



(11) **EP 1 588 661 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
27.06.2007 Bulletin 2007/26

(51) Int Cl.:
A61B 5/028 (2006.01)

(21) Application number: **04101678.3**

(22) Date of filing: **22.04.2004**

(54) **Apparatus, computer system and computer program for determining intrathoracic blood volume and other cardio-vascular parameters**

Vorrichtung, computersystem und computerprogramm zur Bestimmung des intrathorakalen Blutvolumens und anderer kardio-vaskulären Parametern

Dispositif, système informatique et programme informatique pour la détermination du volume sanguin intrathoracique et d'autres paramètres cardio-vasculaires

(84) Designated Contracting States:
DE ES FR GB IT

(43) Date of publication of application:
26.10.2005 Bulletin 2005/43

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Description

FIELD OF THE INVENTION

5 **[0001]** The present invention relates to an apparatus, a computer system and a storage medium with a computer program for determining intrathoracic blood volume and other cardio-vascular parameters of a patient by thermodilution measurements.

BACKGROUND OF THE INVENTION

10 **[0002]** The current state of the art in implementing transpulmonary thermodilution measurement are apparatus for injecting a bolus of thermal indicator into a patient's vena cava superior, and measuring the temperature response at a place of the patient's systemic circulation, e.g. patient's femoral artery to determine the thermodilution curve, i.e. the temperature response as a function of time. From the thermodilution curve, a schematic example of which is illustrated in fig. 3, wherein the abscissa (time axis) 1 is linear and the ordinate (temperature difference axis) 2 is logarithmic, various cardio-vascular parameters can be derived by using computer systems running computer programs, which implement parameter calculations as disclosed in WO 93/21823, the contents of which are included herein by citation, and as set forth briefly below.

20 **[0003]** The Cardiac Output CO can be determined by algorithms based on the Stewart-Hamilton-equation:

$$CO = \frac{V_L(T_B - T_L)K_1K_2}{\int \Delta T_B(t) dt}$$

25 where T_B is the initial blood temperature, T_L is the temperature of the liquid bolus, which is used as thermal indicator, V_L is the thermal indicator volume, K_1 and K_2 are constants to consider the specific measurement setup, and $\Delta T_B(t)$ is the blood temperature as a function of time with respect to the baseline blood temperature T_B . Thermal indicator can either be colder or warmer with respect to blood temperature. To obtain cardiac output, the area under the thermodilution curve has to be determined by mathematical integration.

30 **[0004]** Other parameters that can be derived from the thermodilution curve 3 as schematically illustrated in fig. 1 include the Exponential Decay or Downslope Time DST, i.e. the time the blood temperature difference $\Delta T_B(t)$ takes to drop by the factor e^{-1} , the Appearance Time AT, i.e. the time span between bolus injection IT and first appearance of a noticeable temperature difference $\Delta T_B(t)$ and the Mean Transit Time MTT.

35 **[0005]** The Intrathoracic Thermovolume ITTV and the Intrathoracic blood volume ITBV can be determined as follows:

$$ITTV = CO \cdot MTT$$

$$ITBV = a' \cdot GEDV + b'$$

45 wherein a' and b' are species-specific constants and GEDV is the Global End-Diastolic Volume, which can be determined as follows:

$$GEDV = CO \cdot (MTT - DST)$$

50 **[0006]** An extravascular thermovolume estimate can be determined as the difference between Intrathoracic Thermovolume ITTV and the Intrathoracic blood volume ITBV

$$ETV = ITTV - ITBV$$

55 **[0007]** Extravascular thermovolume correlates, if there is no significant perfusion defect in the lungs (e.g. massive

pulmonary embolism or large single embolism), closely to the degree of Extravascular Lung Water.

[0008] Transpulmonary thermodilution has been shown to be a reliable technique for assessing cardiac output, cardiac preload and extravascular lung water (EVLW), i.e. to quantify pulmonary edema. The estimation of EVLW by the injection of a single thermal indicator is based on the above mentioned relationship $ITBV = a' \cdot GEDV + b'$. This method has been shown to compare favorably with the double-indicator (thermo-dye) dilution technique and with the ex-vivo gravimetric methods.

[0009] However, for mechanically ventilated patients and patients suffering from severe pulmonary edema the results were not entirely satisfactory.

[0010] It is therefore an object of the present invention to provide a new apparatus, a new computer system and a storage medium with a new computer program allowing the determination of the intrathoracic blood volume by single indicator transpulmonary thermodilution with enhanced accuracy especially for patients suffering from severe pulmonary edema and/or for mechanically ventilated patients.

SUMMARY OF THE INVENTION

[0011] The inventors found that several factors (especially pulmonary edema and airway pressure) affect the cardiac blood / pulmonary blood volume relationship, and hence the estimation of EVLW by transpulmonary thermodilution. Indeed, edematous lung areas may compress pulmonary vessels and enhance pulmonary vasoconstriction, both factors that may reduce true pulmonary blood volume and hence lead to overestimation of ITBV and underestimation of extravascular lung water EVLW (when ITBV is estimated as $1.25 \times GEDV$). Similarly, any increase in airway pressure (related either to an increase in tidal volume or the application of a positive end-expiratory pressure) may induce a decrease in pulmonary blood volume which may also change the cardiac/pulmonary blood volume ratio.

[0012] In order to accomplish the above mentioned object, the present invention provides an apparatus for determining intrathoracic blood volume (ITBV) and other cardio-vascular parameters of a patient by thermodilution measurements comprising: temperature influencing means for provoking an initial local temperature change in the proximity of a first place of a patient's vascular system, thus introducing a travelling temperature deviation to patient's blood stream, a temperature sensor device for measuring the local temperature of patient's blood at a second place of patient's vascular system downstream of said first place, a computer system connected to said temperature sensor device and adapted to record said patient's local blood temperature measured at said second place as a function of time to determine a thermodilution curve, said computer system being further adapted to determine patient's global enddiastolic blood volume (GEDV) and patient's intrathoracic thermovolume (ITTV) from said thermodilution curve said computer system being further adapted to determine patient's intrathoracic blood volume (ITBV) according to the following formula:

$$ITBV = f(GEDV, ITTV, P)$$

[0013] ITBV being the intrathoracic blood volume, GEDV being the global enddiastolic blood volume, ITTV being the intrathoracic thermovolume, P being an airway pressure inside patient's lungs.

[0014] In order to accomplish the above mentioned object, the invention also provides a computer system comprising first coupling means to couple said computer system to temperature influencing means and second coupling means to couple said computer system to a temperature sensor device and optionally third coupling means to couple said computer system to an airway pressure sensor device, and accessing means to access executable instructions to cause said computer system to control temperature influencing means for provoking an initial local temperature change in the proximity of a first place of a patient's vascular system, thus introducing a temperature deviation to patient's blood stream, to record said patient's local blood temperature measured by a temperature sensor device for measuring the local temperature of patient's blood at a second place of patient's vascular system downstream of said first place as a function of time to determine a thermodilution curve, to determine patient's global enddiastolic blood volume (GEDV) and patient's intrathoracic thermovolume (ITTV) from said thermodilution curve, to determine patient's intrathoracic blood volume (ITBV) according to the following formula:

$$ITBV = f(GEDV, ITTV, P),$$

[0015] ITBV being the intrathoracic blood volume, GEDV being the global enddiastolic blood volume, ITTV being the intrathoracic thermovolume, P being an airway pressure inside patient's lungs.

[0016] In order to accomplish the above mentioned object, the invention also provides a storage medium with a

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computer computer program for determining intrathoracic blood volume (ITBV) and other cardio-vascular parameters of a patient by thermodilution measurements comprising instructions executable by a computer system to cause said computer system to control temperature influencing means for provoking an initial local temperature change in the proximity of a first place of a patient's vascular system, thus introducing a temperature deviation to patient's blood stream, to record said patient's local blood temperature measured by a temperature sensor device for measuring the local temperature of patient's blood at a second place of patient's vascular system downstream of said first place as a function of time to determine a thermodilution curve, to determine patient's global enddiastolic blood volume (GEDV) and patient's intrathoracic thermovolume (ITTV) from said thermodilution curve, to determine patient's intrathoracic blood volume (ITBV) according to the following formula:

$$ITBV = f(GEDV, ITTV, P),$$

[0017] ITBV being the intrathoracic blood volume, GEDV being the global enddiastolic blood volume, ITTV being the intrathoracic thermovolume, P being an airway pressure inside patient's lungs.

