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Warner

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[54] **HEART-RELATED PARAMETERS MONITORING APPARATUS**

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[73] Assignees: **Sylvia Warner**, St. Laurent; **Priyamvada Sankar**, Brossard, both of Canada

[21] Appl. No.: **556,101**

[22] Filed: **Jul. 20, 1990**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **4,834,107**
Issued: **May 30, 1989**
Appl. No.: **105,803**
Filed: **Oct. 8, 1987**

U.S. Applications:

[63] Continuation-in-part of Ser. No. 59,520, Jun. 8, 1987, abandoned, which is a continuation-in-part of Ser. No. 807,693, Dec. 11, 1985, abandoned, which is a continuation-in-part of Ser. No. 608,955, May 10, 1984, abandoned.

[51] **Int. Cl.**[5] **A61B 5/02**

[52] **U.S. Cl.** **128/668**; 128/666; 128/691; 128/694; 128/713

[58] **Field of Search** 128/666, 668, 691, 694, 128/713

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,030,485 6/1977 Warner .... 128/2.05 A
4,425,920 1/1984 Bowland 128/672

FOREIGN PATENT DOCUMENTS

2092309 8/1982 United Kingdom 128/672

Primary Examiner—Asok Pal
Attorney, Agent, or Firm—Chilton, Alix & Van Kirk

[57] **ABSTRACT**

A non-invasive method, and an apparatus, for determining heart-related parameters in patients. The method and apparatus determine pulse pressure, time constant of the arterial system, systolic and diastolic pressure, peripheral resistance, cardiac output and mean arterial blood pressure.

18 Claims, 6 Drawing Sheets

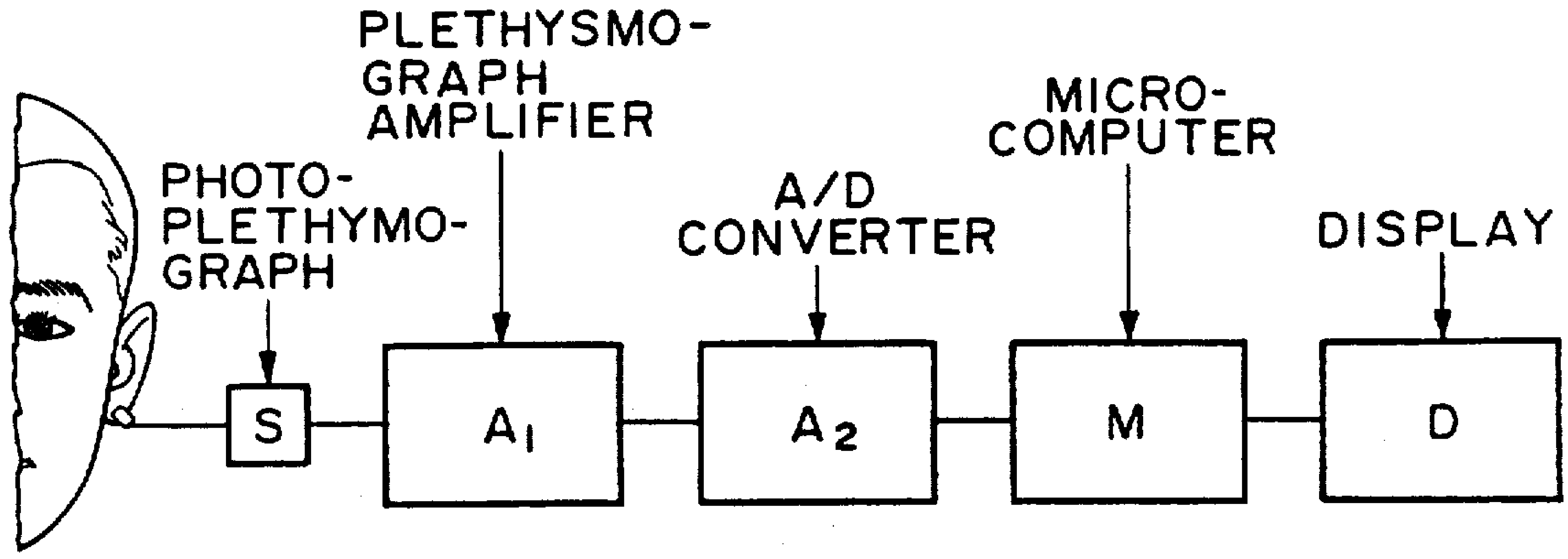
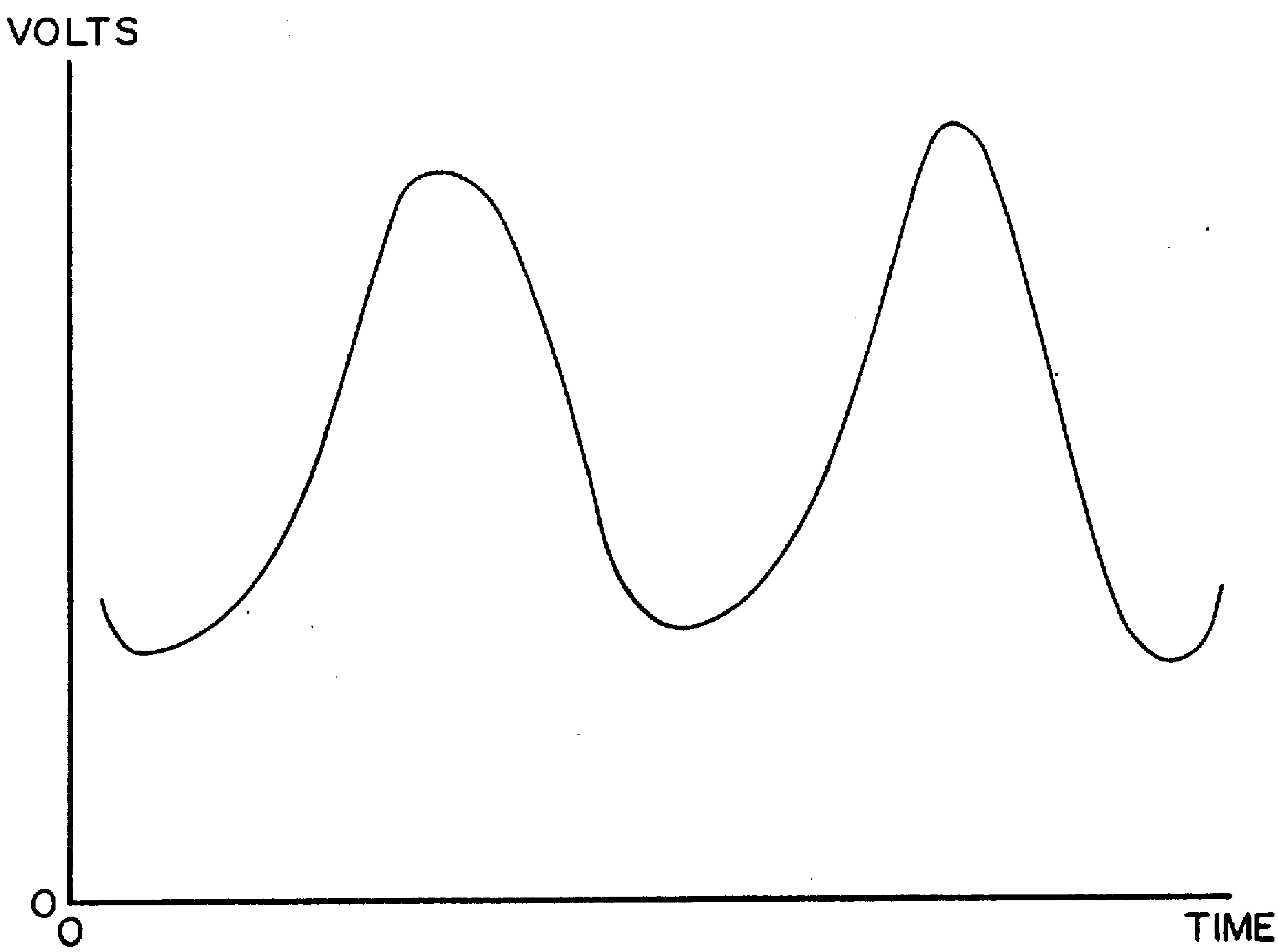

