters are obtained, those skilled in the art will appreciate that various well established relationships allow additional parameters to be derived. For instance, the Fick equation (Fick, A. Wurzburg, *Physikalisch edizinische Gesellschaft Sitzungsbericht* 16 (1870)) relates the arterial oxygen concentration, venous oxygen concentration and cardiac output to the total oxygen consumption of a patient and can be written as:

$$(CaO_2 - CvO_2) \times CO = VO_2$$

[0022] where CaO_2 is the arterial oxygen content, CvO_2 is the venous oxygen content, CO is the cardiac output and VO_2 represents whole body oxygen consumption.

[0023] While the non-invasive derivation of such parameters is helpful in the clinical setting, a more determinative "transfusion trigger" would clearly be beneficial. If PvO_2 or DO_2 is accepted as a reasonable indicator of patient safety, the question of what constitutes a "safe" level of these

parameters arises. Though data exists on critical oxygen delivery levels in animal models, there is little to indicate what a critical PvO₂ might be in the clinical situation. The available data indicate that the level is extremely variable. For instance, in patients about to undergo cardiopulmonary bypass, critical PvO₂ varied between about 30 mm Hg and 45 mm Hg where the latter value is well within the range of values found in normal, fit patients. Safe DO₂ values exhibit similar variability.

[0024] For practical purposes a PvO₂ value of 35 mm Hg or more may be considered to indicate that overall tissue oxygen supply is adequate, but this is implicit on the assumption of an intact and functioning vasomotor system. Similarly, the accurate determination of DO₂ depends on an intact circulatory system. During surgery it is necessary to maintain a wide margin of safety and probably best to pick a transfusion trigger (whether DO₂, PvO₂, SvO₂ or some derivation thereof) at which the patient is obviously in good condition as far as oxygen dynamics are concerned. In practice, only certain patients will be monitored with a pulmonary artery catheter. Accordingly, the above parameters will not be available for all patients leaving the majority to be monitored with the imperfect, and often dangerous, trigger of Hb concentration.

[0025] Efforts to resolve these problems in the past have not proven entirely successful. For example, Faithfull et al. (*Oxygen Transport to Tissue XVI*, Ed. M. Hogan, Plenum Press, 1994, pp. 4149) describe a model to derive the oxygenation status of tissue under various conditions. However, the model is merely a static simulation allowing an operator to gauge what effect changing various cardiovascular or physical parameters will have on tissue oxygenation. No provisions are made for continuous data acquisition and evaluation to provide a dynamic representation of what may actually be occurring. Accordingly, the model cannot be used to provide real-time measurements of a patient's tissue oxygenation under changing clinical conditions.

[0026] Just as tissue oxygenation physiology has been reviewed, ventilation (the movement of air and medical gases in and out of the lung) and oxygenation (the loading of red cell hemoglobin with oxygen in the lung) are critical processes that impact on tissue oxygenation. Thus, what is needed in the art are relatively non-invasive systems for intuitively displaying physiological information to a physician. The embodiments system described below provide such a system to improve a physician's interpretation of patient data (in the areas of ventilation, oxygenation and perfusion). Other aspects of the invention will become apparent in the description that follows.

[0027] U.S. Pat. No. 6,234,963 is hereby incorporated by reference. *Nunn's Applied Respiratory Physiology*, 4th Ed., J. F. Nunn, is also hereby incorporated by reference.

SUMMARY OF THE INVENTION

[0028] The present invention relates to systems and methods for obtaining physiological information from patients and displaying that information in an intuitive and logical format to a physician. The intuitive format may be termed a medical process diagram or object display because physicians reading the displayed information can quickly perceive the importance of changing patient values.

[0029] Research in applied human factors has focused on using graphical displays in high-risk environments similar to the operating room (e.g., nuclear power control rooms and airplane cockpits and flight decks) to reduce human error. The success of medical process diagrams appears to be a function of how well the operator's cognitive needs are illustrated and mapped into the graphical elements of the display. Using accepted task-analysis methods, a system was developed describing how medical doctors interpret oxygen-transport physiological data to diagnose pathological states and subsequently take appropriate corrective action for their patients. In an effort to make the voluminous data that doctors need to interpret more informative, a set of physiological object displays has been developed.

[0030] The object displays of the present invention have been developed to illustrate: 1) the relationships of data to other data; 2) data in context; 3) a frame of reference for the data; 4) the rate of change information for the data; and, 5) event information. Specifically, a system has been developed for presenting and relating cardiac, vascular, hemodynamic, cardiopulmonary, ventilator state, lung airway resistance, oxygenation and oxygen-transport physiology to doctors. The system uses data acquisition hardware, a computer, physiological parameter calculation software and object display software.

[0031] Unfortunately, current display systems that present physiologic data to physicians in critical care or other medical settings force the physicians to perform a great deal of cognitive work to interpret that data. Interpreting data in this manner has been shown to be more likely to introduce human error. In contrast, the display systems described below utilize visual memory cues and perceptual diagrams to map complex data graphically and in an intuitive manner for physicians and other medical personnel. These data maps are then displayed to match the mental model physicians use to interpret various physiological parameters. Because the system receives analog signals from the patient and thereafter calculates several physiological quantities, patient data is used to drive the display in real-time.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0032] FIG. 1 shows an overview of the oxygen cycle;
- [0033] FIG. 2 shows one embodiment of the extended heart object;
- [0034] FIG. 3 is a flowchart illustrating one method that may be used to update the extended heart object;
- [0035] FIG. 4 shows one embodiment of the vascular circuit object;
- [0036] FIG. 5 shows another embodiment of the vascular circuit object, a split RV and LV version;
- [0037] FIG. 6 is a flowchart illustrating one method that may be used to update the vascular circuit objects;
- [0038] FIG. 7 shows one embodiment of the cardiopulmonary bypass object;
- [0039] FIG. 8 is a flowchart of one method that may be used to update the cardiopulmonary bypass object;
- [0040] FIG. 9 shows one embodiment of the ventilator state object;

[0041] FIG. 10 is a flowchart of one method that may be used to update the ventilator state object;

[0042] FIG. 11 shows one embodiment of a mixed ventilator/lung object;

[0043] FIG. 12 shows another embodiment of the mixed ventilator/lung object;

[0044] FIG. 13 shows another embodiment of the mixed ventilator object;

[0045] FIG. 14 shows one method of updating the mixed ventilator/lung object;

[0046] FIG. 15 shows one embodiment of an oxygenation object;

[0047] FIG. 16 is a flowchart of one method of updating the oxygenation object;

[0048] FIG. 17 is a schematic diagram illustrating one system for collecting, processing and displaying various physiological parameters;

[0049] FIG. 18 is a schematic diagram of one embodiment that can be used to run the present system; and,

[0050] FIG. 19 is a flowchart detailing a software scheme that may be used to run the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0051] I. Hardware System

[0052] FIG. 17 illustrates a system 310 constructed according to an embodiment of the invention. A series of probes 312 are connected to various monitoring activities associated with the patient 314, e.g., a heart rate probe 12a. These probes are well known and typically generate analog signals 316 representative of the monitored activity. The signals 316 are converted through well-known A/D devices 318 in a data conversion module 320 to generate digital data corresponding to the analog signals 16. This data is made available on a data bus 322.

[0053] A processing module 324 processes data on the bus 322 to generate usable quantitative measures of patient activity as well as to compare and create object displays that, for example: (1) relate certain data relative to other data; (2) present data in context; (3) relate data to a frame of reference; (4) determine the rate of change information in the data; and/or (5) to present event information.

[0054] One embodiment of the module 324 thus includes a plurality of data processing sections 326a-326c that analyze and/or quantify the data being input from the probe 312. For example, one section 326a, connected in the data chain to probe 312a, processes data on the bus 322 to provide a representation of heart rate in the form of a digital word. As the patient's heart rate changes, so does the digital word. A memory module 328 is used to store selected data, such as the digital word corresponding to heart rate, so that the module 324 contains a record and a current value of the patient's heart rate activity. The memory 328 also stores information, such as nominal values from which to compare data to a frame of reference, or such as extreme values representative of desired patient thresholds. The display driver section 330, connected to sections 326a-326c, can

thus command the display of the heart rate data in context on the display 332, and/or relative to frame of reference data within the memory 328.

[0055] The data from the sections 326a-326c can also be compared to other data or related to stored thresholds within the assessment module 334. By way of example, data corresponding to probe 312a can be compared relative to probe 312b through a process of digital division within the module 334. The driver 330 can in turn command the display of this related data on the display 332. In another example, the assessment module 334 can compare other data to stored data within the memory 328; and a warning event can be displayed on the display 332 if the comparison exceeds a set threshold.

[0056] Those skilled in the pertinent technology should appreciate that certain probes 312 may have self-contained A/D conversion capability and data manipulation. Furthermore, such probes can easily be connected directly to the assessment module 334 and memory 328 by known techniques.

[0057] The system 310 is controlled by inputs at a user interface 336, such as a keyboard, and the display driver 330 formats data into various object formats on the display 332. Accordingly, by commanding selected processes within the assessment module 334—such as comparison of certain data with other data—such data can be automatically displayed on the display 332 in the desired object format. The particular object displays, according to the invention, are described below. These object displays can be displayed simultaneously on different or the same display and thus sufficient probes are required to collect the associated data.

[0058] FIG. 18 shows a representative computer system 455 that may be used in conjunction with the system 310 of FIG. 17. System 455 can be operated in a stand-alone configuration or as part of a network of computer systems. The system 455 can be an integrated system that collects data from the patient and presents processed data to a display for viewing by a physician or other medical personnel.

[0059] The computer system 455 includes various software executed in conjunction with an operating system, for instance any of the Windows software available from the MICROSOFT Corporation, on a computer 460. Other embodiments may use a different operational environment or a different computer or both.

[0060] In an alternate embodiment of the invention, computer 460 can be connected via a wide area network (WAN) connection to other physicians or hospitals. A WAN connection to other medical institutions enables a real-time review of the patient's progress during surgery or in the intensive care unit.

[0061] Referring again to FIG. 18, one embodiment of the computer 460 includes an Intel Pentium or similar micro-processor running at 128 MHz and 128 Kilobytes (Kb) of RAM memory (not shown). The system 455 includes a storage device 465, such as a hard disk drive connected to the processor 470. The hard drive 465 is optional in a network configuration, i.e., the workstation uses a hard disk or other storage device in a file server. If the computer 460 is used in the stand-alone configuration, the hard drive 465 is preferably 2.0 Gb or more. However, the system is not limited to particular types of computer equipment. Any

computer equipment that can run the display system described herein is anticipated to function within the scope of this invention.

[0062] The computer 460 is integrated with a group of computer peripherals, and is connected to a VGA (video graphics array) display standard, or a color video monitor, which provides the display output of the system 455. The display 475 may be a 15, 17 or 19 inch monitor running at (1024×768) pixels with (65,536) colors. A keyboard 480 that is compatible with IBM AT type computers may be connected to the computer 460. A pointing device 485, such as a two or three button mouse can also connect to the computer 460. Reference to use of the mouse is not meant to preclude use of another type of pointing device.

[0063] A printer 490 may be connected to provide a way to produce hard-copy output, such as printouts for file records. In one configuration, a backup device 495, such as a Jumbo (2 Gb) cartridge tape back-up unit, available from Colorado Memory Systems, is preferably connected to the computer 460.

[0064] In an alternate embodiment of a stand-alone configuration, or as one of the workstations of a network configuration, the system 455 may include a portable computer, such as a laptop or notebook computer or other computers available from a variety of vendors. The portable computer (not shown) is equipped with components similar to that described in conjunction with computer 460.

[0065] It will be understood by one skilled in the technology that a programmed computer can also be implemented completely or partially with custom circuitry. Therefore, the chosen implementation should not be considered restrictive in any matter.

[0066] II. Software

[0067] Many different ways of implementing the software of the present invention will be known to skilled technologists. For example, programming languages such as (Lab-view, C++, Basic, Cobol, Fortran or Modula-2) can be used to integrate the features of the present invention into one software package. An alternative method of illustrating the software of the present invention is to use a spreadsheet program to collect and determine the PvO₂ or other data of a patient in real-time. This method is described in detail below.

[0068] As discussed above, the systems and methods of the present invention collect data from a patient and determine various physiological parameters of a patient in real-time. Software is used to direct this process. Those skilled in the art will appreciate that the desired parameters may be derived and displayed using various software structures written in any one of a number of languages.