[0018] By determining intrathoracic blood volume not only as a function of the global enddiastolic blood volume (GEDV) but also as a function of the intrathoracic thermovolume, experience has shown that a better estimation of intrathoracic blood volume and hence also a better estimation of extravasal lung water can be made.

[0019] According to a preferred embodiment of the invention said function f(GEDV, ITTV, P) is selected to be

$$f(GEDV, ITTV, P) = a \cdot GEDV + b + c \cdot ITTV + d \cdot P$$

a being a species dependent parameter, with $1 < a < 2$, b being a species dependent parameter, including zero, c being a species dependent parameter, with c and d being species dependent parameters, including zero, with the limitation that c and d may not be zero simultaneously.

[0020] The term $c \cdot ITTV$ provides for a correction especially for high values of ITTV and the term $d \cdot p$ provides for a correction of ITBV especially when the patient is mechanically ventilated. Once the species-specific parameters a, b, c, and d have been determined the application of this formula allows an optimal coincidence between the estimated values of intrathoracic blood volume and extravasal lung water with precisely measured values in a large population of patients.

[0021] In another preferred embodiment of the invention said function f(GEDV, ITTV, P) is selected to be

$$f(GEDV, ITTV, P) = \frac{a}{c \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + d \cdot \frac{P}{P_{norm}}} GEDV + b$$

a, b, c, and d being species dependent parameters, with $1 < a / (c+d) < 2$, wherein ITTVnorm, GEDVnorm and Pnorm are empirical normal values of ITTV, GEDV and P, respectively. Parameters a, b, c, and d are determined by regression.

[0022] In another preferred embodiment of the invention said function f(GEDV, ITTV, P) is selected to be

$$ITBV = \frac{a \cdot GEDV}{\left[c2 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{norm}} + 1 \right]} + b + c1 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + d1 \cdot \frac{P}{P_{norm}}$$

parameters a, b, c1, d1, c2, d2 can be obtained by a nonlinear regression from comparative double dilution measurements. The parameters are species dependent. The term $a/(c2+1)(d2+1)$ is normally in the range of 0.5 to 10.

[0023] The first part

$$ITBV = a \cdot GEDV + b + c1 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + d1 \cdot \frac{P}{P_{norm}}$$

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describes the total displacement from the thorax to the large circulation.

[0024] The second part

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$$ITBV = \frac{a \cdot GEDV}{\left[c2 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{norm}} + 1 \right]} + b$$

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describes the changed relation between GEDV and PBV.

[0025] Investigations have shown that with the formula according to the prior art ITBV i.e. the sum of PBV and GEDV was underestimated at high ETV and at high airway pressures. This is because a high ETV leads to a tension of the lung tissue, which is disturbing the normal fixed relation between PBV and GEDV ($ITBV = GEDV + PBV = a \cdot GEDV + b$). A similar result is reached at high airway pressure P.

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[0026] Thereby the effective pressure, which is pushing blood out of the lung, is the transmural pressure $P_{tm} = ITP - P_{mv}$. This is the difference between intra thoracic pressure and micro vascular pressure. The peri micro vascular pressure could be neglected. If the lung is very stiff e.g. at a fibrosis, even a high airway pressure has little influence - the intra thoracic pressure remains low.

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[0027] Mostly P_{tm} in the micro vessels of the lung is not available. In this case the intra thoracic pressure or the mean airway pressure could be used instead. Because PEEP (positive end expiratory Pressure) is correlated, it could be also useful.

[0028] The blood is displaced from the lung in two ways

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1. a fraction of the blood is shifted from the lungs into the heart, thereby the normal relation between GEDV and PBV is changed

2. a part of the PBV is totally displaced from the thorax to the large circulation (systemic circulation)

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[0029] Dependent on the dominant factor c1, d1 or c2, d2 could be equal to zero. In a special case of humans $a=1.48$; $b=87\text{ml}$; $c1=-0.18$; $d1=0$; $c2=0$; $d2=0$

[0030] There are also other formulas possible. In general ITBV is a function of GEDV, ITTV and P. It could also be advantageous to apply this to intra thoracic blood volume Index $ITBVI = ITBV/BSA$ which is the ITBV divided by Body surface Area (BSA). In this case ITBVI is a function of $GEDV/BSA$, $ITTV/BSA$ and P.

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[0031] In another preferred embodiment of the invention P is set equal to a transmural lung pressure P_{tm} , being defined as $P_{tm} = ITP - P_{mv}$, ITP being a intrathoracic pressure and P_{mv} being a microvascular pressure. As it is the transmural pressure which is responsible for pulmonary vasoconstriction and which is the reason for an overestimation of the intrathoracic blood volume and the underestimation of extravascular lung water best results are obtained by using the transmural pressure for correction of the intrathoracic blood volume, even if the patient suffers from lung fibrosis.

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[0032] However, the transmural pressure is sometimes difficult to determine. Fairly good results are also obtained according to another embodiment by using for P a mean pressure measured in the airway of a mechanical respirator or a positive end expiratory pressure (PEEP) of a mechanical respirator. These pressures can be determined easily.

[0033] Further advantageous embodiments are described in the subclaims.

[0034] The accompanying drawings serve for a better understanding of the above and other features of the present invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0035]

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Fig.1 shows a schematic illustration explaining the dependencies between global end diastolic volume GEDV, pulmonary blood volume PBV, extra thermal volume ETV, airway volume V_{aw} , and airway pressure P.

Fig.2 shows a schematic sketch of both a patient's vascular system and a preferred embodiment of an apparatus

according to the present invention.

Fig.3 shows a schematic example of a Thermodilution Curve in a diagram with the blood temperature difference as a function of time, wherein the abscissa is linear and the ordinate is logarithmic.

Fig.4 shows a block diagram illustrating the general hardware structure of an embodiment of a computer system according to the present invention being part of the apparatus sketched in fig.2.

DETAILED DESCRIPTION

[0036] Fig.1 shows a schematic illustration explaining the dependencies between global end diastolic volume GEDV, which is roughly the blood located in the heart, pulmonary blood volume PBV 111, which is the blood located in the lungs, extra thermal volume ETV 112, which is roughly the lung water outside the vessels, air way volume Vaw, and air way pressure P. Increasing airway pressure P causes the air way volume Vaw to increase, which leads to a decrease of pulmonary blood volume PBV, in other words, the increasing P causes blood to flow out from the lungs into the heart and / or into the systemic circulation. Similarly, increasing ETV also causes blood to flow out from the lungs into the heart and / or into the systemic circulation.

[0037] Fig.2 illustrates the main components necessary to implement an embodiment of an apparatus according to the invention and schematically shows the first and second places 101, 102 of a patient's vascular system 103, where the apparatus interacts with the patient's vascular system 103. A computer system 104, the general hardware structure of which is schematically illustrated in fig. 4, is connected via port A 201 with a medical dosage device 105 serving together with a catheter 106 as an injection means 107 to inject at the first place 101, e.g. into patient's vena cava superior, a bolus, e.g. 10 ml, or, as a guideline, 0.15 ml/kg patient's body mass. The bolus serving as a thermal indicator liquid is substantially warmer or colder than patient's blood temperature. As a result, travelling temperature deviation is introduced to the patient's vascular system 103, where it continuously changes according to boundary conditions. The temperature deviation passes right atrium and right ventricle 109 of patient's heart 110 to enter the pulmonary circulation 111, where an extravascular thermovolume 112 may be present in the proximity of the patient's vessels. The temperature deviation passes the left atrium 113 and the left ventricle 114 of patient's heart to enter through the aorta 115 the systemic circulation 116. When the travelling temperature deviation reaches the second place 102, e.g. patient's arteria femoralis, where the patient's blood temperature is continuously measured by a sensor device 117, which is connected to the computer system 104 via port B 202, the travelling temperature deviation is recorded by the computer system 104 as Thermodilution Curve, i.e. temperature measured at the second place 102 as function of time. From this Thermodilution Curve the computer system 104 determines an extravascular thermovolume estimate according to the relations explained above. Extravascular thermovolume correlates, if there is no significant perfusion defect in the lungs (e.g. pulmonary embolism), closely to the degree of Extravascular Lung Water.