PLETHYSMO-
GRAPH
AMPLIFIER
MICRO-
COMPUTER
PHOTO-
PLETHYMO-
GRAPH
A/D
CONVERTER
DISPLAY
S
A_1
A_2
M
D

FIG. 1


VOLTS
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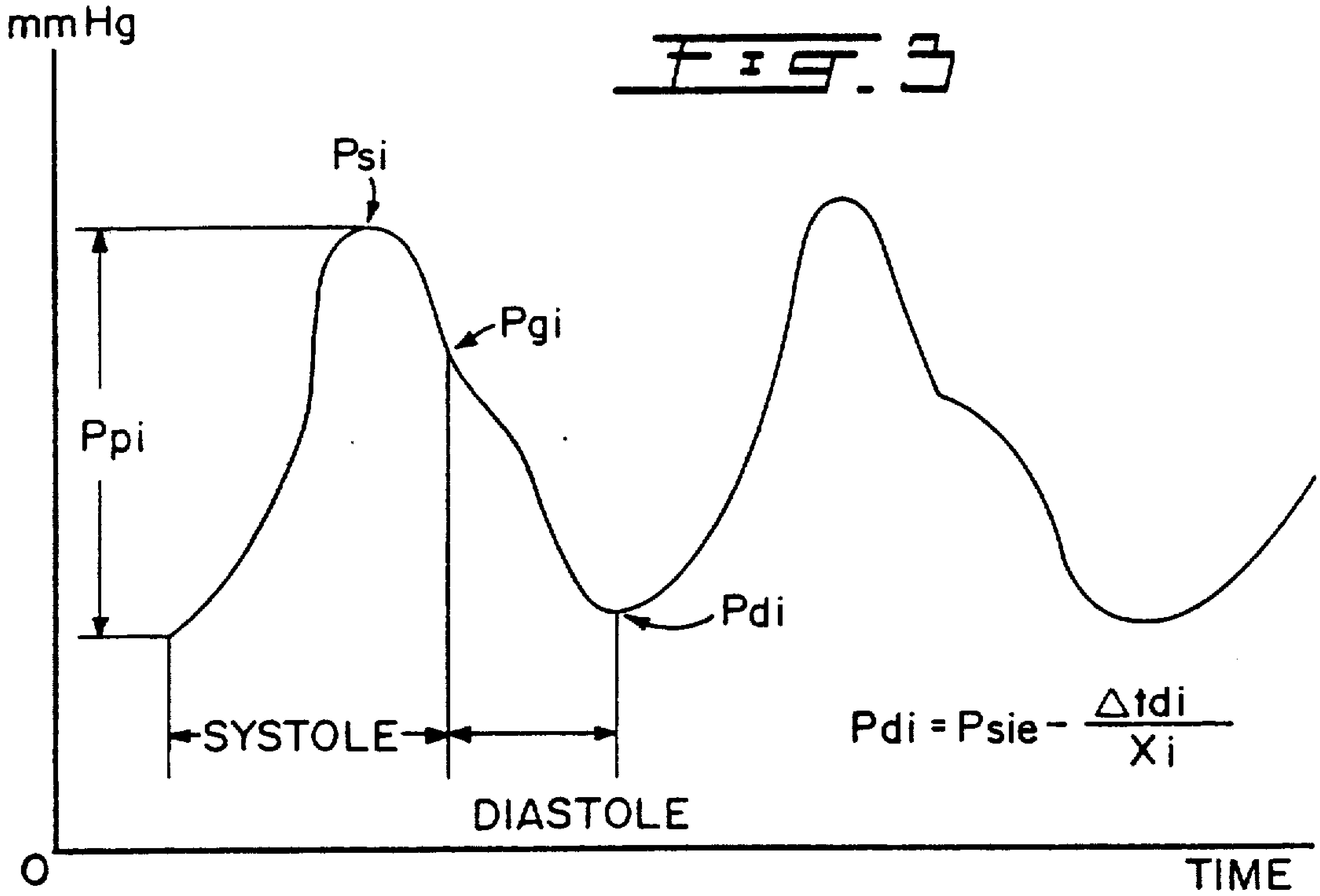
0
TIME

FIG. 2

FIG. 3


mmHg
Psi
Pgi
Ppi
Pdi
SYSTOLE
DIASTOLE
$Pdi = Psie - \frac{\Delta tdi}{Xi}$
0
TIME

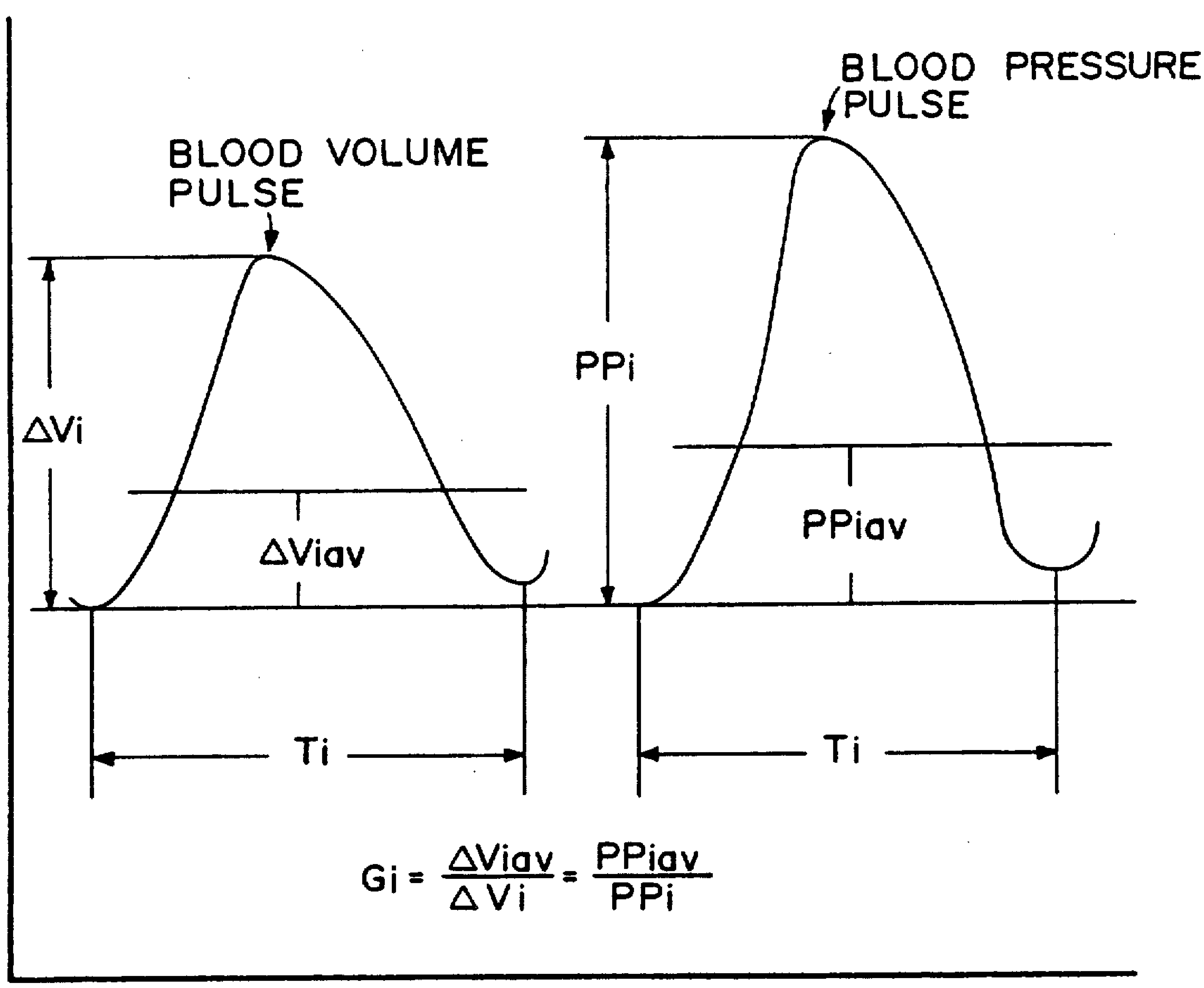

BLOOD PRESSURE PULSE
BLOOD VOLUME PULSE
ΔVi
ΔViav
PPi
PPiav
Ti
Ti
$Gi = \frac{\Delta Viav}{\Delta Vi} = \frac{PPiav}{PPi}$