[0069] Referring now to FIG. 19, the process is begun when a start signal is transmitted by the user to the system at start state 500. The start signal can be a keystroke of mouse command that initiates the software to begin collecting data. After receiving the start command at state 500, arterial pressure data is collected from a patient at state 502. Arterial pressure data may be collected by hooking a patient up to an arterial pressure monitor as is well known.

[0070] Once data have been collected from a patient at state 502, a "data in range" decision is made at decision state

504. At this stage, the software compares the data collected at state 502 with known appropriate ranges for arterial pressure values. Appropriate ranges for arterial pressure data are, for example, between 70/40 and 250/140.

[0071] If data collected at process state 502 are not within the range programmed in decision state 504, or if the arterial pressure wave is abnormal, an error/exception handling routine is begun at state 506. The error handling routine at state 506 loops the software back to process state 502 to re-collect the arterial pressure data. In this manner, false arterial pressure data readings will not be passed to the rest of the program. If the data collected at process state 502 are in the appropriate range at decision state 504, the software pointer moves to process state 508 that contains instructions for collecting arterial data. Preferably the collected data will include patient temperature, arterial pH, hemoglobin levels, PaO₂ and PaCO₂. Moreover, the data is preferably generated by an attached blood chemistry monitor which may provide information on the patient's blood gas levels, acid-base status and hematology status. In such embodiments the data is collected by receiving data streams via the serial connection from the blood chemistry monitor into the computer. Alternatively, the relevant values may be obtained from accessing data that is manually input from the keyboard.

[0072] As described previously, the blood chemistry monitor continually samples arterial blood from the patient preferably determining several properties of the patient's blood from each sample. Data corresponding to each of the properties taken from the blood chemistry monitor at process state 508 are checked so that they are in range at decision state 510. An appropriate range for the pH is 7.15 to 7.65. An appropriate range for the hemoglobin level is from 0 to 16 g/dL. An appropriate range for the PaO₂ is from 50 mm Hg to 650 mm Hg while an appropriate range for the PCO₂ is from 15 mm Hg to 75 mm Hg.

[0073] If data are not within the appropriate ranges for each specific variable at decision state 510, an error/exception handling routine at state 512 is begun. The error/exception handling routine at state 512 independently analyzes variables collected at state 508 to determine whether it is in range. If selected variables collected at state 508 are not within the appropriate range, the error/exception handling routine 512 loops a software pointer back to state 508 so that accurate data can be collected. If the selected data are in range at decision box 510, the software then derives the CaO₂ value along with the cardiac output (CO) from the previously obtained arterial pressure data at state 514.

[0074] As discussed, cardiac output can be derived from arterial pressure measurements by any number of methods. For example, the Modelflow system from TNO Biomedical can derive a cardiac output value in real-time from an arterial pressure signal. Other methods, as discussed above, could also be used at process step 514 to determine cardiac output. Once a cardiac output value has been determined at process step 514, the patient's total oxygen transport (DO₂) may be derived at process step 515. As previously discussed the total oxygen transport is the product of the cardiac output and the arterial blood oxygen content. This parameter may optionally be displayed and, as indicated by decision state 517, the program terminated if the software has received a stop command. However, if the software has not received a keyboard or mouse input to stop collecting data at decision

state **517**, a pointer directs the program to process state **516** to derive further parameters. Specifically, process state **516** relates to the measurement or input of the patient's VO_2 .

[**0075**] The patient's VO_2 can be calculated using the methods previously described measured by hooking the patient up to a suitable ventilator and measuring his oxygen uptake through a system such as the Physioflex discussed above or using a number of other devices such as systems manufactured by Sormedics and Puritan Bennett. By determining the amount of oxygen inspired and expired, the ventilator may be used to calculate the total amount of oxygen absorbed by the patient. After the patient's VO_2 value has been determined at process step **516**, these variables are applied to the Fick equation at state **518** to provide a real time CvO_2 . The Fick equation is provided above.

[**0076**] Once the CvO_2 is known, mixed venous oxyhemoglobin saturation (SvO_2) and the mixed venous oxygen tension (PvO_2) can be derived at state **520**. As previously explained, values for mixed venous pH and PCO_2 are assumed to have a constant (but alterable) relation to arterial pH and $PaCO_2$ respectively and these are used, along with other variables, in the Kelman equations to define the position of the oxyhemoglobin dissociation curve. Alternatively, algorithms can be derived to calculate these values. Knowing the Hb concentration, a PvO_2 is derived that then provides a total CvO_2 (which includes contributions from Hb, plasma and PFC) equal to the CvO_2 determined from the Fick equation. If the CvO_2 value will not "fit" the Fick equation, another PvO_2 value is chosen. This process is repeated until the Fick equation balances and the true PvO_2 is known.

[**0077**] Those skilled in the art will appreciate that the same equations and algorithms may be used to derive, and optionally display, the mixed venous blood oxyhemoglobin saturation SvO_2 . That is, SvO_2 is closely related to PvO_2 and may easily be derived from the oxygen-hemoglobin dissociation curve using conventional techniques. It will further be appreciated that, as with PvO_2 , SvO_2 may be used to monitor the patient's oxygenation state and as an intervention trigger if so desired by the clinician. As discussed above, mixed venous blood oxyhemoglobin saturation may be used alone in this capacity or, more preferably, in concert with the other derived parameters.

[**0078**] After deriving values for PvO_2 , SvO_2 or both, the value or values may be displayed on the computer display at step **522**. If the software has not received a keyboard or

mouse input to stop collecting data at decision state **524**, a pointer loops the program back to process state **502** to begin collecting arterial pressure data again. In this manner, a real-time data loop continues so that the patient's mixed venous blood oxygen tension (PvO_2) or saturation (SvO_2) is constantly updated and displayed on the computer at state **522**. If the software has received a stop command from a keyboard or mouse input at decision state **524**, then a finish routine **526** is begun.

[**0079**] III. Calculating Physiological Values

[**0080**] The following system can utilize a large Microsoft EXCEL® spreadsheet to collect information from the patient and display the desired physiological parameters. Before receiving real-time inputs of cardiovascular and oxygenation variables, a number of oxygenation constants may be entered into the system. These constants preferably include the patient's estimated blood volume, oxygen solubility in plasma and the oxygen content of 1 g of saturated oxyhemoglobin. The oxygenation constants are then stored in the computer's memory for use in later calculations.

[**0081**] TABLE 1 shows commands from part of a Microsoft EXCEL® spreadsheet that collects a patient's data and derives the value of the desired oxygenation parameters. The program is initialized by assigning names to various oxygenation constants that are to be used throughout the software. In the embodiment shown, oxygenation constants corresponding to blood volume (BV), oxygen solubility in a perfluorocarbon emulsion (O2SOL), specific gravity of any perfluorocarbon emulsion (SGPFOB), intravascular half-life of a perfluorocarbon emulsion (HL), weight/volume of a perfluorocarbon emulsion (CONC), barometric pressure at sea level (BARO), milliliters oxygen per gram of saturated hemoglobin (HbO) and milliliters of oxygen per 100 ml plasma per 100 mm of mercury (PIO) are all entered. The constants relating to perfluorocarbons would be entered in the event that fluorocarbon blood substitutes were going to be administered to the patient.

[**0082**] An example of starting values for Kelman constants, a subset of the oxygenation constants, is also shown in TABLE 1. These starting values are used in later calculations to derive the patient's mixed venous oxygenation state or other desired parameters such as mixed venous blood oxyhemoglobin saturation. As with the other oxygenation constants the Kelman constants are also assigned names as shown in TABLE 1.

TABLE 1

VALUES AT START:	
ASSUMPTIONS:	
Blood Volume (ml/kg) -BV	70
O ₂ solubility in PFB (ml/dl @37 deg C.) -O2SOL	52.7
Specific Gravity of PFOB -SGPFOB	1.92
Intravascular half-life of Oxygent HT (hours) -HL = ½ Life of Oxygent	
Wgt/Vol of PFOB emulsion/100 -CONC	0.6
Barometric Pressure @ sea level -BARO	760
MI O ₂ per gram saturated Hb -HbO	1.34
MI O ₂ per 100 ml plasma per 100 mm Hg -HIO	0.3

TABLE 1-continued

	VALUES AT START:
KELMAN CONSTANTS:	
Ka1 =	-8.5322289*1000
Ka2 =	2.121401*1000
Ka3 =	-6.7073989*10
Ka4 =	9.3596087*100000
Ka5 =	-3.1346258*10000
Ka6 =	2.3961674*1000
Ka7 =	-67.104406

[0083] After the oxygenation constants, including the Kelman constants, have been assigned names, real time inputs from the arterial pressure lines and blood chemistry monitor may be initialized and begin providing data. As shown in TABLE 2, the system depicted in this embodiment derives or receives data relating to the arterial oxyhemoglobin saturation percentage (SaO₂). In particular, saturation percentages are derived from arterial data for oxygen tension (PaO₂), pH (pHa), carbon dioxide tension (PaCO₂) and body temperature (TEMP). If desired by the clinician, the present invention provides for the real-time display of SvO₂ values (as derived from calculated PvO₂, pHv, PvCO₂ and temperature) to be used for the monitoring of the patient's tissue oxygenation status. As previously discussed, values for PvCO₂ and pHv are related, by a fixed amount, to those of PaCO₂ and pHa respectively as determined by algorithms. Cardiac output (CO) is also input as is VO₂.

[0084] When Hb concentration, arterial blood gas and acid/base parameters are entered (automatically or manu-

ally) into the program, the O₂ delivery and consumption variables for both red cell containing Hb and for the plasma phase may be determined. Those variables relating to PFC (in the case of blood substitutes) or Hb based oxygen carrier can also be determined.

[0085] Numerical values useful for the calculation of CaO₂ relate to Hb concentration, arterial oxygen tension (PaO₂), arterial carbon dioxide tension (PaCO₂), arterial pH (pHa) and body temperature. The position of the oxygen-hemoglobin dissociation curve is calculated using the Kelman equations, which are input as oxygenation constants in the program. These calculations produce a curve that, over the physiological range of O₂ tensions, is indistinguishable from the parent curve proposed by Severinghaus (*J. Appl. Physiol.* 1966, 21: 1108-1116) incorporated herein by reference. Iteration may be used to calculate a PvO₂ (via SvO₂) that results in the required mixed venous oxygen contents in Hb, plasma and fluorocarbon to satisfy the Fick equation.

TABLE 2

INPUTS:	AT START:
Hemoglobin (Gm/dl) -Hb	6
Arterial Oxyhemoglobin saturation (%) -SaO ₂	
Calculated Arterial Oxyhemoglobin saturation (%) - = SaO ₂ CALC =	$100 * (SPaO2 * (SPaO2 * (SPaO2 * (SPaO2 + Ka3) + Ka2) + Ka1)) / (SPaO2 * (SPaO2 * (S$
Active Input Value for SaO ₂ -SaO ₂ USED =	IF(SaO ₂ <> O, SaO ₂ , SaO ₂ CALC)
Mixed venous blood oxyhemoglobin saturation (%) -SvO ₂	
Calculated Mixed venous blood oxyhemoglobin saturation = -SvO ₂ CALC	$100 * (SPvO2 * (SPvO2 * (SPvO2 * (SPvO2 + Ka3) + Ka2) + Ka1)) / SPvO2 * (SPvO2 * (SP$
Active Input Value for SvO ₂ -SvO ₂ USED =	IF(SvO ₂ <> O, SvO ₂ , SvO ₂ CALC)
Arterial Oxygen Partial Pressure (mm Hg) -PaO ₂	100
Calculated 'standardized' PaO ₂ -SPaO ₂ =	$PaO2 * 10^{((0.024 * (37 - TEMPUSED)) + (0.4 * (pHaUSED - 7.4)) + (0.06 * (LOG10(40) -$
Active Input Value for PaSO ₂ -PaSO ₂ USED =	IF(PaO ₂ <> O, PaO ₂ , SPaO ₂)
Arterial pH -pHa	
Normal Arterial pH -pHaNORM	7.4
Active Input Arterial pH -pHaUSED =	IF(pHa <> O, pHa, pHaNORM)
Arterial PCO ₂ -PaCO ₂	
Normal PaCO ₂ -PaCO ₂ NORM	40
Active Input Arterial PCO ₂ -PaCO ₂ USED =	IF(PaCO ₂ <> O, PaCO ₂ , PaCO ₂ NORM)
Body Temp C. -TEMP	
Normal Body Temp C. -TEMPNORM	37
Active Input Body Temp C. -TEMPUSED =	IF(TEMP <> O, TEMP, TEMPNORM)
Mixed Venous Oxygen Partial Pressure (mm Hg) -PvO ₂	40.6819722973629
Calculated 'standardized' PvO ₂ -SPvO ₂ =	$PvO2 * 10^{((0.024 * (37 - TEMPUSED)) + (0.4 * (pHvUSED - 7.4)) + (0.06 * (LOG10(40) -$
Mixed Venous pH -pHv	
Normal Venous pH	7.4
Active Input Mixed Venous pH -pHvUSED =	IF(pHv <> O, pHv, pHvNORM)
Mixed Venous PCO ₂ -PvCO ₂	
Normal Mixed Venous PCO ₂ -PvCO ₂ NORM	40
Active Input Mixed Venous PCO ₂ -PvCO ₂ USED =	IF(PvCO ₂ <> O, PvCO ₂ , PvCO ₂ NORM)
Cardiac Output (l/mm) -CO =	((14 - Hemoglobin (gm/dl) * CO Response to 1 gram of Hb Depletion) + 5
CO Response to 1 gr Hb depletion -COCHG	0.7