[0038] Fig.4 illustrates the general hardware structure of an embodiment of a computer system 104 according to the invention, suitable to be part of the apparatus shown in Fig.2. Via ports A and B 201, 202 which belong to an input/output subsystem, the computer system 104 is connectable to injection means 107 sensor device 117 and pressure sensor 118, respectively. The input/output subsystem is controlled by a central processing unit (CPU) 204, which communicates via a data and adress bus 205 with the other components of the computer system 104, which include a timer 206 providing timer clock signals to the CPU 204, a system memory (ROM) 207, in which the system software is permanently stored, a data and instructions memory (RAM) 208, where both executable instructions and various data including temperature readings for thermodilution curves and airway pressure readings can be stored, an input device controller 209 controlling an input device 210, such as a keypad, a touch screen or the like, for manually entering system parameters, operation settings and the like, a disc subsystem 211 to read data or program instructions from a storage medium 212, such as a hard disc, floppy disc, compact disc, optical disc or the like, and to store data to the storage medium 212, and a display subsystem 213 controlling a display 214 to display relevant information, such as a Thermodilution Curve or cardiovascular parameters determined by the computer system 104. The pressure sensor device 118, which is adapted to measure the pressure in patient's airway is connected to the computer system 104 via port 203.

[0039] The above described apparatus is adapted to determine MTT, DST, CO from the thermodilution curve and to calculate parameters such as GEDV, ITBV and ETV.

Claims

1. Apparatus for determining intrathoracic blood volume (ITBV) and other cardio-vascular parameters of a patient by thermodilution measurements comprising:

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a) temperature influencing means (107) for provoking an initial local temperature change in the proximity of a first place (101) of a patient's vascular system (103), thus introducing a travelling temperature deviation to patient's blood stream,

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b) a temperature sensor device (117) for measuring the local temperature of patient's blood at a second place (102) of patient's vascular system (103) downstream of said first place (101)

c) a computer system (104) coupled to said temperature sensor device (117) and adapted to record said patient's local blood temperature measured at said second place (102) as a function of time to determine a thermodilution curve,

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d) said computer system (104) being further adapted to determine patient's global enddiastolic blood volume (GEDV) and patient's intrathoracic thermovolume (ITTV) from said thermodilution curve,

characterized in that said computer system (104) is further adapted to determine patient's intrathoracic blood volume (ITBV) according to the following formula:

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$$ITBV = f(GEDV, ITTV, P),$$

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ITBV being the intrathoracic blood volume, GEDV being the global enddiastolic blood volume, ITTV being the intrathoracic thermovolume, P being an airway pressure inside patient's lungs.

2. Apparatus as claimed in claim 1, wherein said function $f(GEDV, ITTV, P)$ is selected to be

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$$f(GEDV, ITTV, P) = a \cdot GEDV + b + c \cdot ITTV + d \cdot P$$

a being a species dependent parameter, with $1 < a < 2$

b being a species dependent parameter, including zero

c being a species dependent parameter, with $c \leq 0$

30

d being a species dependent parameter, including zero,

with the restriction that c and d may not be zero simultaneously.

3. Apparatus as claimed in claim 1, wherein said function $f(GEDV, ITTV, P)$ is selected to be

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$$f(GEDV, ITTV, P) = \frac{a}{c \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + d \cdot \frac{P}{P_{norm}}} GEDV + b$$

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a, b, c, and d being species dependent parameters, with $1 < a / (c+d) < 2$, wherein $ITTV_{norm}$, $GEDV_{norm}$ and P_{norm} are empirical normal values of ITTV, GEDV and P, respectively.

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4. Apparatus as claimed in claim 1, wherein said function $f(GEDV, ITTV, P)$ is selected to be

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$$ITBV = \frac{a \cdot GEDV}{\left[c2 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{norm}} + 1 \right]} + b + c1 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + d1 \cdot \frac{P}{P_{norm}}$$

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a, b, c1, c2, d1, d2 being species dependent parameters, with $0,5 \leq a/(c2+1)(d2+1) \leq 10$, wherein $ITTV_{norm}$, $GEDV_{norm}$ and P_{norm} are empirical normal values of ITTV, GEDV and P, respectively.

5. Apparatus as claimed in any of the preceding claims wherein P is set equal to a transmural lung pressure P_{tm} ,

being defined as

$$P_{tm} = ITP - P_{mv},$$

ITP being a intrathoracic pressure and P_{mv} being a microvascular pressure.

6. Apparatus as claimed in any of the preceding claims, wherein P is a pressure measured in the airway of a mechanical respirator.
7. Apparatus as claimed in claim 6, wherein P is a positive end expiratory pressure (PEEP).
8. Apparatus as claimed in claim 7, wherein P is a mean airway pressure.
9. Apparatus as claimed in any of the preceding claims which is adapted to determine at least one of said cardiovascular parameters by transpulmonary thermodilution.
10. Apparatus as claimed in any of the preceding claims which is adapted to determine an estimate of extravascular lung water (EVLW) as

$$EVLW = ITTV - ITBV,$$

EVLW being the extravascular lung water.

11. Apparatus as claimed in any of the preceding claims which is adapted to determine ITTV as

$$ITTV = CO \cdot MTT,$$

CO being the cardiac output and MTT being the mean transit time, indicating the time required by said temperature deviation to travel from said first place (101) to said second place (102).

12. Apparatus as claimed in any of the preceding claims which is adapted to determine GEDV as

$$GEDV = CO \cdot (MTT - DST),$$

CO being the cardiac output and MTT being the mean transit time, indicating the time required by said temperature deviation to travel from said first place (101) to said second place (102) and DST being a down slope time of said thermodilution curve.

13. Apparatus as claimed in any of the preceding claims further comprising a pressure sensing device (118) coupled to said computer system (104).
14. Computer system (104) comprising first coupling means to couple said computer system (104) to temperature influencing means (107) and second coupling means to couple said computer system (104) to a temperature sensor device (117), and accessing means to access executable instructions to cause said computer system (104)

- a) to control temperature influencing means (107) for provoking an initial local temperature change in the proximity of a first place (101) of a patient's vascular system (103), thus introducing a travelling temperature deviation to patient's blood stream,
- b) to record said patient's local blood temperature measured by a temperature sensor device (117) for measuring

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the local temperature of patient's blood at a second place (102) of patient's vascular system (103) downstream of said first place (101) as a function of time to determine a thermodilution curve,
 c) to determine patient's global enddiastolic blood volume (GEDV) and patient's intrathoracic thermovolume (ITTV) from said thermodilution curve,

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characterized in that said instructions include instructions to cause said computer system (104) to determine patient's intrathoracic blood volume (ITBV) according to the following formula:

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$$ITBV = f(GEDV, ITTV, P),$$

ITBV being the intrathoracic blood volume, GEDV being the global enddiastolic blood volume, ITTV being the intrathoracic thermovolume, P being an airway pressure inside patient's lungs.

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15. Computer system as claimed in claim 14, wherein said function $f(GEDV, ITTV, P)$ is selected to be

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$$f(GEDV, ITTV, P) = a \cdot GEDV + b + c \cdot ITTV + d \cdot P$$

a being a species dependent parameter, with $1 < a < 2$
 b being a species dependent parameter, including zero
 c being a species dependent parameter, with $c \leq 0$
 d being a species dependent parameter, including zero,
 with the restriction that c and d may not be zero simultaneously.

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16. Computer system as claimed in claim 14, said function $f(GEDV, ITTV, P)$ is selected to be

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$$f(GEDV, ITTV, P) = \frac{a}{c \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + d \frac{P}{P_{norm}}} GEDV + b$$

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a, b, c, and d being species dependent parameters, with $1 < a / (c+d) < 2$, wherein $ITTV_{norm}$, $GEDV_{norm}$ and P_{norm} are empirical normal values of ITTV, GEDV and P, respectively.

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17. Computer system as claimed in claim 14, wherein said function $f(GEDV, ITTV, P)$ is selected to be

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$$ITBV = \frac{a \cdot GEDV}{\left[c2 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{norm}} + 1 \right]} + b + c1 \cdot \frac{(ITTV - GEDV)}{(ITTV_{norm} - GEDV_{norm})} + d1 \cdot \frac{P}{P_{norm}}$$

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a, b, c1, c2, d1, d2 being species dependent parameters, with $0,5 \leq a/(c2+1)(d2+1) \leq 10$, wherein $ITTV_{norm}$, $GEDV_{norm}$ and P_{norm} are empirical normal values of ITTV, GEDV and P, respectively.

18. Computer system as claimed in any of claims 14-17, comprising a port coupled to a pressure sensor arranged in the airway of a mechanical respirator.