FIG. 5

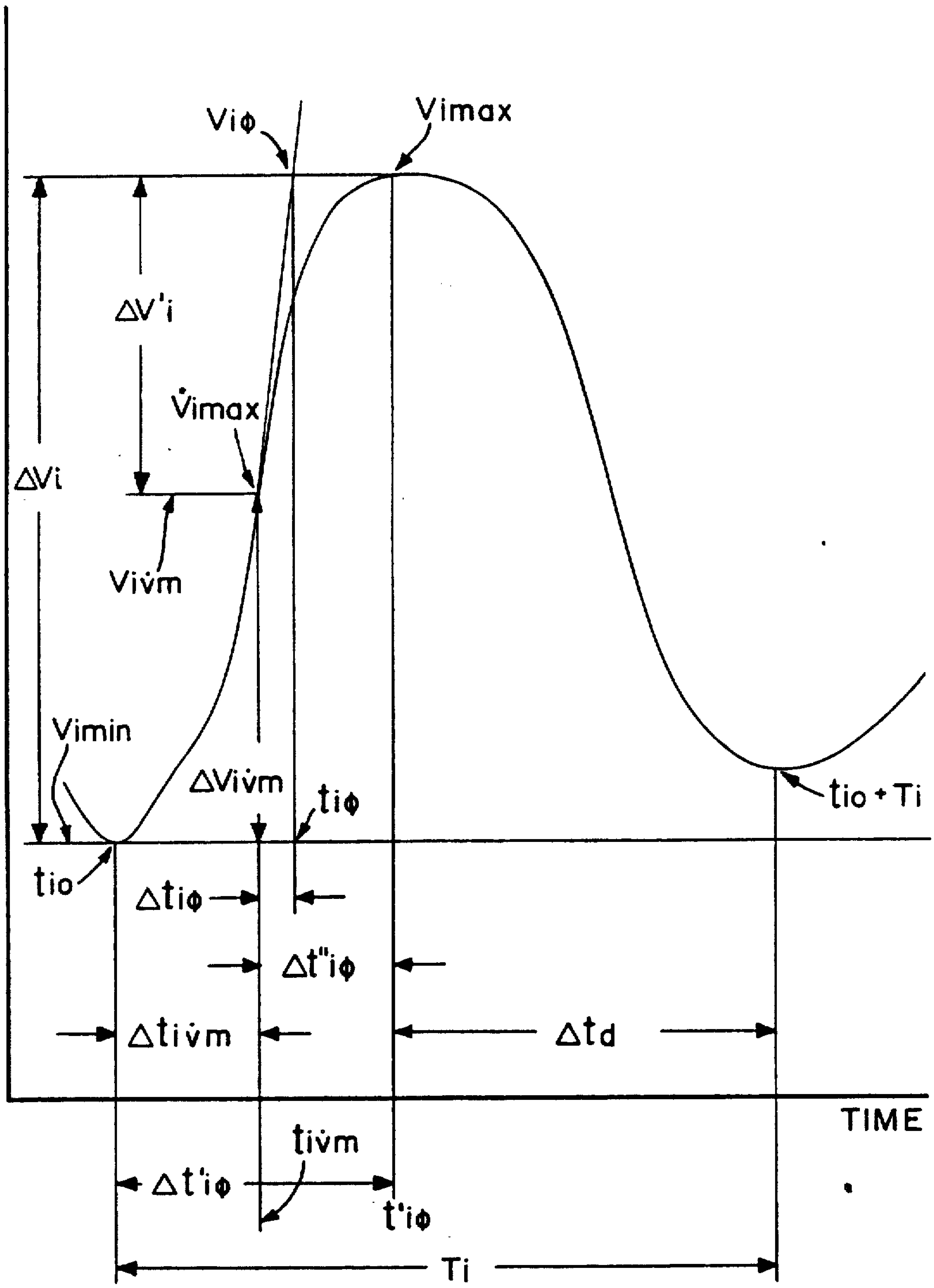
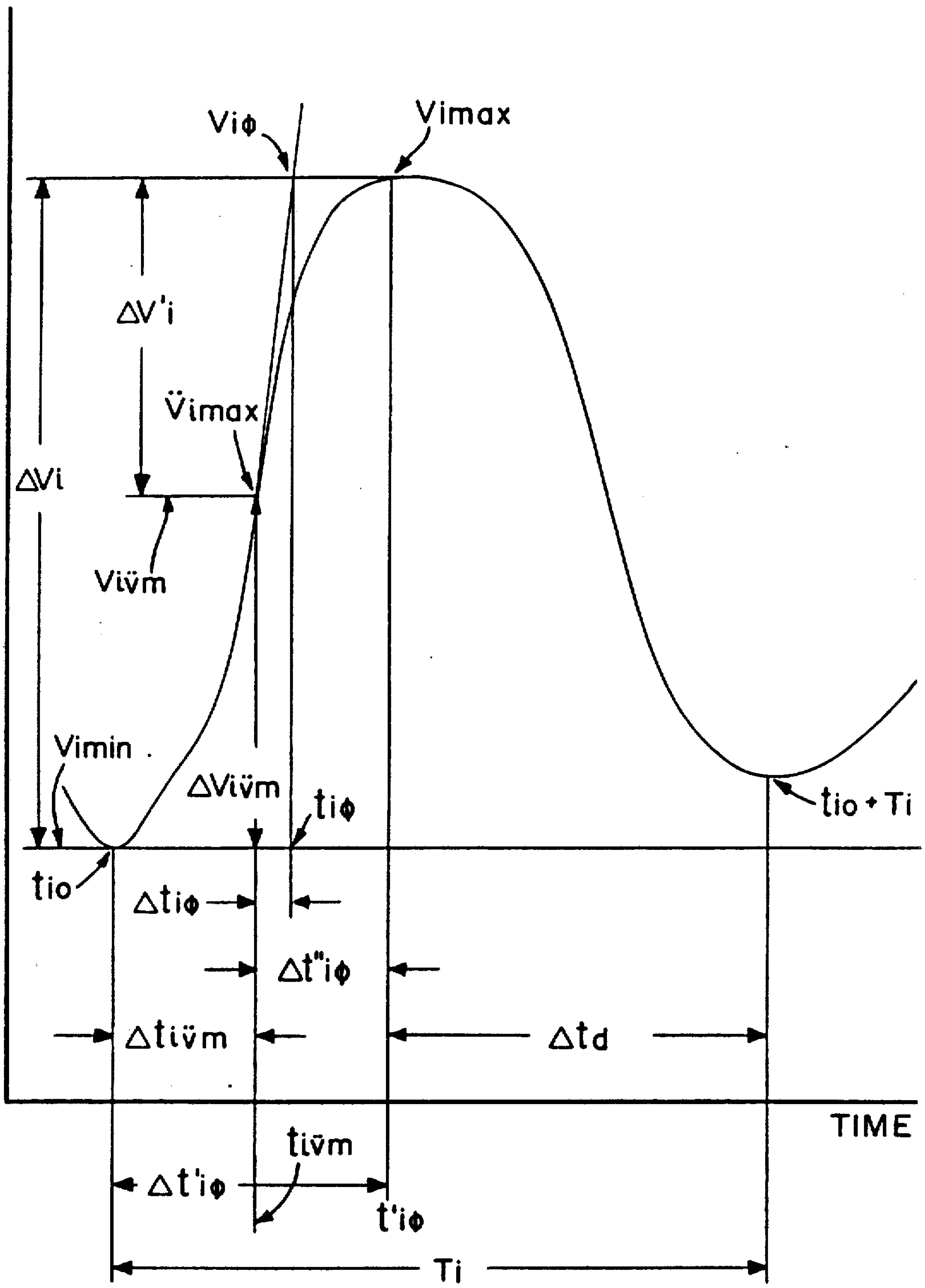