TABLE 2-continued

INPUTS:	AT START:
Intravascular Oxygent HT Dose(ml/kg) -PFB	
Time Adj. Intravascular Oxygent HT Conc(ml/kg) -TAPFB	
Patient's Weight (kg) -kg	70
Total O2 Consumption (ml/min/kg) -VO2KG	3
Calculated Blood Volume (ml) -CBV =	BV*kg
Calc input Total O2 Consumption (ml/min/kg) -VO2 =	kg*VO2KG

⑦ indicates text missing or illegible when filed

[0086]

TABLE 3

DESCRIPTION:	CALCULATIONS:
Arterial O2 Content in Hemoglobin (ml/dl) -CaO2Hb =	$((\text{Hb} \cdot \text{HbO} \cdot \text{SaO2USED}) / 100)$
Arterial O2 Content in Plasma (ml/dl) -CaO2Pl =	$((\text{PaO2} \cdot \text{PIO}) / 100)$
Arterial O2 Content in PFB (ml/dl) -CaO2PFB =	$((\text{PFB} \cdot \text{kg} \cdot \text{CONC}) / \text{SGPFOB}) / (\text{kg} \cdot \text{BV} \cdot 0.01) \cdot ((\text{O2SOL} \cdot \text{PaO2}) / (100 \cdot \text{BARO}))$
Arterial Oxygen Content (ml/dl) -CaO2 =	$(\text{CaO2Hb} + \text{CaO2Pl} + \text{CaO2PFB})$
Mixed Venous O2 Content in Hemoglobin (ml/dl) -CvO2Hb =	$((\text{Hb} \cdot \text{HbO} \cdot \text{SvO2USED}) / 100)$
Mixed Venous O2 Content in Plasma (ml/dl) -CvO2Pl =	$((\text{PvO2} \cdot \text{PIO}) / 100)$
Mixed Venous O2 Content in PFB (ml/dl) -CvO2PFB =	$((\text{PFB} \cdot \text{kg} \cdot \text{CONC}) / \text{SGPFOB}) / (\text{kg} \cdot \text{BV} \cdot 0.01) \cdot ((\text{O2SOL} \cdot \text{PvO2}) / (100 \cdot \text{BARO}))$
Mixed Venous Oxygen Content (ml/dl) -CvO2SUM =	$(\text{CvO2Hb} + \text{CvO2Pl} + \text{CvO2PFB})$
Mixed Venous Oxygen Content (ml/dl) -CvO2 =	$\text{IF}(\text{CvO2SUM} > 0, (\text{CvO2SUM}), \text{CvO2CALC2})$
Mixed Venous O2 Content (ml/dl) -CvO2CALC2 =	$\text{CaO2} - (\text{VO2} / (\text{CO} \cdot 10))$
Percent of VO2 provided from plasma =	$(\text{O}_2 \text{ Used From Plasma} / \text{Active Input Total O}_2 \text{ Consumption}) \cdot 100$
Percent VO2 provided by PFB =	$100 \cdot (\text{O}_2 \text{ Used From Perflubron} / \text{Active Input Total O}_2 \text{ Consumption})$
Percent of VO2 provided by plasma and PFB =	$100 \cdot ((\text{O}_2 \text{ Used From Plasma} + \text{O}_2 \text{ Used From Perflubron} / \text{Active Input} \cdot 100)$

[0087]

TABLE 4

DESCRIPTION:	OUTPUTS:
Total Oxygen Transport (ml/min) -TDO2 =	$\text{CaO2} \cdot \text{CO} \cdot 10$
O2 Transport in Hemoglobin (ml/min) -DO2Hb =	$(\text{CaO2Hb}) \cdot \text{CO} \cdot 10$
O2 Transport in plasma (ml/min) -DO2Pl =	$\text{CaO2Pl} \cdot \text{CO} \cdot 10$
O2 Transport in Perflubron (ml/min) -DO2PFB =	$\text{CaO2PFB} \cdot \text{CO} \cdot 10$
Calc Total O2 Consumption (ml/min) -VO2CALC =	$(\text{CaO2} - \text{CvO2}) \cdot \text{CO} \cdot 10$
Active Input Total O2 Consumption (ml/min) -VO2USED =	$\text{IF}(\text{VO2} < 0, \text{VO2}, \text{VO2CALC})$
Oxygen Used from Hemoglobin (ml/min) -VO2Hb =	$(\text{CaO2Hb} - \text{CvO2Hb}) \cdot \text{CO} \cdot 10$
Oxygen Used from Plasma (ml/min) -VO2Pl =	$(\text{CaO2Pl} - \text{CvO2Pl}) \cdot (\text{CO} \cdot 10)$
Oxygen Used from Perflubron (ml/min) -VO2PFB =	$(\text{CaO2PFB} - \text{CvO2PFB}) \cdot (\text{CO} \cdot 10)$
Total Oxygen Extraction Coefficient -OEC =	$(\text{CaO2} - \text{CvO2}) / \text{CaO2}$
Hemoglobin Oxygen Extraction Coefficient -HOEC =	$(\text{SaO2USED} - \text{SvO2USED}) / \text{SaO2USED}$

[0088] Based on the numerical values provided, the program calculates oxygenation parameters such as PvO₂ and SvO₂ in real time, as shown in TABLE 2. These values are then fed into the display system described below to generate perceptual diagrams. These diagrams are then used by the physician to determine, for example, when to alter the patient's clinical management.

[0089] TABLE 3 and TABLE 4 show additional information that may be provided by the instant invention further demonstrating its utility and adaptability. More specifically, TABLE 3 provides various oxygenation values that may be calculated using the methods disclosed herein while TABLE 4 provides other indices of oxygen consumption and oxygen delivery that are useful in optimizing patient treatment.

[0090] A closer examination of TABLE 3 shows that the system of the present invention may be used to provide the

individual oxygen content of different constituents in a mixed oxygen carrying system. In particular, TABLE 3 provides calculations that give the arterial or venous oxygen content of circulating hemoglobin, plasma or blood substitute respectively.

[0091] TABLE 4 illustrates that the present invention may also be used to provide real-time information regarding oxygen consumption and delivery. As mentioned previously, Hb or Hct measurements are not a suitable reflection of tissue oxygenation. This is mainly because they only give an indication of the potential arterial O₂ content (CaO₂), without providing information about the total oxygen transport (DO₂) to the tissues where it is to be used. However as seen in TABLE 4 the instant invention solves this problem by providing on line oxygen transport information which is derived based on CaO₂ and cardiac output (CO).

[0092] Currently cardiac output is measured using thermodilution, and CaO_2 is calculated typically by measuring the arterial oxyhemoglobin saturation (SaO_2) and hemoglobin levels, and inserting these values into the following equation: $CaO_2 = ([Hb] \times 1.34 \times SaO_2) + (PaO_2 \times 0.003)$, where $[Hb]$ =hemoglobin concentration (in g/dL); 1.34=the amount of oxygen carried per gram of fully saturated hemoglobin; PaO_2 =the arterial oxygen tension; and 0.003 is the amount of oxygen carried by the plasma (per deciliter per mm Hg of oxygen tension).

[0093] The present invention combines the continuous cardiac output algorithm with the Kelman equations to provide the position of the oxygen hemoglobin dissociation curve. Using on-line and off-line inputs of body temperature, hemoglobin, and arterial blood gases, the present invention is able to trend DO_2 on a continuous basis. The factors used to determine DO_2 are displayed along with their product; thus, the etiology of a decrease in DO_2 (inadequate cardiac output, anemia, or hypoxia) would be readily apparent to the physician, decisions regarding the appropriate interventions could be made expeditiously, and the results of treatment would be evident and easily followed.

[0094] More particularly, preferred embodiments of the invention are used to provide and display real-time DO_2 , arterial blood gases, hemoglobin concentration and CO (and all other hemodynamic data already discussed such as BP, heart rate, systemic vascular resistance, rate pressure product and cardiac work). As shown in TABLE 3, such embodiments can also provide separate readouts of contributions of Hb, plasma and PFC (if in circulation) to DO_2 . That is, the oxygen contributions of each component may be accurately monitored and adjusted throughout any therapeutic regimen. Such data would be particularly useful in both the OR and ICU for providing a safety cushion with respect to the oxygenation of the patient.

[0095] The importance of maximizing DO_2 for certain patients in the ICU has been underscored by recent studies. The present invention may also be used for determining when such intervention is indicated and to provide the data necessary for achieving the desired results. Once DO_2 is known it is possible to calculate the maximum O_2 consumption (VO_2) that could be supported for a certain chosen (and alterable) PvO_2 . As previously discussed, this value may be termed deliverable oxygen (dDO_2). For instance, a PvO_2 of 36 mm Hg might be chosen for a healthy 25 year old patient, where as a PvO_2 of 42 mm Hg or higher might be needed for an older patient with widespread arteriosclerosis or evidence of coronary atheroma or myocardial ischemia. Oxygen consumption under anesthesia is variable, but almost always lies in the range of 1.5 to 2.5 ml/kg/min. If the supportable VO_2 , at the chosen PvO_2 , was well above this range all would be

well and no intervention would be necessary. The closer the supportable VO_2 to the normal VO_2 range the earlier intervention could be considered.

[0096] This relationship could be used to provide a single value, based on deliverable oxygen (dDO_2) vs. oxygen consumption (VO_2), that would simplify patient care. As previously explained, dDO_2 is the amount of oxygen transported to the tissue that is able to be delivered before the partial venous oxygen pressure (PvO_2) and, by implication, tissue oxygenation tension falls below a defined level. Thus, if it is desired that the PvO_2 value not fall below 40 (this number is variable for different patients depending on their general medical condition) then DO_2 (and by implication dDO_2) must be maintained at sufficient levels.

[0097] The supply/demand ratio (dDO_2/VO_2) for a selected PvO_2 can be used to provide a single value showing that the amount of oxygen being administered is sufficient to maintain the desired oxygenation state. For example, if it is known that the dDO_2 required to maintain a PvO_2 of 40 is, say, 300 ml/min and the measured (VO_2) is 200 ml/min then the patient is being supplied with enough oxygen for his needs. That is, the supply/demand ratio is 300 ml/min÷200 ml/min or 1.5. A supply/demand ratio of 1 would imply that the PvO_2 (or other selected parameter i.e. SvO_2) was at the selected trigger value (here 40 mm Hg). Conversely, if the dDO_2 (deliverable oxygen) is 200 ml/min and the VO_2 (oxygen consumption) is 300 ml/min then the ratio is 0.66 and the patient is not receiving sufficient oxygen (i.e., the PvO_2 will be less than 40). Continuous monitoring and display of this ratio will allow the clinician to observe the value approaching unity and intervene appropriately.