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19. Computer system as claimed in any of claims 14-18 being caused to determine an estimate of extravascular lung water (EVLW) as

$$EVLW = ITTV - ITBV,$$

5 EVLW being the extravascular lung water.

20. Computer system as claimed in any of claims 14-19 being caused to determine said ITTV as

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$$ITTV = CO \cdot MTT,$$

CO being the cardiac output and MTT being the mean transit time, indicating the time required by said temperature deviation to travel from said first place (101) to said second place (102).

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21. Computer system as claimed in any of claims 14-20 being caused to determine said GEDV as

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$$GEDV = CO \cdot (MTT - DST),$$

CO being the cardiac output and MTT being the mean transit time, indicating the time required by said temperature deviation to travel from said first place (101) to said second place (102) and DST being a down slope time of said thermodilution curve.

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22. Storage medium (212) having physically stored thereon a computer program for determining intrathoracic blood volume (ITBV) and other cardio-vascular parameters of a patient by thermodilution measurements comprising instructions executable by a computer system (104) to cause said computer system (104)

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a) to control temperature influencing means (107) for provoking an initial local temperature change in the proximity of a first place (101) of a patient's vascular system (103), thus introducing a travelling temperature deviation to patient's blood stream,

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b) to record said patient's local blood temperature measured by a temperature sensor device (117) for measuring the local temperature of patient's blood at a second place (102) of patient's vascular system (103) downstream of said first place (101) as a function of time to determine a thermodilution curve,

c) to determine patient's global enddiastolic blood volume (GEDV) and patient's intrathoracic thermovolume (ITTV) from said thermodilution curve,

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characterized in that said instructions include instructions to cause said computer system (104) to determine patient's intrathoracic blood volume (ITBV) according to the following formula:

$$ITBV = f(GEDV, ITTV, P),$$

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ITBV being the intrathoracic blood volume, GEDV being the global enddiastolic blood volume, ITTV being the intrathoracic thermovolume, P being an airway pressure inside patient's lungs.

23. Storage medium (212) as claimed in claim 22, wherein said function $f(GEDV, ITTV, P)$ is selected to be

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$$f(GEDV, ITTV, P) = a \cdot GEDV + b + c \cdot ITTV + d \cdot P$$

55

a being a species dependent parameter, with $1 < a < 2$

b being a species dependent parameter, including zero

c being a species dependent parameter, with $c \leq 0$

d being a species dependent parameter, including zero,

with the restriction that c and d may not be zero simultaneously.

24. Storage medium (212) as claimed in claim 22, wherein said function f(GEDV, ITTV, P) is selected to be

$$f(\text{GEDV}, \text{ITTV}, P) = \frac{a}{\frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \frac{P}{P_{\text{norm}}}} \text{GEDV} + b$$

a, b, c, and d being species dependent parameters, with $1 < a / (c+d) < 2$, wherein ITTVnorm, GEDVnorm and Pnorm are empirical normal values of ITTV, GEDV and P, respectively.

25. Storage medium (212) as claimed in claim 22, wherein said function f(GEDV, ITTV, P) is selected to be

$$\text{ITBV} = \frac{a \cdot \text{GEDV}}{\left[c2 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{\text{norm}}} + 1 \right]} + b + c1 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d1 \cdot \frac{P}{P_{\text{norm}}}$$

a, b, c1, c2, d1, d2 being species dependent parameters, with $0,5 \leq a/(c2+1)(d2+1) \leq 10$, wherein ITTVnorm, GEDVnorm and Pnorm are empirical normal values of ITTV, GEDV and P, respectively.

26. Storage medium (212) as claimed in any of claims 22-25 wherein said instructions include instructions causing said computer system (104) to determine an estimate of extravascular lung water (EVLW) as

$$\text{EVLW} = \text{ITTV} - \text{ITBV},$$

EVLW being the extravascular lung water.

27. Storage medium (212) as claimed in any of claims 22-26 wherein said instructions include instructions causing said computer system (104) to determine ITTV as

$$\text{ITTV} = \text{CO} \cdot \text{MTT},$$

CO being the cardiac output and MTT being the mean transit time, indicating the time required by said temperature deviation to travel from said first place (101) to said second place (102).

28. Storage medium (212) as claimed in any of claims 22-27 wherein said instructions include instructions causing said computer system (104) to determine GEDV as

$$\text{GEDV} = \text{CO} \cdot (\text{MTT} - \text{DST}),$$

CO being the cardiac output and MTT being the mean transit time, indicating the time required by said temperature deviation to travel from said first place (101) to said second place (102) and DST being a down slope time of said thermodilution curve.

Patentansprüche

1. Vorrichtung zum Bestimmen des intrathorakalen Blutvolumens (ITBV) und anderer kardiovaskulärer Parameter

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eines Patienten mittels Thermodilutionsmessungen, welche folgendes aufweist:

- a) Temperaturbeeinflussungsmittel (107) zum Hervorrufen einer anfänglichen lokalen Temperaturänderung in der Umgebung einer ersten Stelle (101) des vaskularen Systems (103) eines Patienten, wodurch eine wandernde Temperaturabweichung in den Blutstrom des Patienten eingebracht wird,
- b) eine Temperatursensorvorrichtung (117) zum Messen der lokalen Temperatur des Bluts des Patienten an einer zweiten Stelle (102) des vaskularen Systems (103) des Patienten stromabwärts von der ersten Stelle (101),
- c) ein mit der Temperatursensorvorrichtung (117) verbundenes Computersystem (104), welches dazu ausgelegt ist, die an der zweiten Stelle (102) gemessene lokale Bluttemperatur des Patienten als Funktion über der Zeit aufzuzeichnen, um eine Thermodilutionskurve zu bestimmen,
- d) wobei das Computersystem (104) ferner dazu ausgelegt ist, das globale enddiastolische Blutvolumen (GEDV) des Patienten und das intrathorakale Thermovolumen (ITTV) des Patienten aus der Thermodilutionskurve zu bestimmen,

dadurch gekennzeichnet, daß das Computersystem (104) ferner dazu ausgelegt ist, das intrathorakale Blutvolumen (ITBV) des Patienten gemäß der folgenden Formel zu bestimmen:

$$\text{ITBV} = f(\text{GEDV}, \text{ITTV}, P),$$

worin ITBV das intrathorakale Blutvolumen, GEDV das globale enddiastolische Blutvolumen, ITTV das intrathorakale Thermovolumen, P ein Luftwegedruck in der Lunge des Patienten ist.

2. Vorrichtung gemäß Anspruch 1, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

$$f(\text{GEDV}, \text{ITTV}, P) = a \cdot \text{GEDV} + b + c \cdot \text{ITTV} + d \cdot P$$

worin a ein spezies-abhängiger Parameter mit $1 < a < 2$ ist,
 b ein spezies-abhängiger Parameter einschließlich null ist,
 c ein spezies-abhängiger Parameter mit $c \leq 0$ ist,
 d ein spezies-abhängiger Parameter einschließlich null ist,
 mit der Einschränkung, daß c und d nicht gleichzeitig null sein dürfen.

3. Vorrichtung gemäß Anspruch 1, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

$$f(\text{GEDV}, \text{ITTV}, P) = \frac{a}{c \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \frac{P}{P_{\text{norm}}}} \text{GEDV} + b$$

worin a, b, c und d spezies-abhängige Parameter mit $1 < a / (c+d) < 2$ sind, wobei ITTV_{norm}, GEDV_{norm} und P_{norm} empirische Normalwerte von ITTV, GEDV bzw. P sind.

4. Vorrichtung gemäß Anspruch 1, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

$$\text{ITBV} = \frac{a \cdot \text{GEDV}}{\left[c2 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{\text{norm}}} + 1 \right]} + b + c1 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d1 \cdot \frac{P}{P_{\text{norm}}}$$

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worin a , b , c_1 , c_2 , d_1 , d_2 spezies-abhängige Parameter mit $0,5 \leq a/(c_2+1)(d_2+1) \leq 10$ sind, wobei ITTVnorm, GEDVnorm und Pnorm empirische Normalwerte von ITTV, GEDV bzw. P sind.

- 5 **5.** Vorrichtung gemäß einem der vorangehenden Ansprüche, wobei P einem transmuralen Lungendruck P_{tm} gleichgesetzt wird, welcher als

$$P_{tm} = ITP - P_{mv},$$

10 definiert ist, wobei ITP ein intrathorakaler Druck und P_{mv} ein microvasaler Druck ist.