Viφ
Vimax
ΔV'i
V̇imax
ΔVi
Viv̇m
Vimin
ΔViv̇m
tiφ
tio + Ti
tio
Δtiφ
Δt"iφ
Δtiv̇m
Δtd
TIME
tiv̇m
Δt'iφ
t'iφ
Ti

FIG. 4


Viφ
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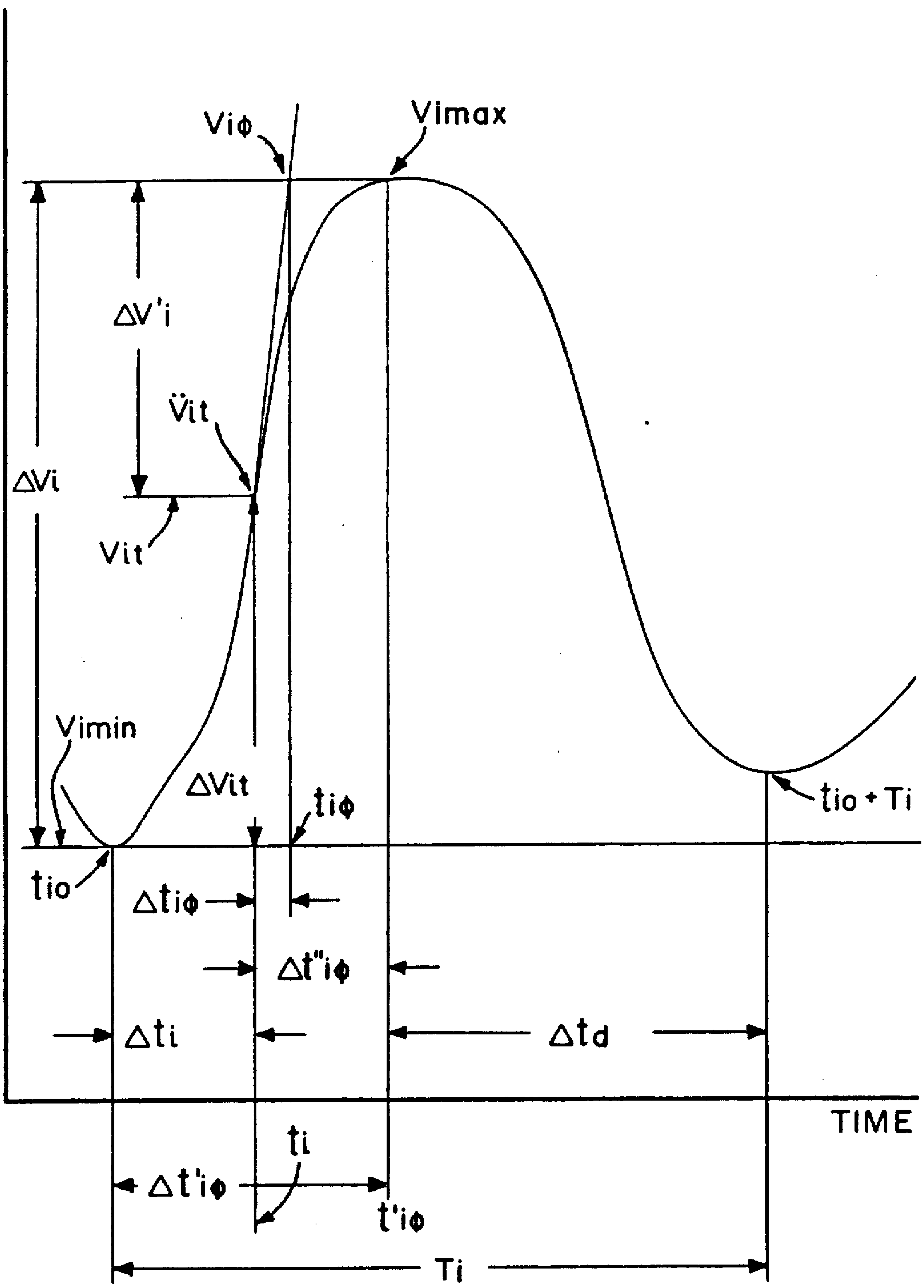
V̈imax
ΔVi
Viv̈m
Vimin
ΔViv̈m
tiφ
tio + Ti
tio
Δtiφ
Δt"iφ
Δtiv̈m
Δtd
TIME
tiv̈m
Δt'iφ
t'iφ
Ti

FIG. 4A



Viφ
Vimax
ΔV'i
V̈it
ΔVi
Vit
Vimin
ΔVit
tiφ
tio + Ti
tio
Δtiφ
Δt"iφ
Δti
Δtd
TIME
ti
Δt'iφ
t'iφ
Ti

FIG. 4B

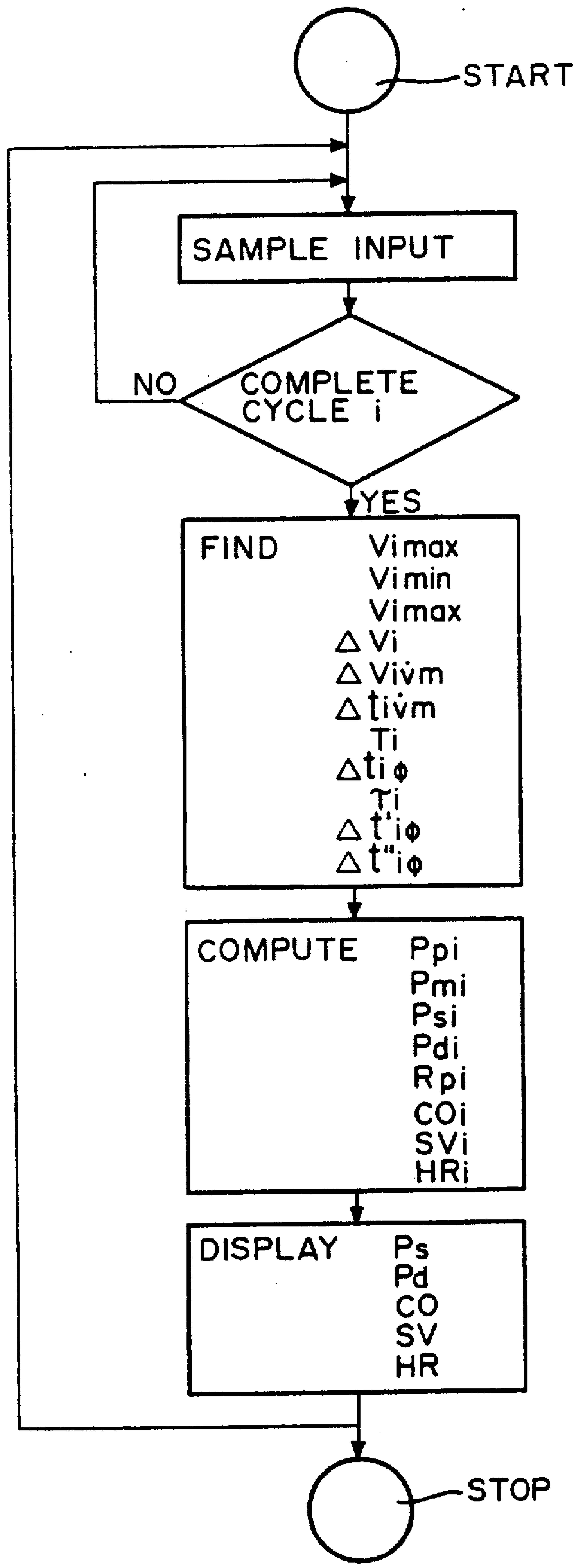

START
SAMPLE INPUT
NO
COMPLETE CYCLE i
YES
FIND Vimax
Vimin
Vimax
ΔVi
ΔViv̇m
Δtiv̇m
Ti
Δtiφ
τi
Δt'iφ
Δt''iφ
COMPUTE Ppi
Pmi
Psi
Pdi
Rpi
COi
SVi
HRi
DISPLAY Ps
Pd
CO
SV
HR
STOP