[0098] A. Ventilator Data

[0099] Data concerning ventilator state information can be derived from most standard ventilators. For example, many ventilators have a standard RS232 serial port, where most data can be collected in either digital or analog form which can then be used to create the ventilator object displays which would display this information in a more intuitive manner. In other embodiments, ventilator's displays could include information, collected from arterial line sensors, concerning blood gases, pH, hemoglobin values and hemodynamic information such as heart rate, blood pressure, cardiac output and SVR. This data could be integrated with the patient's airway pressure and various compliance data and the system could be integrated to recommend tidal volume, PEEP, RR settings and FiO_2 adjustments to a desired oxygenation/ventilation target based upon this information. In the alternative, the ventilator could be peripherally managed by a computer system and act as a gateway for the distribution to computer information systems ("CIS") and/or hospital information system ("HIS") systems.

Ventilator Inputs:	cmH ₂ O		
	Low	High	Max
1. PAP: peak airway pressure	15	60	120
2. P ₁ P: plateau pressure	15		120
3. MAP: mean airway pressure	15		120

-continued

Ventilator Inputs:		cmH ₂ O		
		Low	High	Max
4. PEEP:	positive end expiratory pressure	0	30	100
5. RR:	respiratory rate/breathing frequency	5		150 (min)
6. I:E:	inspiratory to expiratory (time ratio)			
	(I time %)	10		80
	(pause time %)	0		30
7. TV _I :	tidal volume inspiration	0		2000 ml
8. TV _E :	tidal volume expiration	0		2000 ml
9. MV _D :	minute ventilation delivered	0		20 l/min
10. MV _E :	minute ventilation expired			
11. ET _{CO₂} :	end tidal CO ₂	10		80
12. FiO ₂ :	fraction inspired oxygen	21		100%
13. Pa O ₂ :	partial pressure oxygen			
14. C:	compliance			
15. EE _F :	end expiratory flow			

[0100] IV. Object Displays

[0101] As discussed above, the computer system 455 of FIG. 18 includes software and systems for displaying medical process diagrams relating the values derived or calculated above. The display system collects physiological values and creates object displays that are presented to the physician or other medical personnel. Although some of the data may be derived by reading raw analog or digital data from a patient monitor or other device, some of the values may be read from calculated data such as shown in TABLES 1-4 above.

[0102] The system might sample the data at 300 times per second, and update the display every 1 to 2 seconds. However, the system may be capable of higher sampling and display updates to provide the most up to date and accurate data.

[0103] As discussed above, the perceptual diagrams comprise a series of data objects representing physiological processes in the body. Examples of these data objects include an extended heart object, vascular circuit objects, cardiopulmonary bypass objects, ventilator state objects, mixed ventilator/lung objects and oxygenation objects. These objects, as discussed below, can be displayed alone or together to provide a perceptual diagram.

[0104] FIG. 1 represents a conceptual overview 2 of the interrelationship of various factors of the oxygen cycle. FIG. 1 demonstrates that ventilation, oxygenation and perfusion interrelate with the control (brain) and metabolism. The various factors are all interconnected and each factor influences the other factors. FIG. 1 demonstrates that metabolism and control each affect one another and both metabolism and control affect ventilation, oxygenation and perfusion.

[0105] A. Extended Heart Object

[0106] FIG. 2 is an extended heart object display generally noted at 4. The extended heart object display 4, like the human heart, is divided into four chambers: a right atrium ("RA") metaphor 6; a right ventricle ("RV") metaphor 8; the left atrium ("LA") metaphor 10; and, the left ventricle ("LV") metaphor 12. As with all of the object displays, the extended heart object 4 and portions thereof may be dis-

played in black and white, in color or both and various meanings can be assigned to whether the object or portion are displayed in black and white or in color (when medical standards exist, they can be adhered to—e.g., normal zones in green, caution in yellow, violations of alarm conditions in red, etc.).

[0107] The data inputs for constructing the extended heart object are all available cardiac performance parameters including: filling pressures such as pulmonary capillary wedge pressure ("PCWP") 48 and central venous pressure ("CVP") 47; echo data dimensions of the of the RA, RV, LA and LV; valvular data, including aortic stenosis ("AS"), aortic insufficiency ("AI"), mitral stenosis ("MS"), mitral regurgitation ("MR"), tricuspid stenosis ("TS"), tricuspid regurgitation ("TR"), pulmonic regurgitation ("PR"), pulmonic stenosis ("PS); septal holes, wall motion abnormalities, cardiac conduction data conveying heart rhythm information, electrocardiogram ("EKG") data related to ischemia and echocardiogram data showing decreased contractility of the RV and LV, hypertrophy, and/or diastolic dysfunction. Data can be obtained through an EKG that depicts conduction of electrical activity in the heart, and echocardiography to measure blood flow into and between the heart chambers, ventricle compliance and valve conditions, and a pulmonary artery catheter can be used for obtaining data relating to PCWP and CVP.

[0108] The four chamber shaped heart of the extended heart object 4, as shown in FIG. 2, is a reference frame for the "normal" relative proportion and anatomy of the human heart. In other embodiments, the heart could be represented as two, two chambered hearts for the pulmonary versus systemic regulations.

[0109] In the Extendedheart object, the RA, RV, LA and LV of the heart can expand or contract to show the filling state of the individual chambers. For example, in FIG. 2, the RV 8 and the LV 12 are in a filled state. This is demonstrated by the outward bulging of the individual chambers. If the filling pressures were low, the CVP and PCWP meters would point inwards and the display would show the RV and LV chambers to be scalloped inwards. The shape of the chambers conveys the status of FULL vs EMPTY. Located in-between the RA 6 and the RV 8 on the far left is a CVP meter 47 which moves in conjunction with the filling state

of the RV **8**. For example, if the RV is overfilled, the CVP meter **47** moves from the twelve o'clock position toward the eleven o'clock position or beyond. If the RV is under filled (not shown), the CVP meter moves from the twelve o'clock position to the one o'clock position or beyond. At the bottom of the LV chamber is the PCWP meter **48** which, like the CVP meter **47**, moves according to the filling state of the LV **12**.

[0110] Vertical lines (**14** and **32**), extending into and away from the heart chambers, illustrate the flow in and the flow out of blood from the various chambers. For example, global direction of flow is shown by the four arrows **14** from the RA **6** to the RV **8** through the tricuspid valve **16**. The four arrows from the RA **6** to the RV **8** represents normal flow from the RA **6** to the RV **8**. Mild regurgitation could be represented by three arrows in one direction and one arrow in the opposite direction. Arrows pointing in opposite direction as shown at **32** in FIG. 2, can have the following meanings: one arrow in the opposite direction to flow represents regurgitation (mild regurgitation); two arrows in the opposite direction represent (as shown at **32** in FIG. 2 at the mitral valve) represents two plus regurgitation (moderate regurgitation) and three arrows in the opposite direction represents three plus (severe regurgitation) [standard terms used in quantifying valve function from echocardiogram studies].

[0111] Also shown in FIG. 2 is sinus node **20** with conduction/rhythm information in the form of waves emanating outwardly in synchronization with an EKG trace. Extending from the sinus node **20** is the arterial bundle **22**. Extending into the RA **6** is the venacava vein **24**, extending from the RV **8** is the pulmonary artery **26**, extending into the LA **10** is the pulmonary vein **28** and extending from the LV **12** is the aorta **44**.

[0112] In the middle of the Extendedheart object **4** is a bold vertical line representing the septum **34**. In the middle of the septum **34** is an oval shaped object **36** which represents the Atrio-ventricular node (AV-Node) and is intersected by the ventricular bundle (bundle of His **22**). To the left of the septum **34** in the RV **8** is an elongated, rectangular shaded box **38** which represents the compliance state of the right ventricle. A reference box depicting the normal width is the same as the shaded box and therefore not visible. To the right of the septum **34** in the LV **12** are two vertically oriented rectangular, shaded boxes **40A** and **40B**, which illustrates non-compliant left ventricle because the shaded area extends beyond the reference box width that conveys the normal compliance state. Greater than normal compliance would be shown as a shaded area narrower than the reference box. Typically the reference box would be shown in a different color, such as purple, that would make it easy to see the patient state relative to the normal. As noted, to the left of the septum **34** is another elongated, rectangular shaded box **38** and this represents a normal right ventricle. The RV and LV can be represented as being of normal, increased or decreased compliance.

[0113] Inside the two vertically oriented rectangular boxes **40A** and **40B** is a slightly offset triangle **42**, shaded in color wherein the size of triangle **42** changes based on ischemic changes in the EKG in relation to ST-changes which show various conditions such as angina or ischemia.

[0114] Below LV **12** and extending from the Extendedheart object **4** is an example of stenosis of the aortic valve

44. The one arrow extending from the aortic valve **44** shows obstructed blood flow. Separating the aortic valve **44** and the LV **12** are two, side-by-side, bolded, horizontally oriented rectangles **46A** and **46B** which represent a thickened aortic valve. Thickening of any valve would be shown in the same manner. The Extendedheart object **4** of the present invention mimics the human heart and displays information in an intuitive manner to physicians or other medical personnel allowing for the display of a large quantity of information in a simplified manner.

[0115] Referring now to FIG. 3, the process of updating the Extendedheart object begins when a start signal is transmitted by the user at start state **5**. The start signal can be a keystroke or a mouse command that initiates the software to begin collecting data. After receiving the start command at state **5**, the process moves to a state **7** where the stroke volume ("SV") is read. The stroke volume can be read from a table or a buffer in the computer system. After the SV is read, the process moves to a state **9** where the heart rate ("HR") is read.

[0116] Once data has been collected from a patient at any state, for example state **9**, a "data in range" decision can be made. That is, the software compares the data collected at a given state. e.g., state **9**, with known appropriate heart rates for a particular patient or previous heart rates read from previously collected data. If data at a given state, such as state **9**, is not within preprogrammed ranges or are completely anomalous (i.e., out of range of any possible human heart rate), an error/exception handling routine can be initiated and the process begins again. The error/exception handling routine loops the software back to process step **9** and begins again. In this manner, false or erroneous information is not fed into the rest of the program. If data collected at a given state in appropriate ranges, the software pointer moves to the next process state.

[0117] After the HR is read, the process then moves to a state **11** where central venous pressure ("CVP") filling pressure is read. Like HR, CVP filling pressure may be collected from an EKG. A decision is then made at decision state **13** whether the CVP has changed since the last reading. If the CVP has changed, a determination is made at decision state **15** whether the CVP has increased or decreased. If the CVP has decreased, the process moves to a state **17** where the CVP meter is moved to the right and the outer boundary of the right ventricular metaphor moves inward to indicate a less filled right RV. In the alternative, if at decision state **15** the determination is made that the CVP has increased, the process moves to state **19** where the CVP meter is moved to the left and the outer boundary of the right ventricular metaphor moves outward to indicate a swollen or overfilled RV.

[0118] The process then moves to a state **21** where the pulmonary capillary wedge pressure ("PCWP") is read. The process then moves to a state **23** to determine whether the PCWP has changed since the last reading. If the PCWP has changed, a determination is made at state **25** as to whether the PCWP has increased or decreased. If the PCWP has decreased, the process moves to state **27** where the PCWP meter is moved to the left and the outer boundary of the LV heart chamber moves inward, or to the left, to indicate an under filled LV. If the value of the PCWP has increased, the process moves to state **29** where the PCWP meter is moved

outward, or to the right, and the outer boundary of the LV metaphor moves outward to indicate an overfilled or swollen LV.

[0119] The process then moves to decision state **31** where the valve function from RA to RV is read. The process then moves to a state **33** where a determination is made whether the valve function from the RA to the RV has changed since the last reading. If the valve function has changed, the process moves to state **35** where if the valve flow has decreased, the process moves to state **37** where the number of lines extending from the RA to the RV through the tricuspid valve is decreased and bars showing stenosis are extended. If the valve flow from the RA to the RV has increased, the process moves to state **39** where if the valve function has increased, the number of lines extending from RA to RV through the tricuspid valve is increased and the bars of stenosis are shortened.

[0120] The process then moves to state **41** where the valve function from the RV through the pulmonary artery ("PA") is read. The process then moves to a state **43** where a determination is made whether the valve function from the RV through the pulmonary artery has changed since the last reading. If the valve function has changed, the process moves to state **45** to determine whether the valve flow has increased or decreased. If the valve flow has decreased, the process moves to state **47** where the number of lines extending from the RV through the pulmonary artery is decreased and bars showing stenosis are extended. If the valve flow has increased, the process moves to state **49** where the number of lines extending from the RV through the pulmonary artery is decreased and the bars of stenosis shortened.