- 6.** Vorrichtung gemäß einem der vorangehenden Ansprüche, wobei P ein im Luftweg eines mechanischen Beatmers gemessener Druck ist

- 15 **7.** Vorrichtung gemäß Anspruch 6, wobei P ein positiver Ausatemsenddruck (positive end expiratory pressure PEEP) ist.

- 8.** Vorrichtung gemäß 7, wobei P ein mittlerer Luftwegedruck ist.

- 20 **9.** Vorrichtung gemäß einem der vorangehenden Ansprüche, welche dazu ausgelegt ist, mindestens einen der kardiovaskulären Parameter durch transpulmonale Thermodilution zu bestimmen.

- 10.** Vorrichtung gemäß einem der vorangehenden Ansprüche, welche dazu ausgelegt ist, eine Näherung des extravasalen Lungenwassers (EVLW) als

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$$EVLW = ITTV - ITBV,$$

30

zu bestimmen, worin EVLW das extravasale Lungenwasser ist.

- 11.** Vorrichtung gemäß einem der vorangehenden Ansprüche, welche dazu ausgelegt ist, ITTV als

35

$$ITTV = CO \cdot MTT,$$

40 zu bestimmen, worin CO das Herzzeitvolumen (Cardiac Output) und MTT die mittlere Verweilzeit (mean transit time) ist, welche die Zeit angibt, welche die Temperaturabweichung benötigt, um von der ersten Stelle (101) zu der zweiten Stelle (102) zu wandern.

- 12.** Vorrichtung gemäß einem der vorangehenden Ansprüche, welche dazu ausgelegt ist, GEDV als

45

$$GEDV = CO \cdot (MTT - DST),$$

50 zu bestimmen, worin CO das Herzzeitvolumen (Cardiac Output) und MTT die mittlere Verweilzeit (mean transit time) ist, welche die Zeit angibt, welche die Temperaturabweichung benötigt, um von der ersten Stelle (101) zu der zweiten Stelle (102) zu wandern, und DST eine exponentielle Abfallzeit (down slope time) der Thermodilutionskurve ist.

- 55 **13.** Vorrichtung gemäß einem der vorangehenden Ansprüche, welche ferner eine mit dem Computersystem (104) verbundene Drucksensorvorrichtung (118) aufweist.

- 14.** Computersystem (104) welches erste Verbindungsmittel zum Verbinden des Computersystems (104) mit Tempe-

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raturbeeinflussungsmitteln (107) und zweite Verbindungsmittel zum Verbinden des Computersystems (104) mit einer Temperatursensorvorrichtung (117) aufweist, und Zugriffsmittel zum Zugreifen auf ausführbare Anweisungen, um das Computersystem (104) dazu zu veranlassen

- 5 a) die Temperaturbeeinflussungsmittel (107) zu steuern, eine anfängliche lokale Temperaturänderung in der Umgebung einer ersten Stelle (101) des vaskulären Systems (103) eines Patienten hervorzurufen, wodurch eine wandernde Temperaturabweichung in den Blutstrom des Patienten eingebracht wird,
 b) die von einer Temperatursensorvorrichtung (117) zum Messen der lokalen Temperatur des Bluts des Patienten an einer zweiten Stelle (102) des vaskulären Systems (103) des Patienten stromabwärts von der ersten Stelle (101) gemessene lokale Bluttemperatur als Funktion über der Zeit aufzuzeichnen, um eine Thermodilutionskurve zu bestimmen,
 10 c) das globale enddiastolische Blutvolumen (GEDV) des Patienten und das intrathorakale Thermovolumen (ITTV) des Patienten aus der Thermodilutionskurve zu bestimmen,

15 **dadurch gekennzeichnet, daß** die Anweisungen Anweisungen enthalten, welche das Computersystem (104) dazu veranlassen,
 das intrathorakale Blutvolumen (ITBV) des Patienten gemäß der folgenden Formel zu bestimmen:

$$20 \quad \text{ITBV} = f(\text{GEDV}, \text{ITTV}, P),$$

worin ITBV das intrathorakale Blutvolumen, GEDV das globale enddiastolische Blutvolumen, ITTV das intrathorakale Thermovolumen, P ein Luftwegedruck in der Lunge des Patienten ist.

25

15. Computersystem gemäß Anspruch 14, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

30

$$f(\text{GEDV}, \text{ITTV}, P) = a \cdot \text{GEDV} + b + c \cdot \text{ITTV} + d \cdot P$$

worin a ein spezies-abhängiger Parameter mit $1 < a < 2$ ist,
 b ein spezies-abhängiger Parameter einschließlich null ist,
 c ein spezies-abhängiger Parameter mit $c \leq 0$ ist,
 35 d ein spezies-abhängiger Parameter einschließlich null ist,
 mit der Einschränkung, daß c und d nicht gleichzeitig null sein dürfen.

16. Computersystem gemäß Anspruch 14, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

40

$$f(\text{GEDV}, \text{ITTV}, P) = \frac{a}{c \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \frac{P}{P_{\text{norm}}}} \text{GEDV} + b$$

45

worin a, b, c und d spezies-abhängige Parameter mit $1 < a / (c+d) < 2$ sind, wobei ITTV_{norm}, GEDV_{norm} und P_{norm} empirische Normalwerte von ITTV, GEDV bzw. P sind.

50

17. Computersystem gemäß Anspruch 14, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

55

$$\text{ITBV} = \frac{a \cdot \text{GEDV}}{\left[c2 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{\text{norm}}} + 1 \right]} + b + c1 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d1 \cdot \frac{P}{P_{\text{norm}}}$$

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worin a , b , c_1 , c_2 , d_1 , d_2 spezies-abhängige Parameter mit $0,5 \leq a/(c_2+1)(d_2+1) \leq 10$ sind, wobei ITTVnorm, GEDVnorm und Pnorm empirische Normalwerte von ITTV, GEDV bzw. P sind.

5 18. Computersystem gemäß einem der Ansprüche 14-17, welches einen mit einem im Luftweg eines mechanischen Beatmers angeordneten Drucksensor verbundenen Anschluß aufweist.

10 19. Computersystem gemäß einem der Ansprüche 14-18, welches veranlaßt wird, eine Näherung des extravasalen Lungenwassers (EVLW) als

$$\text{EVLW} = \text{ITTV} - \text{ITBV},$$

15 zu bestimmen, worin EVLW das extravasale Lungenwasser ist.

20 20. Computersystem gemäß einem der Ansprüche 14-19, welches dazu veranlaßt wird, ITTV als

$$\text{ITTV} = \text{CO} \cdot \text{MTT}$$

25 zu bestimmen, worin CO das Herzzeitvolumen (Cardiac Output) und MTT die mittlere Verweilzeit (mean transit time) ist, welche die Zeit angibt, welche die Temperaturabweichung benötigt, um von der ersten Stelle (101) zu der zweiten Stelle (102) zu wandern.

30 21. Computersystem gemäß einem der Ansprüche 14-20, welches dazu veranlaßt wird, GEDV als

$$\text{GEDV} = \text{CO} \cdot (\text{MTT} - \text{DST})$$

35 zu bestimmen, worin CO das Herzzeitvolumen (Cardiac Output) und MTT die mittlere Verweilzeit (mean transit time) ist, welche die Zeit angibt, welche die Temperaturabweichung benötigt, um von der ersten Stelle (101) zu der zweiten Stelle (102) zu wandern, und DST eine exponentielle Abfallzeit (down slope time) der Thermodilutionskurve ist.

40 22. Speichermedium (212) auf welchem physikalisch ein Computerprogramm zum Bestimmen des intrathorakalen Blutvolumens (ITBV) and und anderer kardiovaskulärer Parameter eines Patienten mittels Thermodilutionsmessungen gespeichert ist, welches von einem Computersystem (104) ausführbare Anweisungen aufweist, um das Computersystem (104) dazu zu veranlassen,

45 a) Temperaturbeeinflussungsmittel (107) zu steuern, eine anfängliche lokale Temperaturänderung in der Umgebung einer ersten Stelle (101) des vaskulären Systems (103) eines Patienten hervorzurufen, wodurch eine wandernde Temperaturabweichung in den Blutstrom des Patienten eingebracht wird,

b) die von einer Temperatursensorvorrichtung (117) zum Messen der lokalen Temperatur des Bluts des Patienten an einer zweiten Stelle (102) des vaskulären Systems (103) des Patienten stromabwärts von der ersten Stelle (101) gemessene lokale Bluttemperatur als Funktion über der Zeit aufzuzeichnen, um eine Thermodilutionskurve zu bestimmen,

50 c) das globale enddiastolische Blutvolumen (GEDV) des Patienten und das intrathorakale Thermovolumen (ITTV) des Patienten aus der Thermodilutionskurve zu bestimmen,

dadurch gekennzeichnet, daß die Anweisungen Anweisungen enthalten, welche das Computersystem (104) dazu veranlassen,

das intrathorakale Blutvolumen (ITBV) des Patienten gemäß der folgenden Formel zu bestimmen:

$$\text{ITBV} = f(\text{GEDV}, \text{ITTV}, P),$$

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worin ITBV das intrathorakale Blutvolumen, GEDV das globale enddiastolische Blutvolumen, ITTV das intrathorakale Thermovolumen, P ein Luftwegedruck in der Lunge des Patienten ist.