FIG. 6

HEART-RELATED PARAMETERS MONITORING APPARATUS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS-REFERENCE TO RELATED APPLICATIONS

This *application is a reissue of application Ser. No. 105,803, filed Oct. 8, 1987, now U.S. Pat. No. 4,834,107, which* application is a continuation-in-part application Ser. No. 059,520, filed June 8, *now abandoned* which is a continuation-in-part application Ser. No. 807,693, filed Dec. 11, 1985, now abandoned which is a continuation-in-part of parent application Ser. No. 608,955, filed May 10, 1984, now all abandoned.

BACKGROUND OF INVENTION

1. Field of the Invention

The invention relates to a non-invasive method of measuring arterial blood pressure and cardiac output. The invention also relates to an apparatus for carrying out the method.

2. Description of Prior Art

Non-invasive methods and apparatus for measuring arterial blood pressure and cardiac output are known in the art. Once such method and apparatus is illustrated in U.S. Pat. No. 4,030,485, Warner, issued June 21, 1977. A second such method and apparatus is taught in U.S. Pat. No. 4,418,700, Warner, issued Dec. 6, 1983. The present invention constitutes an improvement and refinement of the method and apparatus as taught in the latter patent.

SUMMARY OF INVENTION

The invention relates to a non-invasive method, and an apparatus for determining heart-related parameters in patients. The method and apparatus determine pulse pressure, time constant of the arterial system, systolic and diastolic pressure, peripheral resistance, and cardiac output and means arterial blood pressure.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be better understood by an examination of the following description together with the accompanying drawings in which:

FIG. 1 is a block diagram of the apparatus for carrying out the inventive method;

FIG. 2 is a typical sensor output of the system as illustrated in FIG. 1;

FIG. 3 illustrates arterial blood pressure pulses;

FIGS. 4, 4a and 4b illustrate a blood volume pulse;

FIG. 5 illustrates a blood volume pulse and a blood pressure pulse to illustrate the ratio g; and

FIG. 6 is a simplified flowchart for a computer program for performing calculations in accordance with the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

As seen in FIG. 1, an apparatus in accordance with the invention comprises a volume sensor such as a photo-electric plethysmograph S, an amplifier A_1, an analog to digital converter A_2, a microcomputer M and a display device D. The plethysmograph sensor S is attached to, for example, the earlobe of a subject. The sensor could also be attached to other suitable parts of the body such as the forehead, fingertips or toes.

As is known, the plethysmograph, detects changes in blood volume of the region to which it is attached. A typical sensor output signal is shown in FIG. 2. As seen in FIG. 2, the output signal has a pulsating component and a DC component.

The output of the sensor is applied to the plethysmograph amplifier A_1 where it is amplified and filtered and the DC component is discarded. The output of A_1 has a DC component, but this is not directly related to the sensor DC component.

The output of A_1 is fed to the analog to digital (A/D) converter A_2 which digitizes the signal. In a preferred embodiment, the sampling rate is 100 per second.

Microcomputer M accepts signals from A_2 and processes them according to the instructions it contains. These instructions are schematically represented in the simplified flowchart of FIG. 6.

The computer quantities are then displayed on a CRT monitor D or other suitable display means.

THEORY

Arterial blood pressure pulses are shown in FIG. 3. The shape of these curves vary according to the site where they are measured. The highest pressure reached during a cycle i is called the arterial systolic blood pressure, P_{si}. The lowest pressure reached during the same cycle is called the arterial diastolic blood pressure, P_{di}. The pressure rise from P_{di} to p_{si} in the same cycle is the pulse pressure, p_{pi}.

By definition

$$p_{si}-p_{di}=p_{pi} \tag{1}$$

To find P_{pi}

A plethysmographic pulse is shown in FIG. 4. The minimum value at the beginning of the pulse is V_{imin}. The maximum value of the pulse is V_{imax}. As the pulse volume rises from V_{imin} to V_{imax}, the time rate of volume change reaches a maximum $\dot{V}_{imax}$ at time $t_{i\dot{V}m}$. The pulse volume at time $t_{i\dot{V}m}$ is $V_{i\dot{V}m}$.

let

$$\frac{V_{i\dot{v}m}-V_{imin}}{V_{imax}-V_{imin}}=\frac{\Delta V_{i\dot{v}m}}{\Delta V_i}=R_i \tag{2}$$

In addition to finding the values of $\dot{V}_{iVm}$ corresponding to $\dot{V}_{imax}$, see U.S. Pat. No. 4,418,700, Warner, values of $V_{i\dot{V}m}$ are also found corresponding to $\dot{V}_{imax}-^1$, $\dot{V}_{imax}-^2$, . . . $\dot{V}_{imax}-^k$, where k is a function of $\dot{V}_{imax}$.

All of the values of $\dot{V}_{iVm}$ corresponding to the time rates of volume change lying between and including $\dot{V}_{imax}$ and $\dot{v}_{imax}-^k$ are averaged and used to compute $\Delta V_{i\dot{V}m}$.

The average value of $V_{i\dot{V}m}$ is

$$\overline{V}_{ivm}=\frac{\sum_{1}^{n0} V_{iv0mn0}+\sum_{1}^{nl} V_{i\dot{v}lmnl}+\ldots+\sum_{1}^{nk} V_{ivkmnk}}{n0+nl+\ldots+nk}$$

where

n0 = number of values of $V_{i\dot{V}0}m$ corresponding to $\dot{V}_{imax}$

nl = number of values of V_{ivlm} corresponding to $V_{imax} - 1$

. . . = . . .

nk = number of values of $V_{iVk}m$ corresponding to $V_{imax} - k$

$k = (V_{imax/m})$ (integral values only) + 1

m = constant . . . a preferred value of $m = 20$

l = constant . . . a preferred value of $l = 1$

$$P_{pi} = K_{pp}\left(\frac{R_i - r_1}{(1 + r_2 - R_i)}\,\alpha\right) \tag{4a}$$

K_{pp} = constant determined by a first calibration

r_1 = constant . . . preferably equal to 0

r_2 = constant . . . preferably equal to 0

$0 \leqq \alpha \leqq 1$

R_{i1} can now be defined, as per equation (2) above, but using the average value of V_{iVm} so that equation (2) can be rewritten

$$\text{let } \frac{\overline{V}_{i\mathring{v}m} - V_{imin}}{V_{imax} - V_{imin}} = \frac{\Delta V_{i\mathring{v}m}}{\Delta V_i} = R_i \tag{2}$$

From FIG. 4

$$\Delta V'_i = \Delta V_i - \Delta V_{ivm}$$

$$\frac{\Delta V'_i}{\Delta V_i} = R' = \frac{\Delta V_i - \Delta V_{i\mathring{v}m}}{\Delta V_i} = 1 - \frac{\Delta V_{i\mathring{v}m}}{\Delta V_i} - 1 - R_l$$

wherein

$$R'_i = 1 - R_i$$

or

$$R_i = 1 - R'_i$$

No other calibration should be required with different subjects. However, if desired, K_{pp} can be determined for each subject.