[0121] The process then moves to state **51** where valve function from the LA to the LV through the mitral valve is read. The process then moves to a state **53** where a determination is made whether the blood flow from the LA to the LV has changed since the last reading. If the valve function has changed, the process moves to state **55** to determine whether the blood flow has increased or decreased. If the valve flow has decreased, the process moves to state **57** where the number of lines extending from the LA to the LV through the mitral valve is decreased and bars showing stenosis are extended. If the valve flow has increased, the process moves to state **59** where the number of lines extending from the LA to the LV through the mitral valve is decreased and the bars showing stenosis are shortened.

[0122] The process then moves to state **61** where valve function from the LV through the aortic valve **44** is read. The process then moves to a state **63** where a determination is made whether the valve function from the LV through the aortic valve has changed since the last reading. If the valve flow has changed, the process moves to state **65** to determine whether the valve flow has increased or decreased. If the valve flow has decreased, the process moves to state **67** where the number of lines extending from the LV through the aortic valve is decreased and the bars of stenosis are extended. If the valve flow has increased, the process moves to state **69** where the number of lines extending from the LV through the aortic valve is decreased and the bars of stenosis are shortened. If ST-changes are present on EKG, a triangle will be shown that represents a region of ischemia. The process then moves to state **89** where right and left ven-

tricular compliance are read. The process then moves to state **91** where it is determined whether either the left ventricle or right ventricle has become less compliant (stiffened or thickened). If it is determined that either or both the RV or LV have become less compliant, the process then moves to state **93** to determine which or whether both ventricles have thickened. If either or both the RV or the LV have been identified as having thickened, rectangular boxes **38** and **40** are increased in width. This is shown in **FIG. 2** where two rectangular boxes, **40A** and **40B** are shown to illustrate a mildly noncompliant RV and a moderately noncompliant LV. The process then ends at an end state **97**.

[0123] B. Vascular Circuit Object

[0124] **FIG. 4** shows a vascular circuit object **52** which visually illustrates the oxygenation circuit of blood as it is pumped from the RA **6** and RV **8** of the heart **4** to the alveolus **54** back through the LA **10** and LV **12** of the heart **4** for oxygenation of the cell/tissues **56**. Arrows depict the direction of the flow of blood from the RV **8** to the alveolus **54** and through the LV **12** to provide oxygen to the cell/tissues **56**. The vascular resistor objects (**58** and **76**) are used by medical personnel to optimize the hemodynamic physiology of patients during surgery.

[0125] Located between the heart object **4** and the alveolus object **54** is a pulmonary vascular resistor object **58** which measures blood flow as it leaves the RV **8**. Both vascular resistor objects **58** and **76** are used to display the blood flow equivalent of Ohm's law and represents the following equations:

$$\frac{(\text{Mean Arterial Pressure})-(\text{Central Venous Pressure})}{(\text{Cardiac Output})\times(\text{Systemic Vascular Resistance})};$$

and

$$\frac{(\text{Mean Pulmonary Arterial Pressure})-(\text{Pulmonary Capillary Wedge Pressure})}{(\text{Cardiac Output})\times(\text{Pulmonary Vascular Resistance})}.$$

[0126] This data is displayed into linear scales relating to the pressure gradient for blood flow in the form of a "pipe" shaped object which is the pulmonary vascular resistor object **58** wherein blood flow is from right to left. A set of two Y axes, **60** and **62**, produce the pipe shape of the vascular resistor object **58**. Right Y axis **60** includes a mean arterial pressure (MAP) indicator **64** and a central venous pressure (CVP) indicator **66** which are in the form of diamond shaped objects. The distance between the MAP indicator **64** and the CVP indicator **66** indicates the blood input area **68** and represents the flow of blood into the pipe. A left Y axis **62** includes a cardiac output (CO) indicator **70** which reflects the calculated or measured cardiac output of the patient. As the cardiac output of the patient increases, the distance between the horizontal line intersecting the CO indicator and parallel X-axis beneath the CO increases as CO increases and the distance decreases as CO decreases.

[0127] Upstream of pulmonary vascular resistor object **58** is red blood cell object **72**. Red blood cell object **72** reflects the level of oxygenation of the arterial blood prior to the blood reaching the alveolus **54**. Arterial Oxygenation Content=(Arterial Oxygen Saturation) \times (Hemoglobin) \times (1.34). As displayed in **FIG. 4**, the amount of shading of the blood cell object **72** shows the percentage of oxygenation of the blood. As shown at **72** in **FIG. 3**, less than half of the blood is oxygenated (when less than half shaded, the cell is only half filled with oxygen).

[0128] As the blood passes through the lungs the blood becomes oxygenated. This is illustrated in FIG. 4 by the placement of the alveolus 54 between the left blood cell object 72 and the right blood cell object 74. Right blood cell object 74 illustrates the level of oxygenation of venous blood oxygenated by the lung 54. As with red blood cell object 72, the level of oxygenation of the blood leaving the alveolus is indicated by the percentage of shading of red blood cell 74. Both red blood cell objects mimic the in vivo state of oxygenation of the blood and are thus intuitive to physicians.

[0129] The blood then passes through the LA and the LV of the heart. As the blood leaves LV 12, it passes through systemic vascular resistor object 76 which operates in the same manner as described with pulmonary vascular resistor object 58. MAP indicator 78 and CVP indicator 80 represents the blood input area and represents the inflow of blood into the pipe. CO indicator 82 represents the calculated or measured cardiac output of the patient.

[0130] An alternative embodiment of the vascular circuit is shown in FIG. 5. In this embodiment, the Extendedheart object is omitted. In its place is an abbreviated heart object showing only the right ventricle ("RV") object 86. Blood flow is indicated by an arrow between the cell/tissue object 84 and RV object 86. In this embodiment, the chambers of the heart are split with the LV 96 downstream. Blood flow leaves RV 86 and enters into a pulmonary vascular resistor object 88 which functions in the same manner as vascular resistor object 58 of FIG. 4. Vascular resistor object 88 is used to display the blood flow equivalent to Ohm's law and the data is visually displayed in the form of object 58 as a "pipe" shaped object wherein blood flow is from right to left. The area inside the pipe can be darkened to represent the inflow of blood into the pipe and to aid visually. Both vascular resistance objects of FIG. 5 can have a MAP, CVP and CO indicators in the same manner as vascular resistor objects 58 and 76 of FIG. 4.

[0131] Downstream of the RV is a red blood cell object 90 which indicates the level of oxygenation of the blood leaving the RV which, as previously described, is visually indicated by the amount of shading of the red blood cell object 90. Further downstream from the red blood cell object 90, beyond alveolus 94, is a second red blood cell object 92. Red blood cell object 92 shows that the blood, at this point in the vascular circuit, is almost completely oxygenated. This is of course due to the fact that the blood is oxygenated by alveolus 94 located between the red blood cell objects 90 and 92.

[0132] Downstream from the red blood cell object 92 is LV 96 where blood passes through to the systemic vascular resistance object 98. Vascular resistance object 98 operates in a similar manner as the vascular resistance object 76 shown in FIG. 4. Blood flow is from the left to right and the widened area of the "pipe" illustrates a large inflow of blood to the and the narrowed darkened portion of the pipe represents the flow of blood from the to the cells/tissue 84. Blood then leaves the cell/tissue 84 area and enters the RV 86 and the cycle is repeated.

[0133] In an one embodiment, all of the information of Extendedheart object 2 is incorporated into the Vascular Circuit Object 52 in FIG. 4 and can be displayed. This information could be accessed or suppressed at the desire of the user.

[0134] Referring to FIG. 6, a process of updating the Vascular Circuit Object is described. The process begins at start state 105 and then moves to a state 107 wherein the mean arterial pressure (MAP) is read. A determination is made at decision state 109 whether the MAP has changed since the last reading. If the MAP has changed, the process moves to state 111 to determine whether the MAP has increased or decreased. If MAP has decreased, the process moves to state 113 where MAP indicator 64 is moved downward along Y-axis 60. If a determination was made at state 111 that MAP has increased, the process moves to state 115 where the MAP indicator moves upward along Y-axis 60.

[0135] The process then moves to state 117 wherein the central venous pressure ("CVP") of the patient is read. A determination is made at decision state 119 whether the CVP has changed since the last reading. If the CVP has changed, the process moves to state 121 to determine whether the CVP has increased or decreased. If the CVP has decreased, the process moves to state 123 wherein the CVP indicator 66 moves down Y-axis 60. If the CVP has increased, the process moves to state 125 where the CVP indicator 66 moves up Y-axis 60.

[0136] The process then moves to state 127 where the cardiac output (CO) is read. A determination is made at state 129 whether or not the CO has changed since the last reading. If the CO has changed, the process moves to state 131 to determine whether the CO has increased or decreased. If the CO has decreased, the process moves to state 133 wherein the cardiac output indicator 70 is moved downward along Y-axis 62. If a determination is made at state 131 that the CO has increased, the process moves to state 135 wherein the cardiac output indicator 70 moves up Y-axis 62.

[0137] The process then moves to a state 137 where it reads the CaO₂ value of the blood prior to the blood being oxygenated by the lungs. This value could be read from a data table or from any type of memory storage in the computer system. Once the CaO₂ values are read, the process moves to state 139 to determine whether the CaO₂ value has changed from the last reading. If the CaO₂ value has changed, the process moves to state 141 to determine whether the CaO₂ value has increased or decreased since the last reading. If the CaO₂ value has decreased, the process moves to state 143 and the level of shading of red blood cell object 72 is decreased. However, if the process determined that the CaO₂ value has increased, the process moves to state 145 where the level of shading of red blood cell object 72 is increased.

[0138] The process then moves to state 147 where the CvO₂ value of the blood is read after the blood is oxygenated by the lungs. This value could be read from a data table or from any type of memory storage in the computer system. Once the CvO₂ value is read, the process moves to state 149 to determine whether the CvO₂ value has changed since the last sampling. If the CvO₂ value has changed, the process moves to state 151 to determine whether the CvO₂ has increased or decreased since the last reading. If the CvO₂ value has decreased, the process moves to state 153 and the level of shading of red blood cell object 74 is decreased. However, if the process determines that the CvO₂ value has increased, the process moves to state 155 where the level of shading of the red blood cell object 74 is increased.

[0139] Returning to FIG. 4, the blood then passes through LA 10 and LV 12 of Vascular Circuit 52 and then the process moves to systemic vascular resistor object 76. Systemic vascular resistor object 76 works in the same manner as pulmonary vascular resistor object 58 and the process steps will not be repeated again.

[0140] C. Cardiopulmonary Bypass Object

[0141] As shown in FIG. 7 is a cardiopulmonary bypass object 102. The cardiopulmonary bypass object 102 illustrates information on the oxygenation of blood diverted from the heart during a cardiopulmonary bypass procedure. The cardiopulmonary bypass object 102 is comprised generally of three components (reading right to left in FIG. 7): 1) a venous reservoir object 104; 2) a roller pump object 106; and, 3) an oxygenator object 108.

[0142] The venous reservoir object 104 graphically illustrates the quantity of blood in the venous reservoir. In the illustration of FIG. 7, a diamond shaped marker 110 shows the level of stored venous blood and moves up and down metered scale 104 as the volume of blood fluctuates. Blood flow moves from the venous reservoir 104 to the roller pump object 106. Roller pump object 106 depicts the state of the pump as either being "off" or "on" by showing the roller 112 rotating clockwise or counter clockwise when "on" or static or unmoving when the pump is "off". The roller 112 rotates clockwise or counter-clockwise depending on where the pump is located and the underlying global direction of blood flow. Total blood flow from the roller pump object is depicted by a diamond shaped marker 114 which, in the example of FIG. 7, has the number 5.1 located therein which depicts 5.1 L/min blood flow into the oxygenator object 108. Horizontally extended lines 116 extending from roller pump to the oxygenation object 108 also depict blood flow. Five (5) arrows are shown which roughly corresponds to the 5.1 number in diamond shaped marker 114 representing 5.1 liters per minute of blood flow to oxygenator object 108.

[0143] Intersecting diamond shaped marker 114 is a bold line 118 oriented above and parallel to the five (5) arrows 116. Line 118 connects the roller pump object 106 to the blood oxygenator object 108 and also intersects and moves up and down a vertically oriented scale 120. Scale 120 is metered (L/min) to show blood flow from the roller pump object 106 to the blood oxygenator object 108. The shorter dashed lines 122 pointing to scale 120 show potential unused blood flow. As blood flow increases, horizontal bold line 118 moves vertically upward in a Y-axis direction (but remains horizontally oriented) and shorter dashed lines 122 lengthen and become solid lines and pass through under bold line 118 illustrating actual blood flow. As blood flow decreases, horizontal bold line 118 moves vertically downward and lines 116 shorten into shorter dashed lines 122.