23. Speichermedium (212) gemäß Anspruch 22, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

$$f(\text{GEDV}, \text{ITTV}, P) = a \cdot \text{GEDV} + b + c \cdot \text{ITTV} + d \cdot P$$

worin a ein spezies-abhängiger Parameter mit $1 < a < 2$ ist,
 b ein spezies-abhängiger Parameter einschließlich null ist,
 c ein spezies-abhängiger Parameter mit $c \leq 0$ ist,
 d ein spezies-abhängiger Parameter einschließlich null ist,
 mit der Einschränkung, daß c und d nicht gleichzeitig null sein dürfen.

24. Speichermedium (212) gemäß Anspruch 22, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

$$f(\text{GEDV}, \text{ITTV}, P) = \frac{a}{c \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \frac{P}{P_{\text{norm}}}} \text{GEDV} + b$$

worin a, b, c und d spezies-abhängige Parameter mit $1 < a / (c+d) < 2$ sind, wobei ITTVnorm, GEDVnorm und Pnorm empirische Normalwerte von ITTV, GEDV bzw. P sind.

25. Speichermedium (212) gemäß Anspruch 22, wobei die Funktion $f(\text{GEDV}, \text{ITTV}, P)$ ausgewählt wird als

$$\text{ITBV} = \frac{a \cdot \text{GEDV}}{\left[c2 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{\text{norm}}} + 1 \right]} + b + c1 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d1 \cdot \frac{P}{P_{\text{norm}}}$$

worin a, b, c1, c2, d1, d2 spezies-abhängige Parameter mit $0,5 \leq a / (c2+1)(d2+1) \leq 10$ sind, wobei ITTVnorm, GEDVnorm und Pnorm empirische Normalwerte von ITTV, GEDV bzw. P sind.

26. Speichermedium (212) gemäß einem der Ansprüche 22-25, wobei die Anweisungen Anweisungen enthalten, welche das Computersystem (104) dazu veranlassen, eine Näherung des extravasalen Lungenwassers (EVLW) als

$$\text{EVLW} = \text{ITTV} - \text{ITBV},$$

zu bestimmen, worin EVLW das extravasale Lungenwasser ist.

27. Speichermedium (212) gemäß einem der Ansprüche 22-26, wobei die Anweisungen Anweisungen enthalten, welche das Computersystem (104) dazu veranlassen, ITTV als

$$\text{ITTV} = \text{CO} \cdot \text{MTT},$$

zu bestimmen, worin CO das Herzzeitvolumen (Cardiac Output) und MTT die mittlere Verweilzeit (mean transit

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time) ist, welche die Zeit angibt, welche die Temperaturabweichung benötigt, um von der ersten Stelle (101) zu der zweiten Stelle (102) zu wandern.

- 5 28. Speichermedium (212) gemäß einem der Ansprüche 22-27, wobei die Anweisungen Anweisungen enthalten, welche das Computersystem (104) dazu veranlassen, GEDV als

$$\text{GEDV} = \text{CO} \cdot (\text{MTT} - \text{DST}),$$

10 zu bestimmen, worin CO das Herzzeitvolumen (Cardiac Output) und MTT die mittlere Verweilzeit (mean transit time) ist, welche die Zeit angibt, welche die Temperaturabweichung benötigt, um von der ersten Stelle (101) zu der zweiten Stelle (102) zu wandern, und DST eine exponentielle Abfallzeit (down slope time) der Thermodilutionskurve ist.

Revendications

- 20 1. - Appareil pour déterminer le volume sanguin intrathoracique (ITBV - intrathoracic blood volume) et d'autres paramètres cardio-vasculaires d'un patient par des mesures de thermodilution comprenant :

25 (a) un moyen influençant la température (107) pour provoquer un changement initial de température locale à proximité d'un premier emplacement (101) du système vasculaire (103) d'un patient, permettant ainsi d'introduire dans le courant sanguin du patient un écart de température se déplaçant ;

(b) un dispositif détecteur de température (117) pour mesurer la température locale du sang du patient à un second emplacement (102) du système vasculaire (103) du patient en aval dudit premier emplacement (101) ;

30 (c) un système informatique (104) couplé audit dispositif détecteur de température (117) et adapté pour enregistrer ladite température locale du sang du patient mesurée audit second emplacement (102) en fonction du temps pour déterminer une courbe de thermodilution ;

(d) ledit système informatique (104) étant en outre adapté pour déterminer le volume sanguin télédiastolique global du patient (GEDV - global enddiastolic blood volume) et le thermovolume intrathoracique du patient (ITTV - intrathoracic thermovolume) à partir de ladite courbe de thermodilution ;

35 **caractérisé par le fait que** ledit système informatique (104) est en outre adapté pour déterminer le volume sanguin intrathoracique (ITBV) du patient selon la formule suivante :

$$\text{ITBV} = f(\text{GEDV}, \text{ITTV}, P),$$

40 ITBV étant le volume sanguin intrathoracique, GEDV étant le volume sanguin télédiastolique global, ITTV étant le thermovolume intrathoracique, P étant une pression trachéale à l'intérieur des poumons du patient.

- 45 2. - Appareil selon la revendication 1, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

$$f(\text{GEDV}, \text{ITTV}, P) = a \cdot \text{GEDV} + b + c \cdot \text{ITTV} + d \cdot P$$

50 a étant un paramètre dépendant de l'espèce, avec $1 < a < 2$

b étant un paramètre dépendant de l'espèce, incluant zéro

c étant un paramètre dépendant de l'espèce, avec $c \leq 0$

d étant un paramètre dépendant de l'espèce, incluant zéro,

avec la restriction que c et d ne peuvent pas être zéro simultanément.

- 55 3. - Appareil selon la revendication 1, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

$$f(\text{GEDV}, \text{ITTV}, P) = \frac{a}{c \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \frac{P}{P_{\text{norm}}}} \text{GEDV} + b$$

a, b, c et d étant des paramètres dépendants de l'espèce, avec $1 < a/(c+d) < 2$, ITTVnorm, GEDVnorm et Pnorm étant des valeurs normales empiriques de respectivement ITTV, GEDV et P.

4. - Appareil selon la revendication 1, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

$$\text{ITBV} = \frac{a \cdot \text{GEDV}}{\left[c2 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{\text{norm}}} + 1 \right]} + b + c1 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d1 \cdot \frac{P}{P_{\text{norm}}}$$

a, b, c1, c2, d1, d2 étant des paramètres dépendant de l'espèce, avec $0,5 \leq a/(c2+1)(d2+1) \leq 10$, ITTVnorm, GEDVnorm et Pnorm étant des valeurs normales empiriques de respectivement ITTV, GEDV et P.

5. - Appareil selon l'une quelconque des revendications précédentes, dans lequel P est fixée égale à une pression transmurale des poumons Ptm, étant définie comme :

$$P_{tm} = \text{ITP} - P_{mv}$$

ITP étant une pression intrathoracique et Pmv étant une pression microvasculaire.

6. - Appareil selon l'une quelconque des revendications précédentes, dans lequel P est une pression mesurée dans le tubage endotrachéal d'un respirateur mécanique.
7. - Appareil selon la revendication 6, dans lequel P est une pression positive en fin d'expiration (PEEP - positive end expiratory pressure).
8. - Appareil selon la revendication 7, dans lequel P est une pression trachéale moyenne.
9. - Appareil selon l'une quelconque des revendications précédentes, qui est adapté pour déterminer au moins l'un desdits paramètres cardio-vasculaires par thermodilution transpulmonaire.
10. - Appareil selon l'une quelconque des revendications précédentes, qui est adapté pour déterminer une estimation de l'eau pulmonaire extravasculaire (EVLW - extravascular lung water) comme :

$$\text{EVLW} = \text{ITTV} - \text{ITBV}$$

EVLW étant l'eau pulmonaire extravasculaire.