To find mean blood pressure

The mean blood pressure P_{mi} during a cycle i is given by

$$P_{mmi} = K_4\left[\frac{\Delta V_l}{\Delta\mathring{V}_{imax}}\right]^{-b3} \tag{5}$$

$$P_{ml} = P_{mmi} + P_0 \tag{6}$$

b_3 = exponent . . . the preferred value of b_3 is equal to 0.5

K_4 = constant determined at calibration for each subject. It is only necessary to find this constant once for each subject. The measurements carried out at different times on the same subject do not require separate calibration

P_0 = constant . . . preferred 25 mmHg

$$\Delta\mathring{V}_{imax} = \text{maximum time rate of change of } \Delta V_l = \mathring{V}_{lmax}$$

-continued

$$P_{si} = P_{ml} + (1 - g_i)P_{pl} \tag{7}$$

where

$g_i = (\Delta V_{iAV}/\Delta V_i)$

ΔV_{iAV} = average value of ΔV_i over the time interval T_i

$$P_{di} = P_{si} - P_{pi} \tag{8}$$

The variable g_i can take on a constant value g_0 whose preferred value is 0.333.

Alternatively, mean blood pressure can be determined using the following expression:

$$P_{mmi} = K_4\left[\frac{\Delta V_i}{\Delta V_{imax}[G(t)]}\right]^{-b3} = K_4\left(\frac{1}{r_i}\right)^{-b3} \tag{5'}$$

(for definition of r_i see Equation 10 below);

where

$G(t)$ = a function of t, in a particular case,

$G(t) = (\phi_c/\phi_i)$

$\phi_c = [(](1/\Delta t_c)[)]^Y$

$\phi_i = [(](1/\Delta t_i)[)]^Y$

$\Delta t_c = (\Delta t'_{i\phi c}$

$\Delta t_i = \Delta t'_{i\phi}$

where

[T_c = T at calibration] $\Delta t_c = \Delta t$ *at calibration* $\Delta t'_{i\phi}$(-*see FIG. 4B*)

[t_c = t at calibration $\Delta t'_{i\phi c}$ (see FIG. 4B)]

[$\phi_c = (T_c/t_c) = (T/t)$ at calibration] $\phi_c = (1/\Delta t)^y$ *at calibration*

y = constant

The remainder of the terms in equation 5' are the same as similar terms in equation 5.

Determination of ratio R (FIG. 4b)

From FIG. 4b, the ratio R is

$R_i = (\Delta V_{it}/\Delta V_i)$

where

ΔV_{it} = change in volume at predetermined time ti

ΔV_i = total volume change during cycle i

t_i = time such that $\Delta t_i = K_T\Delta t'_{i\phi}$

K_T = constant

Estimation of pulse pressure, PP

$$\frac{1 - e^{K'TkPPl}}{1 - e^{-kPPi}} = R_i$$

where

PP_i = pulse pressure = $p_s - P_d$

P_s = systolic blood pressure

P_d = diastolic blood pressure

k = constant

K'_T = constant $\simeq K_T$

In FIG. 4B

$$\Delta V'_i = \Delta V_i - \Delta V_{it}$$

$$\Delta V'_l = \Delta V_l - \Delta V_{it}$$

$$\frac{\Delta V_i}{\Delta V_i} = \frac{\Delta V_i - \Delta V_{it}}{\Delta V_i} = 1 - \frac{\Delta V_{it}}{\Delta V_i} = 1 - R_i = R'_i$$

-continued

$$\left[\frac{\Delta V'_i}{\Delta V_i} = \frac{\Delta V_i - \Delta V_{it}}{\Delta V_i} = 1 - \frac{\Delta v_{it}}{\Delta V_i} = 1 - R_i = R'_i\right]$$

wherein from the above equation:

$$1 - \frac{1 - e^{-KTkPPi}}{1 - e^{-kPPi}} = 1 - R_i$$

$$\frac{1 - e^{-kPPi} - (1 - e^{-KTkPPi})}{1 - e^{-kPPi}} = 1 - R_i$$

$$\frac{-e^{-kPPi} + e^{-KTkPPi}}{1 - e^{-kPPi}} = .1 - R_i$$

multiply numerator and denominator by e^{kPP_i}

$$\frac{-1 + e^{kPPi}\, e^{-KTkPPi}}{e^{kPPi} - 1} = 1 - R_i$$

$$\frac{e^{kppi(1-KT)} - 1}{e^{kPPi} - 1} = 1 - R_i = R'_i.$$

Determination of r

From FIG. 4

$$r_i = (\dot{V}_{imax}/\Delta V_i)G(t)$$

where

V_{imax} = maximum time rate of volume increase in cycle i

ΔV_i = total volume increase during cycle i

From FIG. 4b

[$r_i = (\dot{V}_{it}\Delta V_i)G(t)$]

$r_i = (V_{it}/V_i)G(t)$

V_{it} = time rate of increase of volume $V_{i(t)}$ at time t_i

[ΔV_i = total volume increase of volume during]

ΔV_i = total increase of volume during time interval $\Delta t_{i\phi}$

Estimation of Mean Blood Pressure

(1) $P_{mi}' = K_1 r_{ic}^a$

K_1 = calibration constant

$P_{mi}' = (P_s + P_d)/2 - P_o$

P_{si} = systolic blood pressure, in cycle i

$P_{mi} = (P_s + P_d)/2$

P_{di} = diastolic blood pressure, in cycle i

a = constant

P_o = constant

[(2) e^{kp}mi $= K_2 R_{ic}^b$] (2) $e^{kpmi} = K_2 r_{ic}^b$

where

K_2 = constant (calibration)

b = constant

$$(K_3)\,\frac{e^{-k(Pmo - j\phi 1i)} - e^{-k(Pmo + \phi 2i)}}{e^{-k(Pmo - \phi 1i)} - e^{-k(Pmo + \phi 2i)}} = r_i \qquad (9)$$

where

P_{mo} = constant at calibration

$\phi_{1i} + \phi_{2i} = PP_i$ = pulse pressure during cycle i

k = constant

j = constant

solve equation by making LHS=RHS by varying ϕ_{1i} and $\phi_{2i}(\phi_{2i} = PP_i - \phi_{1i})$

then

$P_{si} = P_{mo} + \phi_{2i} + P_0$

$P_{di} = P_{mo} - \phi_{1i} + P_o$

$P_{mi} = (P_{si} + P_{di})/2$

P_0 = constant

r_i = ratio of exponentials

K_3 = coefficient (variable or constant)

Correction for r_i

r_i (corrected) $= r_{ic} = r_i\, e^{m(\phi_o - \phi_i)}$

m = constant

$\phi_0 = PP_i$ at calibration

ϕ_i = current value of PP_i.

Equation (9) above is only one form which this particular equation can take. By simple mathematical manipulations, the invention may take two other forms as per (10) and (11) below. What follows is the manipulations as well as the two other forms of the equation:

As above noted

$$\phi_{2i} + \phi_{1i} = PP_i = P_{si} - P_{di}$$

$$\phi_{2i} + \phi_{1i} = (P_{si} - P_o) - (P_{di} - P_o)$$

Let

$P'_{si} = P_{si} - P_o$

$p'_{di} = P_{di} - P_0$

$\phi_{2i} + \phi_{1i} = P'_{si} - P'_{di}$

add and subtract P_{mo} on RHS above

$$\phi_{2i} + \phi_{1i} = P'_{si} - P_{mo} + P_{mo} - P'_{di} \qquad (A)$$

ϕ_{2i} and ϕ_{1i} can take on any values in satisfying the above equation (A)

Put $\phi_{2i} = P'_{si} - P_{mo}$

and $\phi_{1i} = P_{mo} - P'_{di}$ in equation (9)

then

$$K_3\left[\frac{e^{-k(Pmo - j(Pmo - Pdi))} - e^{-k(Pmo + j(Psi - Pr10))}}{e^{-k(Pmo - (Pmo - Pdi))} - e^{-k(Pmo + (Psi - Pr2o))}}\right] = r_i \qquad (10)$$

simplifying the denominator

$$K_3\left[\frac{e^{-k(Pmo - j(Pmo - Pdi))} - e^{-k(Pmo + j(Psi - Pr10))}}{e^{-kPdl} - e^{-kPsi}}\right] = r_i \qquad (11)$$

To solve equation 11:

(1) Set $P'_{di} = P'_{si} - PP_i$ and solve for P'_{si}

$P'_{mi} = (P_{si} + P_{di})/2 - P_o$

(2) Set $P'_{si} = P'_{di} - PP_i$ and solve for P'_{di}

Although particular embodiments have been illustrated, this was for the purpose of describing, but not limiting, the invention. Various modifications, which will come readily to the mind of one skilled in the art, are within the scope of the invention as defined in the appended claims.