[0144] Blood flow is then shown moving from the roller pump object 106 to oxygenator object 108 as shown by the bold arrow 109 (which is a static line) moving through the top of oxygenator object 108. Oxygenator object 108 graphically illustrates the relationship of blood flow and gas flow and concentration across a diffusion surface represented by the dashed line. Two sets of vertically oriented rectangles 124A, 124B and 126A, 126B, side-by-side, measure blood flow, gas flow and gas concentration. For example, 124A is metered to measure arterial carbon dioxide concentration (PaCO₂) in the bloodstream while 124B is metered to

measure gas flow (oxygen) into the bloodstream. 126A measures fraction of inspired oxygen in the blood stream (FiO₂) and 126B measures mixed arterial oxygen tension (PaO₂). Two diamond shaped markers, one (128A) measuring mixed arterial carbon dioxide tension PaCO₂ and the other gas flow (128B) are shown and can be connected by a horizontal line which helps the user visualize the interrelationship of the PaCO₂ parameter of the blood and gas flow. Two other markers visually displaying FiO₂ 130A and the other marking displaying PaO₂ (130B) are also displayed.

[0145] In an alternate embodiment, a meter could be displayed, adjacent or near the PaCO₂ meter, for measuring in real time the amounts of the anesthetic isoflurine both administered and respired. In the same manner as with the other meters for measuring various values, a marker could be used for measuring the amounts of administered isoflurine and another marker for measuring amounts of expired isoflurine. Both markers would move vertically up and down the meter (which would measure isoflurine in ml/L). When the meters indicate two different values, this would indicate to the physician that the administered and measured isoflurine amounts are different telling the physician the amount of anesthetic in the patient.

[0146] Referring to FIG. 8, a process for updating Cardiopulmonary Bypass Object 102 is described. The process begins at start state 171 and then moves to state 173 wherein the level of stored venous blood in venous reservoir 104 is read. The process then moves to state 175 wherein the process determines whether the level of stored venous blood has changed since the last reading. If the level of stored venous blood has changed, the process moves to state 177 to determine whether the level of stored venous blood has increased or decreased. If the level has decreased, the process moves to state 179 where if the level of stored venous blood has decreased, diamond 110, which acts as a marker along the venous reservoir object 104, moves downward along venous reservoir object 104. If it is determined that the level of stored venous blood has increased, the process moves to state 181 where the diamond 110 moves upward along object 104.

[0147] The process then moves to state 183 where a determination is made whether the pump is activated. If the pump is not activated, the process moves to state 187 where object 112 is made stationary. However, if the pump is activated, that is "turned on", the process moves to state 189 where the pump object rotates in the clockwise direction.

[0148] The process then moves to state 191 where the quantity of blood flow from roller pump object 106 to oxygenator object 108 is read. The process then moves to state 193 where it is determined whether the amount of blood flow from roller pump object 106 to oxygenator object 108 has changed. If it is determined that there has been a change, the process moves to state 195 where a determination is made whether the amount of blood flow from roller pump object 106 to oxygenator object 108 has increased or decreased. If it has decreased, the process moves to state 197 and line 118, along with marker 114, move down scale 120 in the Y direction and the number of horizontally extended arrows 116, which correspond to the liters of blood flow from the roller pump object 106 to the blood oxygenator object 108, are decreased accordingly. If the blood flow from roller pump object 106 to the blood pump object 108 has

been determined to have increased at state **195**, the process moves to state **199** and the line **118**, along with marker **114**, are moved upward along meter **120** in the Y direction and the number of horizontally extended arrows **116** are increased accordingly.

[**0149**] The process then moves to state **201** where the PaCO₂ value of the blood is read. The process moves to state **203** where it is determined if the PaCO₂ value has changed. If the value has changed, the process moves to state **205** where it is determined whether the PaCO₂ value has increased or decreased. If the PaCO₂ value has decreased, the process moves to state **207** where diamond marker **128A** lowers along meter **124A** and reflects the appropriate PaCO₂ value. If it is determined that the PaCO₂ value has increased, the process moves to state **209** where diamond shaped marker **128A** raises along meter **124A** to reflect the updated PaCO₂ value.

[**0150**] The process then moves to state **211** where the gas flow, as shown in **FIG. 7**, is read. The process then moves to state **213** where it is determined whether the gas flow has changed since the last reading. If the gas flow has changed, the process moves to state **215** where it is determined whether the gas flow has increased or decreased. If the gas flow has decreased, the process moves to state **217** where marker **128B**, which marks the flow of gas as shown by meter **124B**, is lowered along meter **124B** to the sampled gas flow measurement. However, if it is determined that the gas flow has increased, the process moves to state **219** where marker **128B** is raised along meter **124B** to the corresponding value.

[**0151**] The process then moves to state **221** where the FiO₂ value of blood is read. The process then moves to state **223** where it is determined whether the FiO₂ value of the blood has changed since its last reading. If it has changed, the process moves to step **225** where it is determined whether the FiO₂ value has increased or decreased since the last sampling. If it has decreased, the process moves to state **227** where marker **130a** is lowered along meter **126A** in the Y direction to the appropriate reading. If it is determined at state **225** that the FiO₂ value has increased, the process moves to state **229** and marker **130A** moves upward along meter **126A** to the corresponding FiO₂ value reading.

[**0152**] The process then moves to state **231** where the PaO₂ value is read. A determination is then made at decision state **235** whether the PaO₂ value of the blood has increased or decreased since the last sampling. If it is determined that the PaO₂ value has changed, the process moves to state **237** where it is determined whether the PaO₂ value has increased or decreased. If it is determined that the PaO₂ value has decreased, the process moves to state **239** where marker **130B**, which marks the PaO₂ value along meter **126B**, is lowered along meter **126B** to mark the last measured PaO₂ value. If it determined at state **237** that the PaO₂ value has increased, the process moves to state **241** and marker **130B** is raised to the appropriate PaO₂ value along meter **126B**.

[**0153**] D. Ventilator State Object

[**0154**] As shown in **FIG. 9** is Ventilator State Object **140**. Ventilator State Object **140** has two major components: a volume ventilator object **142** and a pressure ventilator object **144**. Many ventilators are either volume or pressure ventilators and some ventilators are mixed volume/pressure. The

object display of **FIG. 9** allows physiological display information as to both types of ventilators or a mixed volume-pressure ventilator. However, when in a volume mode, the pressure ventilator settings are shaded gray or shaded in another color. Likewise, when in a pressure mode, the volume ventilator settings are shaded gray or shaded in another color.

[**0155**] The volume ventilator object **142**, which may be used in conjunction with a standard volume ventilator, is comprised of a rectangular box **146** which displays information related to respiratory rate ("RR"), breath cycle time ("BCT"), inspiration time ("I"), expiration time ("E"), I:E ratio and volume setting of the ventilator. Much of this data can be obtained from the RS232 serial ports on most ventilators.

[**0156**] A shaded rectangle **247** is divided between a darker shaded portion **148** which represents inspiratory time and another more lightly shaded portion of the rectangle **150** which represents expiratory time **150**. Both inspiratory and expiratory time added together equal breath cycle time "BCT" which is shown in lower BCT meter **152**.

[**0157**] As shown in **FIG. 9**, the I portion of the BCT is 1 second with the shading between the three and four second mark. The expiratory time portion ("E" portion) is 1.5 seconds (111.5 I:E ratio) which is the difference between 4 and 5.5 seconds of the BCT meter. Marker **154** shows the division between inspiratory time and expiratory time of the breath cycle. As the breath cycle shortens or lengthens based upon volume settings, rectangle **247** will also shorten or lengthen.

[**0158**] Above BCT meter **152** is respiratory rate ("RR") meter **162**. Respiratory rate is defined as the number of breaths per minute and is set by the physician on the ventilator. In **FIG. 9**, the RR is set at 10 breaths/minute as is seen on the RR meter **162**. The lower the respiratory rate, the longer the BCT. Square marker **156** gives the user a clear indication between BCT and RR.

[**0159**] Above rectangular box **146** is a bellows object **158** which visually displays the volume of air being pushed into the lungs. In the case of **FIG. 9**, **700** cubic centimeters of air are shown as being pushed into the lungs by the ventilator. Marker **160** gives a clear indication of the setting of the ventilator.

[**0160**] Pressure ventilator object **144** is an alternate ventilator object useful with pressure ventilators. Located within the pressure ventilator object **144** is a propeller object **262** which rotates in the counter-clockwise direction to illustrate flow of air from the pressure ventilator to the patient. When the pressure ventilator is off or not functioning, the propeller object **262** is static and does not rotate. In an alternative embodiment, the rotational velocity of the propeller object **262** can indicate the level of air flow from the pressure ventilator to the patient.

[**0161**] Flow from the pressure ventilator to the patient is illustrated in the series of horizontal lines **164** extending from the pressure ventilator object **144** to the patient. The six horizontal lines indicate that 60 liters/min of air is flowing from the pressure ventilator to the patient. This is also illustrated by the diamond shaped object **166** which displays the number of liters of air per minute which is flowing to the

patient. Horizontal bold line **168** intersects object **166** and the line **168** moves up and down depending on air flow to the patient.

[0162] The series of four horizontal lines **170** adjacent to propeller object **262** and above horizontal lines **164** illustrate potential unused air flow. Meter **172** also illustrates the quantity of liters of air per minute to the patient. The series of horizontal lines **164** are only displayed during inspiration of the patient's breath. During inspiration, the horizontal lines are turned off and are not shown.

[0163] To the right of object **166** is valve **174** which is closed while the patient is inspiring and open when the patient is expiring (when the pressure ventilator is activated). At the right hand side of the pressure ventilator object **144** is a meter **176** for displaying peak inspiratory pressure ("PIP") and mean airway pressure ("MAP"). Meter **176** has a diamond shaped object **178** for displaying PIP levels and a diamond shaped object **180** for displaying MAP levels. Both objects move up and down meter **176** depending on the PIP and MAP levels. PIP and MAP levels are sometimes set by the physician depending on the ventilation mode.

[0164] Beneath the PIP and MAP indicators is positive end expiratory pressure ("PEEP") indicator **182**. PEEP may be a triggered setting (patient initiated setting) which is indicated by the presence of box **184** which has a "T" inside of the box. PEEP can also be measured wherein the PEEP indicator **182** would be diamond shaped and box **184** would not be shown. When measured, diamond shaped PEEP indicator **182** moves vertically up and down meter **176**.

[0165] Beneath pressure ventilator object **144** is meter **186** which provides information on respiratory rate ("RR") and breath cycle time ("BCT") of the pressure ventilator in the same manner as with the volume ventilator. In an alternative embodiment, a similar configuration of the volume ventilator or pressure ventilator object can be positioned over the volume ventilator **142**.

[0166] Referring to FIG. 10, the process starts of modulating the ventilator state object starts at **261**. The process moves to state **263** where it is determined whether the ventilator is a volume ventilator, pressure ventilator or a mixed volume/pressure ventilator. If the process determines that it is a pressure ventilator, the process moves to state **283**. If the process determines that it is a volume ventilator, the process moves to state **265** where the process reads the volume of air being delivered to the patient's lungs. As stated previously, the volume of air pushed into the patient's lungs is a set parameter. After reading the volume, the process moves marker **160** to the corresponding reading on bellows object **158**. The process then moves to state **269** and reads the respiratory rate ("RR") set by the physician. The process then moves to state **271** where marker **156** is moved to correspond to the RR along meter **162**. The process then moves to state **273** where inspiratory and expiratory times are read. The process then moves to state **275** where breath cycle time (the sum of inspiratory and expiratory time) is displayed on meter **152**. The process then moves to state **277** where the inspiratory/expiratory ("I:E") time ratio is read. The process then moves to state **279** where the I:E ratio is displayed.