11. - Appareil selon l'une quelconque des revendications précédentes, qui est adapté pour déterminer ITTV comme :

$$ITTV = CO \cdot MTT.$$

5

CO étant le débit cardiaque et MTT étant le temps de transit moyen, indiquant le temps requis par ledit écart de température pour se déplacer dudit premier emplacement (101) audit second emplacement (102).

10

12. - Appareil selon l'une quelconque des revendications précédentes, qui est adapté pour déterminer GEDV comme :

$$GEDV = CO \cdot (MTT - DST),$$

15

CO étant le débit cardiaque et MTT étant le temps de transit moyen, indiquant le temps requis par ledit écart de température pour se déplacer dudit premier emplacement (101) audit second emplacement (102), et DST étant un temps de décroissance de ladite courbe de thermodilution.

20

13. - Appareil selon l'une quelconque des revendications précédentes, comprenant en outre un dispositif de détection de pression (118) couplé audit système informatique (104).

25

14. - Système informatique (104) comprenant un premier moyen de couplage pour coupler ledit système informatique (104) au moyen influençant la température (107) et un second moyen de couplage pour coupler ledit système informatique (104) à un dispositif détecteur de température (117), et un moyen d'accès pour accéder à des instructions exécutables pour amener ledit système informatique (104) à :

30

(a) commander le moyen influençant la température (107) pour provoquer un changement initial de température locale à proximité d'un premier emplacement (101) du système vasculaire (103) d'un patient, permettant ainsi d'introduire dans le courant sanguin du patient un écart de température se déplaçant ;

35

(b) enregistrer ladite température locale du sang du patient mesurée par un dispositif détecteur de température (117) pour mesurer la température locale du sang du patient à un second emplacement (102) du système vasculaire (103) du patient en aval dudit premier emplacement (101) en fonction du temps pour déterminer une courbe de thermodilution ;

(c) déterminer le volume sanguin télédiastolique global (GEDV) du patient et le thermovolume intrathoracique (ITTV) du patient à partir de ladite courbe de thermodilution ;

40

caractérisé par le fait que lesdites instructions comprennent des instructions pour amener ledit système informatique (104)

à déterminer le volume sanguin intrathoracique (ITBV) du patient selon la formule suivante :

$$ITBV = f(GEDV, ITTV, P),$$

45

ITBV étant le volume sanguin intrathoracique, GEDV étant le volume sanguin télédiastolique global, ITTV étant le thermovolume intrathoracique, P étant une pression trachéale à l'intérieur des poumons du patient.

50

15. - Système informatique selon la revendication 14, dans lequel ladite fonction $f(GEDV, ITTV, P)$ est sélectionnée pour être :

55

$$f(GEDV, ITTV, P) = a \cdot GEDV + b + c \cdot ITTV + d \cdot P$$

a étant un paramètre dépendant de l'espèce, avec $1 < a < 2$

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b étant un paramètre dépendant de l'espèce, incluant zéro
 c étant un paramètre dépendant de l'espèce, avec $c \leq 0$
 d étant un paramètre dépendant de l'espèce, incluant zéro,
 avec la restriction que c et d ne peuvent pas être zéro simultanément.

5

16. - Système informatique selon la revendication 14, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

10

$$f(\text{GEDV}, \text{ITTV}, P) = \frac{a}{c} \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \frac{P}{P_{\text{norm}}} \text{GEDV} + b$$

15

a, b, c et d étant des paramètres dépendants de l'espèce, avec $1 < a/(c+d) < 2$, $\text{ITTV}_{\text{norm}}$, $\text{GEDV}_{\text{norm}}$ et P_{norm} étant des valeurs normales empiriques de respectivement ITTV, GEDV et P.

17. - Système informatique selon la revendication 14, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

20

$$\text{ITBV} = \frac{a \cdot \text{GEDV}}{\left[c2 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{\text{norm}}} + 1 \right]} + b + c1 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \cdot \frac{P}{P_{\text{norm}}}$$

25

a, b, c1, c2, d1, d2 étant des paramètres dépendants de l'espèce, avec $0,5 \leq a/(c2+1)(d2+1) \leq 10$, $\text{ITTV}_{\text{norm}}$, $\text{GEDV}_{\text{norm}}$ et P_{norm} étant des valeurs normales empiriques de respectivement ITTV, GEDV et P.

30

18. - Système informatique selon l'une quelconque des revendications 14-17, comprenant un port couplé à un détecteur de pression disposé dans le tubage endotrachéal d'un respirateur mécanique.

35

19. - Système informatique selon l'une quelconque des revendications 14-18, étant amené à déterminer une estimation de l'eau pulmonaire extravasculaire (EVLW) comme :

$$\text{EVLW} = \text{ITTV} - \text{ITBV},$$

40

EVLW étant l'eau pulmonaire extravasculaire.

45

20. - Système informatique selon l'une quelconque des revendications 14-19, étant amené à déterminer ledit ITTV comme :

$$\text{ITTV} = \text{CO} \cdot \text{MTT},$$

50

CO étant le débit cardiaque et MTT étant le temps de transit moyen, indiquant le temps requis par ledit écart de température pour se déplacer dudit premier emplacement (101) audit second emplacement (102).

55

21. - Système informatique selon l'une quelconque des revendications 14-20, étant amené à déterminer ledit GEDV comme :

$$\text{GEDV} = \text{CO} \cdot (\text{MTT} - \text{DST}),$$

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CO étant le débit cardiaque et MTT étant le temps de transit moyen, indiquant le temps requis par ledit écart de température pour se déplacer dudit premier emplacement (101) audit second emplacement (102), et DST étant un temps de décroissance de ladite courbe de thermodilution.

5 **22.** - Support de stockage (212) sur lequel un programme informatique est physiquement stocké pour déterminer le volume sanguin intrathoracique (ITBV) et d'autres paramètres cardio-vasculaires d'un patient par des mesures de thermodilution comprenant des instructions exécutables par un système informatique (104) pour amener ledit système informatique (104) à :

10 (a) commander le moyen influençant la température (107) pour provoquer un changement initial de température locale à proximité d'un premier emplacement (101) du système vasculaire (103) d'un patient, permettant ainsi d'introduire dans le courant sanguin du patient un écart de température se déplaçant ;

15 (b) enregistrer ladite température locale du sang du patient mesurée par un dispositif détecteur de température (117) pour mesurer la température locale du sang du patient à un second emplacement (102) du système vasculaire (103) du patient en aval dudit premier emplacement (101) en fonction du temps pour déterminer une courbe de thermodilution ;

(c) déterminer le volume sanguin télédiastolique global (GEDV) du patient et le thermovolume intrathoracique (ITTV) du patient à partir de ladite courbe de thermodilution ;

20 **caractérisé par le fait que** lesdites instructions comprennent des instructions pour amener ledit système informatique (104)

à déterminer le volume sanguin intrathoracique (ITBV) du patient selon la formule suivante :

25

$$\text{ITBV} = f(\text{GEDV}, \text{ITTV}, P),$$

30 ITBV étant le volume sanguin intrathoracique, GEDV étant le volume sanguin télédiastolique global, ITTV étant le thermovolume intrathoracique, P étant une pression trachéale à l'intérieur de poumons du patient.

23. - Support de stockage (212) selon la revendication 22, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

35

$$f(\text{GEDV}, \text{ITTV}, P) = a \cdot \text{GEDV} + b + c \cdot \text{ITTV} + d \cdot P$$

40 a étant un paramètre dépendant de l'espèce, avec $1 < a < 2$

b étant un paramètre dépendant de l'espèce, incluant zéro

c étant un paramètre dépendant de l'espèce, avec $c \leq 0$

d étant un paramètre dépendant de l'espèce, incluant zéro, avec la restriction que c et d ne peuvent pas être zéro simultanément.

45

24. - Support de stockage (212) selon la revendication 22, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

50

$$f(\text{GEDV}, \text{ITTV}, P) = \frac{a}{\frac{c}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d \frac{P}{P_{\text{norm}}}} \text{GEDV} + b$$

55

a, b, c et d étant des paramètres dépendants de l'espèce, avec $1 < a/(c+d) < 2$, ITTV_{norm}, GEDV_{norm} et P_{norm} étant des valeurs normales empiriques de respectivement ITTV, GEDV et P.

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25. - Support de stockage (212) selon la revendication 22, dans lequel ladite fonction $f(\text{GEDV}, \text{ITTV}, P)$ est choisie pour être :

$$\text{ITBV} = \frac{a \cdot \text{GEDV}}{\left[c2 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + 1 \right] \cdot \left[d2 \cdot \frac{P}{P_{\text{norm}}} + 1 \right]} + b + c1 \cdot \frac{(\text{ITTV} - \text{GEDV})}{(\text{ITTV}_{\text{norm}} - \text{GEDV}_{\text{norm}})} + d1 \cdot \frac{P}{P_{\text{norm}}}$$

a, b, c1, c2, d1, d2 étant des paramètres dépendants de l'espèce, avec $0,5 \leq a/(c2+1)(d2+1) \leq 10$, $\text{ITTV}_{\text{norm}}$, $\text{GEDV}_{\text{norm}}$ et P_{norm} étant des valeurs normales empiriques de respectivement ITTV , GEDV et P .

26. - Support de stockage (212) selon l'une quelconque des revendications 22-25, dans lequel lesdites instructions comprennent des instructions amenant ledit système informatique (104) à déterminer une estimation de l'eau pulmonaire extravasculaire (EVLW) comme :

$$\text{EVLW} = \text{ITTV} - \text{ITBV},$$

EVLW étant l'eau pulmonaire extravasculaire.

27. - Support de stockage (212) selon l'une quelconque des revendications 22-26, dans lequel lesdites instructions comprennent des instructions amenant ledit système informatique (104) à déterminer ITTV comme :

$$\text{ITTV} = \text{CO} \cdot \text{MTT},$$

CO étant le débit cardiaque et MTT étant le temps de transit moyen, indiquant le temps requis par ledit écart de température pour se déplacer dudit premier emplacement (101) audit second emplacement (102).

28. - Support de stockage (212) selon l'une quelconque des revendications 22-27, dans lequel lesdites instructions comprennent des instructions amenant ledit système informatique (104) à déterminer GEDV comme :

$$\text{GEDV} = \text{CO} \cdot (\text{MTT} \cdot \text{DST}),$$

CO étant le débit cardiaque et MTT étant le temps de transit moyen, indiquant le temps requis par ledit écart de température pour se déplacer dudit premier emplacement (101) audit second emplacement (102), et DST étant un temps de décroissance de ladite courbe de thermodilution.

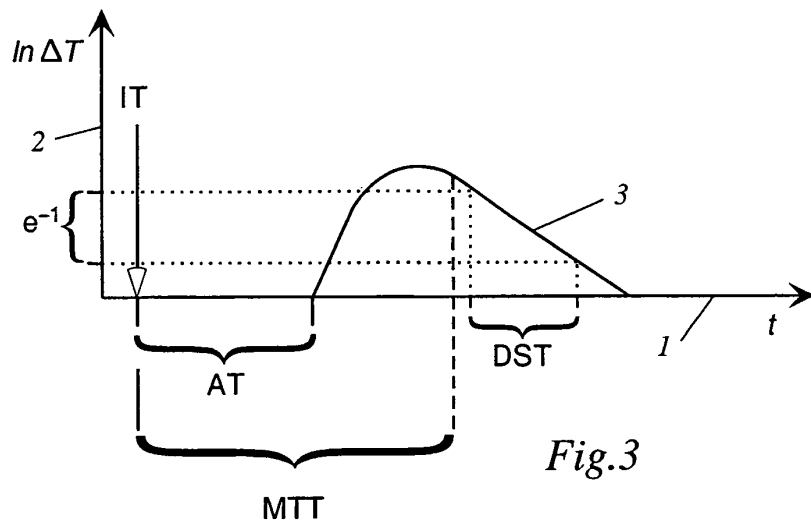


Fig.3

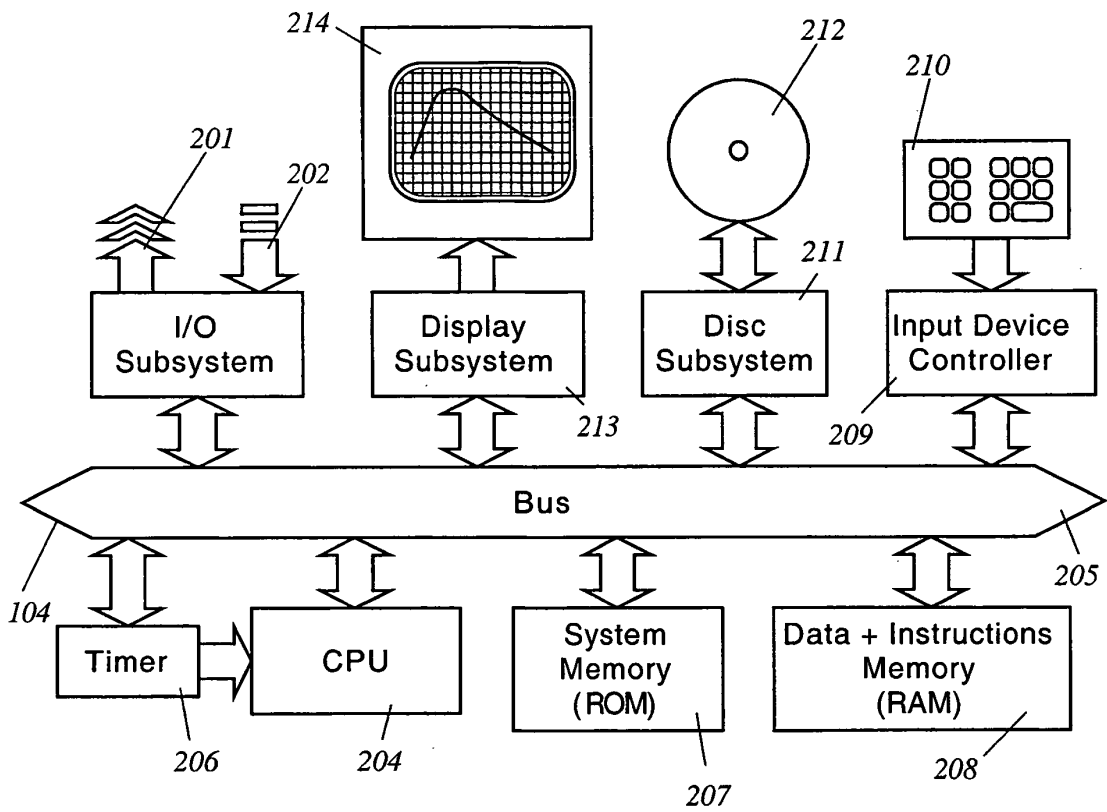


Fig.4

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 9321823 A [0002]

专利名称(译)	用于确定胸内血容量和其他心血管参数的装置，计算机系统和计算机程序		
公开(公告)号	EP1588661B1	公开(公告)日	2007-06-27
申请号	EP2004101678	申请日	2004-04-22
申请(专利权)人(译)	压出性医疗系统公司		
当前申请(专利权)人(译)	压出性医疗系统公司		
[标]发明人	PFEIFFER ULRICH J MICHARD FREDERIC KNOLL REINHOLD		
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IPC分类号	A61B5/028 A61B5/00 A61B5/02		
CPC分类号	A61B5/028		
其他公开文献	EP1588661A1		
外部链接	Espacenet		

摘要(译)

用于通过热稀释测量确定患者的胸内血容量 (ITBV) 和其他心血管参数的装置，计算机系统，计算机程序和存储介质。该装置包括：温度影响装置 (107)，用于将行进温度偏差引入患者的血流；温度传感器装置 (117)，用于测量所述温度影响装置 (107) 下游的患者血液的局部温度，计算机系统 (104) 适于：记录作为时间函数测量的局部血液温度以确定热稀释曲线，从所述热稀释曲线确定全球舒张末期血容量 (GEDV) 和胸内热容积 (ITTV)，确定胸内血容量 (ITBV) 作为函数 GEDV，ITTV 和患者肺部气道压力 (P)。通过不仅从 GEDV 确定 ITBV 而且还根据 ITTV 和 P 确定 ITBV，可以获得增强的准确性，特别是如果患者患有肺水肿和/或机械通气。

$$CO = \frac{V_L (T_B - T_L) K_1 K_2}{\int \Delta T_B(t) dt}$$