[0167] If the ventilator is only a volume ventilator, the process moves to end state **281**. If the ventilator is a pressure

ventilator the process moves from state **263** to state **283**. Or, if the ventilator is a mixed pressure/volume ventilator, the process moves from state **279** to state **283**. At state **283**, the process determines if the pressure ventilator is on. If the pressure ventilator is off, the process moves to state **285** where propeller object **262** is made stationary. If the pressure ventilator is on, the process moves to state **287** where the propeller object **262** is rotated in the counter-clockwise direction. The process then moves to state **289** where air flow to the patient is read. The process then moves to state **291** where it is determined if the air flow has changed. If the air flow has changed, the process then moves to state **293** where it is determined whether the airflow has increased or decreased. If the airflow has decreased, horizontal line **168** along with air flow marker **166** is moved downward along meter **172**. If it is determined at state **293** that the air flow has increased, the process moves to state **297** and horizontal line **168** and marker **166** are moved up meter **172** to reflect the sampled air flow.

[0168] The process then moves to state **299** where the peak inspiratory pressure ("PIP") is read. The process then moves to state **301** where it is determined whether the PIP has changed. If the PIP has changed, the process moves to state **303** where it is determined whether PIP has increased or decreased. If PIP has decreased, the process moves to state **305** where the PIP indicator **178**, moves downward along meter **176**. If it is determined at state **303** that PIP has increased, the process moves to state **307** where PIP indicator **178** moves up meter **176** to reflect the PIP reading.

[0169] The process then moves to state **309** where the mean airway pressure ("MAP") is read. The process then moves to state **311** where it is determined whether the MAP has changed. If the MAP has changed, the process moves to state **313** where it is determined whether the MAP has increased or decreased. If the MAP has decreased, the process moves to state **315** where MAP indicator **180** is moved down meter **176**. If it is determined at state **313** that the MAP has increased, the process moves to state **317** and MAP indicator **180** is moved up meter **176** to reflect the higher MAP value.

[0170] The process then moves to state **319** where the system determines if the PEEP is patient triggered. If the PEEP is not patient triggered, the process moves to state **321** where box **184** is not displayed. If it is determined that PEEP is patient triggered, the process moves to state **323** where box **184**, with the letter "T" located therein indicating that PEEP is patient triggered, is displayed.

[0171] The process then moves to state **325** where PEEP is read. The process then moves to state **327** where it is determined whether PEEP has changed. If PEEP has changed, the process moves to state **329** where it is determined whether PEEP has increased or decreased. If PEEP has decreased, the process moves to state **331** and PEEP indicator **182** is lowered along meter **176**. If it is determined that PEEP has increased, the process moves to state **333** where PEEP indicator **182** moves upward along meter **176** to reflect the PEEP reading.

[0172] The process then moves to state **335** where respiratory rate ("RR"), which is set by the physician, is read. The process then moves to state **337** where RR is displayed at **186**. The process then moves to state **339** where breath cycle

time (“BCT”) is read. The process then moves to state **341** where BCT is displayed at **186**. The process then moves to end state **343**.

[0173] E. Combined Lung and Ventilator Object

[0174] In FIGS. **11-13** are objects displaying information concerning airway resistance and ventilator data. In FIGS. **11-13**, combined lung and ventilator object **190** displays information such as tidal volume inspired (“TVI”), tidal volume expired (“TVE”), respiratory rate (“RR”), peak inspiratory pressure (“PIP”), positive end respiratory pressure (“PEEP”), lung compliance, information on CO₂ elimination, and information as to both pressure and volume ventilators.

[0175] Inside combined lung and ventilator object **190** is lung object **240**. Lung object **240** provides physicians with information concerning TVI and TVE (located behind the TVI diamond when TVI and TVE are the same) which are displayed by diamond shaped markers **192** (TVI) and **196** (TVE)(Not shown in FIG. **11**). Markers **192** and **196** move up and down meter **194** and displays to a physician the amount of air inhaled and exhaled by a patient. As shown at **198**, each breath for a total duration of a minute (longer intervals can be displayed) are displayed at **198** between meter **194** and **216**. Meter **216**, forming an X-axis, measures respiratory rate (“RR”) which is measured in breaths per minute. As shown in FIG. **11**, 10 breaths are displayed by vertically oriented columns **198** located above meter **216** which provides for an RR of 10 breaths/minute. Each breath is represented by an elongated, vertically oriented column. There are a series of columns **198**, each of which conveys certain information to a physician. For example, the first column at **198** shows that the first breath had a TVI and a TVE of slightly above a volume of 500 ml. All other subsequent breaths had TVI and TVE of 1000 ml. The object can also display discrepancies between TVI and TVE. For example, in FIG. **12**, the second breath shows a slightly lower TVE than TVI. This difference between TVI and TVE might indicate that air is being lost possibly through a leak in tubing or even a hole in the lung.

[0176] Lung object **240** is surrounded by a pair of curved outer boundaries **204** which represent the lungs. In FIG. **11**, it is a thin boundary and represents a normal lung. However, in FIG. **12**, outer boundaries **204** are thickened and represent diseased noncompliant lungs. Located adjacent the upper boundary **204** is meter **226** which measures compliance of the lungs. In FIG. **11**, which illustrates compliant lungs, compliance is shown to be slightly above 120 ml/cm H₂O. However, in FIG. **12**, which shows a noncompliant lung, lung compliance is shown to be slightly above 60 ml/cm H₂O.

[0177] Upstream from lung object **240** is an airway resistance object **208** which conveys information to a physician or user concerning resistance in the respiratory tract. Airway resistance object **208** uses a “pipe” shaped metaphor to convey information concerning resistance to air inspiration and expiration in the respiratory tract. Part of the pipe shaped metaphor, section **210**, contracts or levels off depending on whether blockage or resistance is encountered. For example, in FIGS. **11** and **12**, section **210b** is contracted or narrowed and could represent a bronchospasm, mucous plug or a tube with a kink. Located within airway resistance object **208** are PIP, mean airway pressure (“MAP”) (not

shown) and PEEP indicators which, in the same manner as the ventilator state object of FIG. **9**, display values for these parameters. Diamond marker **218** displays the PIP value on meter **224**. Diamond marker **220** displays Pplateau (behind the PIP diamond) on meter **224**. Rectangular marker **222** displays the PEEP value on meter **224**. PEEP marker **222** is rectangular shaped rather than diamond shaped to indicate that it is a physician set parameter rather than a measured patient parameter. When the PIP minus Pplateau are large, as is the case when obstruction to airflow is present, the resistor object will show narrowing as in FIG. **13**.

[0178] Pressure ventilator object **212** (see FIG. **11**) is virtually the same as pressure ventilator object **144**. Located within pressure ventilator object **212** is propeller object **262** which as shown in pressure ventilator object **144**, rotates counter clockwise when there is flow of air from the pressure ventilator to the patient and is static and stationary where there is no air flow. Meter **172** and arrows **164** also display the amount to air flowing to the patient. The three horizontal lines indicate that there is 30 liters air/minute being directed to the patient. Below is meter **186**, which like meter **146** in FIG. **9** as to the volume ventilator, displays information concerning RR and the ratio of inspiration to expiration time.

[0179] Above pressure object **212** is volume ventilator object **214**. As shown in FIG. **11**, the volume ventilator is turned off and this can be understood in that volume ventilator object **214** is in gray and all of the parameters indicate that it is turned off. However, in FIG. **12**, pressure ventilator **212** is turned off and volume ventilator **214** is turned on. However, as mentioned before, there are mixed volume-pressure ventilators. In Ventilator and Lung Object **190**, were the patient receiving air from a mixed ventilator, both the volume ventilator object **214** and the pressure ventilator object **212** would be on and indicated as being operational.

[0180] In FIG. **12**, volume ventilator object **214** is indicated as being on. Like the volume ventilator object of FIG. **11**, volume ventilator object **214** has a bellows object **158** which indicates the volume of air the patient is receiving (the volume ventilator shows volume per breath on its scale and the pressure ventilator shows flow in L/min). Below volume ventilator **214** is box **146** which, like in FIG. **9**, displays information concerning RR and inspiration and expiration time and I:E ratio.

[0181] Located above the lung object **210** is CO₂ elimination object **230**. For example, in FIG. **13**, CO₂ elimination object displays information concerning CO₂ elimination in real time. Meter **242** displays information concerning minute ventilation total (“MVt”) as represented by marker **246** and minute ventilation ventilator (“MVv”) as represented by marker **248**. The left portion of meter **242** is shaded to represent how much CO₂ is eliminated by the ventilator (MVv) and the right portion of meter **242** demonstrates how much CO₂ is being eliminated by the patient. MVt marker gives the total CO₂ eliminated. The difference between MVt and MVv provides the amount of CO₂ eliminated by the patient.

[0182] Next to meter **242** is meter **244** which provides information concerning target CO₂ elimination value (as noted by marker **250**), measured partial pressure CO₂ (“pCO₂”) and measured exhaled CO₂ values (“Et CO₂”). pCO₂ values are noted by marker **252** and EtCO₂ values are

noted by marker **254**. Such values can be obtained from a spirometer. Differences between $p\text{CO}_2$ and EtCO_2 values can be an indicator of certain types of disease.

[**0183**] Meter **244** moves up and down in the Y direction depending on the $p\text{CO}_2$ and EtCO_2 values. The position of meter **244** along the Y axis and the position of markers **252** and **254** in relation to the MVt reading of **242** visually indicates excessive ventilation.

[**0184**] In **FIG. 14**, the process of updating the Combined Lung and Ventilator Object **190** is much the same as that of updating the Ventilator State Object **140** and therefore all of the steps will not be repeated here. When the process moves to updating lung object **210**, the process moves to state **361** to read PIP. The process then moves to state **363** to determine whether PIP has changed from the last reading. If it has not, the process moves to state **371**. However, if PIP has changed, the process moves to state **365** to determine whether PIP has increased or decreased. If PIP has decreased, the process moves to state **367** and lowers marker **218** to the appropriate PIP value on scale **224**. However, if PIP has increased, the process moves to state **369** where marker **218** is raised above marker **220** which also raises a portion **210a** of pipe shaped metaphor **210** to raise level **210a** above **210b** and gives the “pipe” an expanded appearance.

[**0185**] The process then moves to state **371** where MAP is read. The process moves to state **373** where it is determined whether MAP has changed since its last reading. If MAP has changed, the process then moves to state **375** where it is determined whether MAP has increased or decreased. If MAP has decreased, the process moves to state **377** where MAP marker **220** is lowered along meter **224** to the appropriate setting. However, if it is determined at state **375** that MAP has increased, the state moves to state **379** where MAP marker **220** is raised along meter **224** to the corresponding MAP value.

[**0186**] The process then moves to state **381** where PEEP is read. The process then moves to state **383** to determine whether PEEP has changed since its last reading. If it is determined that PEEP has changed, the process moves to state **385** to determine whether PEEP has increased or decreased. If it is determined that PEEP has decreased, the process moves to state **387** where PEEP marker **212** is lowered along meter **224** to the appropriate setting. If it is determined that PEEP has increased, the process moves to state **389** where PEEP marker **212** is raised to the appropriate setting along meter **224**.

[**0187**] The process then moves to state **401** where total volume inspired (“TVI”) is read. The process then moves to state **403** where it is determined whether TVI has changed since its last reading. If it is determined that TVI has changed, the process moves to state **405** where it is determined whether TVI has increased or decreased. If it is determined that TVI has decreased, the process moves to state **407** where TVI marker **192** is lowered along meter **194**. If it is determined that TVI has increased, the process is moved to state **409** where marker **192** is raised along meter **194** and the corresponding TVI reading is indicated.

[**0188**] The process then moves to state **411** where respiratory rate (“RR”) is read. If process then moves to state **413** where it is determined whether RR has changed. If it is

determined that RR has changed, the process moves to state **415** where it is determined whether RR has increased or decreased. If the RR has decreased, the process then moves to state **417** where the process moves RR marker **202** to the left. If the process determines that RR has increased, the process moves to state **419** where RR marker **202** is moved to the right to reflect the accurate RR reading.

[**0189**] The process then moves to state **421** where lung compliance is read. The process then moves to state **423** where it is determined whether lung compliance has changed. If lung compliance has changed, the process moves to state **425** to determine whether lung compliance has increased or decreased. If lung compliance has decreased, the process then moves to state **427** and scale **226** is updated and arrow **228** is moved to reflect the accurate lung compliance measurement. The process then moves the process to state **429** where the process enlarges i.e. thickens outer lung boundaries **204** to illustrate that the lungs have poor compliance. If the process determines that lung compliance has increased, the process moves to state **431** where scale **226** is updated to reflect the accurate lung compliance measurement.

[**0190**] The process then moves to state **431** where CO_2 elimination information is read. The process then moves to state **433** where it is determined whether CO_2 has changed. If it has changed, the process moves to state **435** where it is determined whether CO_2 elimination has increased or decreased. If it has decreased, the process moves to state **437** where markers **246** or **248** are moved down meter **242** to the appropriate reading. If the process determines that CO_2 elimination has increased, the process moves to state **439** and markers **246** and **248** are moved upward to the appropriate reading.

[**0191**] The process then moves to state **441** where $p\text{CO}_2$ is read. The process then moves to state **443** to determine whether $p\text{CO}_2$ has changed. If it has changed, the process then moves to state **445** where the process determines whether $p\text{CO}_2$ has increased or decreased. If $p\text{CO}_2$ has decreased, process moves to state **447** where marker **252** is moved down meter **244**. If $p\text{CO}_2$ has increased, the process moves to state **449** and marker **252** moves up meter **244**.

[**0192**] The process then moves to state **451** where EtCO_2 values are read. The process then moves to state **453** where it is determined whether EtCO_2 values have changed. If EtCO_2 values have changed, the process moves to state **455** where it is determined whether EtCO_2 values have increased or decreased. If the process determined that EtCO_2 values have decreased, the process moves to state **457** and marker **254** is moved down meter **244**. If the process determines that EtCO_2 values have increased, the process moves to state **459** and marker **254** moves up meter **244**. The process then moves to end state **461**.

[**0193**] F. Oxygenation Object

[**0194**] **FIG. 15** illustrates an Oxygenation Object **600** which displays information relating to oxygenation of the blood and the state of lung tissue. Red blood cell object **602** is shown prior to being oxygenated by the lungs (flow, as indicated by the arrows, is from right to left). Boxes **604**, **606** and **608** represent cross sections of blood vessels in the lung. Boxes **604**, **606** and **608** can narrow or widen based on the difference between PaO_2 (marker **618**) and PaO_2 (marker

620). Located within box 608 is red blood cell object 610 and soluble oxygenation object 612. Soluble oxygenation object 612 shows the concentration of oxygen in the plasma which can be influenced by a liquid such as perflubron based OXYGENT, a soluble oxygen carrier of Alliance Pharmaceutical Corp. Soluble oxygenation object 612 can increase in size depending on the contribution of soluble oxygenation of the blood. Linking soluble oxygenation object 612 and red blood cell object 602 is soluble O₂ line 614. The slope of line 614 can change based upon the level of soluble oxygenation of the blood. Where there is little or no oxygen solubility of the blood, the line levels out to a more horizontal slope.

[0195] Red blood cell object 610, which is intersected by an oxy-hemoglobin curve 616, visually indicates the level of hemoglobin and oxygenation of the arterial blood. CaO₂ total, represented by diamond 622 on the far left, represents the total arterial oxygenation of the blood. Marker 624 represents the amount of oxygenation of the blood by hemoglobin and marker 626 represents the amount of soluble oxygenation of the arterial blood. Both 624 and 626 move up and down in the Y direction as the respective values change. Marker 628 represents the arterial oxygen saturation (SaO₂) and 630 represents the hemoglobin ("Hb") concentration in the blood. Thus as the Hb value increases marker 630 moves to the right and the red blood cell object 610 increases in size and can reach the ideal size that is shown as circle 632.

[0196] Located above the red blood cell oxygenation portion of object 600 is the membrane portion of object 600 which illustrates physiological parameters as to oxygenation of the lung during ventilation and visual cues which indicate over ventilation of the lung. To the far left is lung object 640. Above lung object 640 is a marker 642 for positive end expiratory pressure ("PEEP") and a marker 644 for peak inspiratory pressure ("PIP"). Both PEEP marker 642 and PIP marker 644 move along X-oriented axis 646 to display the PIP and PEEP values. Adjacent PEEP and PIP markers are rectangular shaped objects 648 and 650 which are PEEP and PIP normal zones. When the PEEP or PIP marker 642 or 644 move beyond rectangular boxes 648 and 650 respectively, this indicates that the values are in a danger zone. For example, in FIG. 15, PIP marker 644 is beyond the PIP normal zone 650 and shows that it is in a danger zone. Below PIP and PEEP markers 642 and 644 is arrow 652 which shows the distance between PIP and PEEP values as further illustrated by vertically oriented lines 654 (extending downward from PIP marker 644) and line 656 descends from PEEP marker 642. As lines 654 and 656 separate, as further indicated by arrow 652, this visually cues the physician or other user that the patient might be in danger.

[0197] Adjacent lung object 640 is nonfunctional (collapsed or damaged) alveolus object 660. As shown in FIG. 15, nonfunctional alveolus object 660 is in a collapsed state which may be due to various diseases such as atelectases, post-pneumonic states, etc. This further indicates that the current respirator settings need adjusting. Above lung object 640 and alveolar unit 660 is meter 658 which visually indicate the percentage of oxygen intake by the patient in real time. Below lung object 640 and dysfunctional alveolar unit 660 are PaO₂ and PAO₂ markers 618 and 620. Together these illustrate the alveolar arterial oxygen gradient and anatomic shunt. Markers 618 and 620 can move both in the

X direction and provide important information as to oxygen intake. The movement of PaO₂ from left to right affects many of the other parameters of object 600. Above and linked to PAO₂ marker 620 is FiO₂ marker 662 which is linked to PAO₂ marker 620 by line 664 (the relationship between the FiO₂ scale and the PO₂ scale is through Charles Law).

[0198] The process of updating object 600 is described in FIG. 16. The process reads the level of oxygenation of the blood at state 601 prior to oxygenation by the lungs. The process then moves to state 603 where it is determined whether the level of oxygenation of the blood has changed. If it is determined that the level of oxygenation has changed, the process then moves to state 605 where the process determines whether the level of oxygenation has increased or decreased. If it has decreased, the process then moves to state 607 the shading of object 602 is decreased. If it is determined at 605 that the level of oxygenation has increased, the process then moves to state 609 where the process determined whether there has been soluble oxygenation of the blood. If it is determined that there has been oxygenation of the blood by a soluble source, the size of box 612 is increased. If it is determined that there has been no contribution of a soluble oxygen carrier, the process then moves to state 613 where the hemoglobin concentration (i.e. oxygenation of the blood) is read. the size of circle 610 is changed to reflect the Hg concentration in the blood. Markers 622, 624, 626, 628, 630 and the oxy-hemoglobin curve are all moved accordingly based wholly or in part on the Hg concentrations and oxygenation levels of the blood at this stage.

[0199] The process then moves to state 617 where PAO₂ is read. The process moves to state 619 where it is determined whether PAO₂ has changed. If it is determined that PAO₂ has changed, the process then moves to state 621 where it is determined whether PAO₂ has increased. If PAO₂ has increased, the process moves to state 623 where marker 620 is moved to the left. If it is determined that PAO₂ has decreased, the process then moves to state 625 where 620 is moved to the right.

[0200] The process then moves to state 627 where PaO₂ is read. The process then moves to state 629 where it is determined whether PaO₂ has changed. If it is determined that PAO₂ has increased, the process then moves to state 633 where marker 618 is moved to the right. If the process determines that PaO₂ has decreased, marker 618 is moved to the left. Boxes 604, 606, 608 and alveolar object 660 can all change sizes based upon movement of PAO₂ and PaO₂.

[0201] The process then moves to state 637 where PEEP is read. The process then moves to state 639 where it is determined whether PEEP has changed since its last reading. If it has changed, the process then moves to state 641 where it is determined whether PEEP has increased or decreased. If PEEP has increased the process then moves to state 643 where marker 642 is moved to the right. If PEEP has decreased, the process then moves to state 645 where marker 642 is moved to the left.

[0202] The process then moves to state 647 where PIP is read. The process then moves to state 649 where it is determined whether PIP has changed. If PIP has changed, the process moves to state 651 where it is determined whether PIP has increased or decreased. If PIP has increased,

the process moves to state **653** where marker **644** is moved to the right. If PIP has been determined to have decreased, PIP marker **644** is moved to the left. The process then moves to end state **657**.

1. A data object for visually displaying physiological information concerning the human heart in real time, comprising:

an object representing a heart wherein the heart is divided into four chambers and arrows are used to display blood flow information between the individual heart chambers.

2. The data object of claim 1 wherein at least one of the individual heart chambers expands and contracts to display the filling state of the heart chambers.

3. The data object of claim 2 wherein each of the individual heart chambers expands and contracts in real time to show the filling state of the individual heart chamber.

4. The data object of claim 1 wherein visual information is displayed to show the compliance state of the right and left ventricle.

5. The data object of claim 4 wherein the compliance of the right and left ventricle is illustrated can be illustrated as mildly, moderately or severely noncompliant based by the presence of shaded rectangular boxes located within the right or left ventricle.

6. A data object for visually representing the resistance to blood flow in a patient and the oxygenation state of a patient's blood wherein the object is visually representative of the patient's mean arterial pressure (MAP), the patient's central venous pressure (CVP) and the cardiac output (CO) of the patient in real time.

7. The data object of claim 6 wherein the data object reflects the oxygenation of the arterial and venous blood in real time.

8. The data object of claim 6 wherein the data object updates the vascular resistance and cardiac output of the patient in real time of the blood after it has left the RV of the heart and after it has left the LV of the heart.

9. A data object useful for displaying and updating in real-time the oxygenation of the blood of a patient during a cardiopulmonary bypass procedure, comprising:

a venous reservoir object for visually displaying in real time the amount of stored venous blood;

a pump object for visually displaying in real time the amount of blood diverted to the patient; and

an oxygenator object for displaying in real time visual information concerning at least one parameter selected from the group consisting of carbon dioxide concentration (PaCO₂), gas flow (oxygen) into the blood-stream, inspired oxygen in the blood stream (FiO₂) and mixed arterial oxygen tension (PaO₂).

10. The data object of claim 9 wherein blood flow to the patient is visually indicated by horizontally oriented arrows extending to the oxygenator object wherein each arrow represents on liter of blood.

11. The data object of claim 9 wherein blood flow to the patient is visually indicated by a horizontally oriented line intersecting a vertically oriented meter wherein the horizontally oriented line moves in real time and intersects the vertically oriented meter to visually indicate the amount of blood flow to the patient.

12. The data object of claim 9 wherein the oxygenator object displays information concerning of carbon dioxide concentration (PaCO₂), gas flow (oxygen) into the blood-stream, inspired oxygen in the blood stream (FiO₂) and mixed arterial oxygen tension (PaO₂).

13. The data object of claim 12 wherein markers move up and down vertically oriented scales to show the actual carbon dioxide concentration (PaCO₂), gas flow, inspired oxygen (FiO₂) and mixed arterial oxygen tension (PaO₂) in the blood stream in real time.

14. The data object of claim 13 where visual and auditory alarms are used to indicate whether critical levels of carbon dioxide concentration (PaCO₂), gas flow, inspired oxygen (FiO₂) and mixed arterial oxygen tension (PaO₂) in the blood stream in real time are occurring.

15. A data object for visually displaying information of either a volume or pressure ventilator in real time comprising: an object display wherein the object display is divided into a one object for visually displaying information in real time concerning a volume ventilator and one object for visually displaying in real time concerning a pressure ventilator.

16. The data object of claim 15 wherein the object visually displays an oscillating bellows or horizontally displaced arrows for displaying information in real time as to air flow to the patient.

17. The data object of claim 15 wherein horizontally oriented scales are utilized for displaying in real time information concerning respiration rate, breath cycle time, inspiration time and expiration time.

18. The data object of claim 15 where information concerning PIP, MAP and PEEP are visually indicated by markers moving up and down a vertically oriented scale for displaying such information in real time.

19. A data object for visually displaying information concerning volume ventilation, pressure ventilation and air intake of a patient in real time comprising:

one object representing a volume ventilator;

one object representing a pressure ventilator; and,

one object representing a patient wherein the object for representing the patient displays in real time physiological information concerning lung compliance, CO₂ elimination and total air volume inhaled ("TVI").

20. The data object of claim 19 wherein physiological information is also displayed concerning obstruction of airflow to the patient.

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摘要(译)

所公开的发明涉及用于从患者获得生理信息并以直观和逻辑的形式向医师显示该信息的系统和方法。公开了物体显示器，其能够实时地可视地显示关键信息，以允许医生快速感知改变患者值的重要性。