$P_{mi} = (P_{si} + P_{di})/2$

I claim:

1. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising;

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum aplitude, said maximum rate of change of said signal, said first difference, said second different, said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein means for calculating calculates the magnitude of the pulse pressure parameter in accordance with the following expression;

$$P_{pi} = K_{pp}\left[\frac{R_{il} - r_1}{(1 + r_2 - R_{il})}\right]$$

wherein

P_{pi}=pulse pressure during cycle i

K_{pp}=constant determined by a first calibration

r_1=constant

r_2=constant

$R_{il}=(\Delta\dot{V}_{iVm}/\Delta V_i)$

where $\Delta V_{i\dot{V}m}$=volume change at time t_{iVm} during cycle i corresponding to maximum rate of volume change, V_{imax}

ΔV_i=maximum volume change during cycle i

$\Delta t_{i\dot{V}m}$=time interval from start of cycle i to time of maximum rate of volume change V_{imax}.

2. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising;

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby *detect* said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum **[**aplitude,**]** *amplitude,* said maximum rate of change of said signal, said first difference, said second **[**different,**]** *difference,* said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein means for calculating **[**calculates**]** *calculates* the magnitude of the mean arterial blood pressure, P_{mi} parameter in accordance with the following expression:

$$P_{mi} = P_o + P_{mmi}$$

$$P_{mmi} = \left[K_4 \frac{\Delta V_i}{\Delta V_{imax}[G(t)]}\right]^{-b3}$$

$$\left[P_{mmi} = K_4\left[\frac{\Delta V_i}{\Delta V_{imax}[G(t)]}\right] - b_3\right]$$

where

K_4=constant determined for each subject

b_3=constant

P_{mmi}=pseudo mean arterial blood pressure during cycle i

[Δ_i**]** ΔV_i=maximum volume change during cycle i

$$\Delta\dot{V}_{imax} = \text{maximum time rate of change of } \Delta V_i = \dot{V}_{imax}$$

where

$$G(t) = \frac{\phi_c}{\phi_l}$$

-continued

$$\phi_c = \left[\frac{1}{\Delta t_c}\right]^y$$

$$\phi_l = \left[\frac{1}{\Delta t_l}\right]^y$$

where

$\Delta t_c = \Delta t$ at calibration $= \Delta t_{i\phi c}$

$\Delta t_l = \Delta t_{i\phi}$

y = constant.

3. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising;

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum **[**aplitude,**]** *amplitude,* said maximum rate of change of said signal, said first difference, said second **[**different,**]** *difference,* said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein means for calculating calculates the magnitude of the systolic pressure (P_{si}) parameter in accordance with the following expression:

$$P_{si} = P_{mi} + (1 - g_0)P_{pi}$$

wherein

g_0 = constant.

4. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising:

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum **[**aplitude,**]** *amplitude,* said maximum rate of change of said signal, said first difference, said second **[**different,**]** *difference,* said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein means for calculating calculates the magnitude of the systolic pressure (P_{si}) parameter in accordance with the following expression:

$$P_{si} = P_{mi} + (1 - g_i)P_{pi}$$

wherein:

$g_i = (\Delta V_{iAV} / \Delta V_i)$

P_{pi} = pulse pressure during cycle i

ΔV_i = represented by said first difference

ΔV_{iAV} = represented by the difference between said minimum amplitude and an amplitude equal to the average value of a pulse in a cycle i.

5. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising;

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said blood volume variation being [cycle] *cyclic* in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum [aplitude,] *amplitude,* said maximum rate of change of said signal, said first difference, said second [different,] *difference,* said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein means for calculating calculates the magnitude of the arterial blood pressure, P_{mi} parameter in accordance with the following expression:

$$P_{mi} = P_o + P_{mmi}$$

$$P_{mmi} = \left[K_4 \frac{\Delta V_i}{\Delta V_{imax}[G(t)]} \right]^{-b3}$$

$$[P_{mmi} = K_4 \left[\frac{\Delta V_i}{\Delta \dot{V}_{imax}[G(t)]} \right] - b_3]$$

where

K_4 = constant determined for each subject

b_3 = constant

P_{mmi} = pseudo mean arterial blood pressure during cycle i

ΔV_i = maximum volume change during cycle i

$$\dot{V}_{imax} = \text{maximum time rate of change of } V_i = \dot{V}_{imax}$$

P_o = constant

where

$G(t)$ = a function of t.

6. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representative of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of the pulse pressure parameter in accordance with the following expression:

$$P_{pi} = K_{pp} \left[\frac{R_{il} - r_1}{(1 + r_2 - R_{il})} \right]$$

wherein

P_{pi} = pulse pressure during cycle i

K_{pp} = constant determined by a first calibration

r_1 = constant

r_2 = constant

$R_{il} = (\Delta V_{i\dot{V}m} / \Delta V_i)$

where

[ΔV_{iVm} = volume change at time t_{iVm} during cycle i corresponding to maximum rate of volume change, V_{imax}]

ΔV_{iVm} = volume change at time t_{iVm} during cycle i corresponding to maximum rate of volume change, V_{imax}

ΔV_i = maximum volume change during cycle i

$\Delta t_{i\dot{V}m}$ = time interval from start of cycle i to time of maximum rate of volume change V_{imax}.

7. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representative of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of the mean [artial] *arterial* pressure P_{mi} in accordance with the following expression:

$$P_{mi} = P_o + P_{mmi}$$

$$P_{mmi} = \left[K_4 \frac{\Delta V_i}{\Delta \dot{V}_{imax}[G(t)]} \right]^{-b3}$$

$$[P_{mmi} = K_4 \left[\frac{\Delta V_i}{\Delta V_{imax}[G(t)]} \right] - b_3]$$

where

K_4=constant determined for each subject

b_3=constant

P_{mmi}=pseudo mean arterial blood pressure during cycle i

ΔV_i=maximum volume change during cycle i

$\Delta \dot{V}_{imax}$=maximum time rate of change of $\Delta V_i = \dot{V}_{imax}$

$$G(t) = \frac{\phi_c}{\phi_i}$$

$$\phi_c = \left[\frac{1}{\Delta t_c} \right]^y$$

$$\phi_i = \left[\frac{1}{\Delta t_i} \right]^y$$

where

$\Delta t_c = \Delta t$ at calibration $= \Delta t_{i\phi c}$

$\Delta t_i = \Delta t_{i\phi}$

y = constant.

8. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representative of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of the systolic pressure (P_{si} parameter in accordance with the following expression:

$$P_{si} = P_{mi} + (1 - g_0)P_{pi}$$

wherein

g_0=constant.

9. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representive of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of the systolic pressure (P_{si}) parameter in accordance with the following expression:

$$P_{si}=P_{mi}+(1-g_i)P_{pi}$$

wherein:

$g_i=(\Delta V_{iAV}/\Delta V_i)$

P_{pi}=pulse pressure during cycle i

ΔV_i=represented by said first difference

ΔV_{iAV}=represented by the difference between said minimum amplitude and an amplitude equal to the average value of a pulse in a cycle i.

10. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representative of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of the arterial blood pressure, P_{mi} parameter in accordance with the following expression:

$$P_{mi}=P_o+P_{mmi}$$

$$P_{mmi}=\left[K_4\frac{\Delta V_i}{\Delta V_{imax}[G(t)]}\right]^{-b3}$$

$$[\![P_{mmi}=K_4\left[\frac{\Delta V_i}{\Delta \dot{V}_{imax}[G(t)]}\right]-b_3]\!]$$

where

K_4=constant determined for each subject

b_3=constant

P_{mmi}=pseudo mean arterial blood pressure during cycle i

ΔV_i=maximum volume change during cycle i

$\Delta \dot{V}_{imax}$=maximum time rate of change of $V_i=\dot{V}_{imax}$

P_o=constant

G(t)=a function of t and T.

11. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising:

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum [[aplitude,]] *amplitude,* said maximum rate of change of said signal, said first difference, said second [[different,]] *difference,* said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein means for calculating calculates the magnitude of the pulse pressure parameter in accordance with the following expression:

$$P_{pi}=K_{pp}\left[\frac{R_{il}-r_1}{(1+r_2-R_{il})}\right]$$

wherein

P_{pi}=pulse pressure during cycle i

K_{pp}=constant determined by a first calibration

r_1=constant

r_2=constant

$R_{i1}=\Delta V_{i\dot{V}m}/\Delta V_i$

where

ΔV_{iVm}=volume change at preselected time t_{iVm} during cycle i

ΔV_i=maximum volume change during cycle i

Δt_{iVm}=time interval from start of cycle i to preselected time of t_{iVm}.

12. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representative of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of **[**charge**]** *change* of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of the pulse pressure parameter in accordance with the following expression:

$$P_{pi} = K_{pp}\left[\frac{R_{il} - r_1}{(1 + r_2 - R_{il})}\right]$$

wherein

P_{pi}=pulse pressure during cycle i

K_{pp}=constant determined by a first calibration

r_1=constant

r_2=constant

$R_{i1}=(\Delta V_{i\hat{V}m}/V_i)$

where

$\Delta V_{i\hat{V}m}$=volume change at preselected time t_{iVm} during cycle i

ΔV_i=maximum volume change during cycle i

Δt_{iVm}=time interval from start of cylcle i to predetermined time of t_{iVm}.

13. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising;

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second different, said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein the means for calculating calculates the magnitude of the mean pressure parameter in accordance with the following expression:

(1) $P'_{mi}=K_1 r_{ic}^a$

where

K_1=calibration constant

[$P'_{mi}=(P_s+P_d)/2-P_o$**]**

P_{si}=systolic blood pressure, in cycle i

[$P_{mi}=(P_s+P_d)/2$**]**

P_{di}=diastolic blood pressure, in cycle i

a=constant

P_o=constant.

14. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal **[**representation**]** *representative* of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of mean pulse pressure in accordance with the following expression:

[(1) $P_{mi}=K_1 r_{ic}^{a}$]

(1) $P'_{mi}=K_I r_{ic} a$

where

K_1=calibration constant

[$P'_{mi}=(P_s+P_d)/2-P_o$]

$P'_{mi}=(P_{si}+P_{di})/2-P_o$

P_{si}=systolic blood pressure, in cycle i

[$P_{mi}=(P_s+P_d)/2$]

$P_{mi}=(P_{si}+P_{di})/2$

P_{di}=diastolic blood pressure, in cycle i

a=constant

P_o=constant.

15. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising;

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second [different,] *difference,* said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein the means for calculating calculates implicitly the magnitude of the mean pulse pressure in accordance with the following expression:

$$(K_3)\,\frac{e^{-k(P_{mo}-j\phi_{1i})}-e^{-k(P_{mo}+\phi_{2i})}}{e^{-k(P_{mo}-\phi_{1i})}-e^{-k(P_{mo}+\phi_{2i})}}=r_i \quad (3)$$

$$\left[K_3\,\frac{-k(P_{mo}-j\phi_{1i})-e^{-k(P_{mo}+\phi_{2i})}}{e^{-k(P_{mo}-\phi_{1i})}-e^{-k(P_{mo}+\phi_{2i})}}=r_i\right]$$

where

P_{mo}=constant at calibration

$\phi_{1i}+\phi_{2i}=PP_i$=pulse pressure during cycle i

k=constant

j=constant

$P_{si}=P_{mo}+\phi_{2i}+P_o$

$P_{di}=P_{mo}-\phi_{1i}+P_o$

$P_{mi}=(P_{si}+P_{di})/2$

P_o=constant

r_i=ratio of exponentials

K_3=coefficient (variable or constant).

16. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representative of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and the said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

wherein the means for calculating calculates implicitly the magnitude of mean pulse pressure in accordance with the following [expressure] *expression*:

$$(K_3)\frac{e^{-k(Pmo-j\phi 1i)} - e^{-k(Pmo+\phi 2i)}}{e^{-k(Pmo-\phi 1i)} - e^{-k(Pmo+\phi 2i)}} = r_i \quad (3)$$

$$\left[K_3 \frac{e^{-k(Pmo-j\phi 1i)} - e^{-k(Pmo+\phi 2i)}}{e^{-k(Pmo-\phi 1i)} - e^{-k(Pmo+\phi 2 1i)}} = r_l \right]$$

where

P_{mo}=constant at calibration

$\phi_{1i}+\phi_{2i}=PP_i$=pulse pressure during cycle i

k=constant

j=constant

[$P_{2i}=P_{mo}+\phi_{2i}+P_o$]

$P_{si}=P_{mo}+\phi_{2i}+P_o$

$P_{di}=P_{mo}-\phi_{1i}+P_o$

$P_{mi}=(P_{si}+P_{di})/2$

P_o=constant

r_i=ratio of exponentials

K_3=coefficient (variable or constant).

17. Apparatus for determining the magnitude of heart-related parameters in a patient;

comprising:

means for detecting blood volume, and thereby blood volume variation, in said patient, and for providing a signal representative of said blood volume, and thereby said blood volume variation;

said means for detecting being attachable to said patient to thereby detect said blood volume, and thereby said blood volume variation;

said blood variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said minimum amplitude and said maximum amplitude, a maximum rate of change of said signal being representative of the maximum rate of increase of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum rate of change of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

means for measuring said maximum amplitude; said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

means for calculating the magnitude of selected ones of said parameters, said means for calculating being connected to both said means for detecting and means for measuring;

wherein means for calculating calculates the magnitude of the pulse pressure parameter in accordance with the following expression;

$$\frac{1 - e^{-KTPP_i}}{1 - e^{kPP_i}} = R_i$$

where

PP_i=Pulse Pressure—P_s-P_d

P_s=Systolic blood pressure

P_d=diastolic blood pressure

k=constant

K'=constant.

18. A method for determining the magnitude of heart-related parameters in a patient;

comprising:

detecting blood volume, and thereby blood volume variation, in said patient and providing a signal representative of said blood volume, and thereby said blood volume variation;

said blood volume variation being cyclic in nature whereby said signal comprises a cyclic curve having, in each cycle of variation, a variable slope, a maximum amplitude representative of the maximum amount of blood volume, a minimum amplitude representative of the minimum amount of blood volume, a first time interval between said maximum amplitude and said minimum amplitude, a maximum rate of change of said signal being representative of the maximum rate of change of blood volume, a second time interval between the minimum amplitude and the time of the maximum rate of change of said signal, a first difference in amplitude between said maximum amplitude and said minimum amplitude, a second difference in amplitude between the maximum amplitude and the amplitude at the time of maximum change of rate of said signal being representative of the difference in volume between the maximum amount of blood volume and the volume at the time of maximum rate of change of said blood volume, and a pulse repetition period;

measuring said maximum amplitude, said minimum amplitude, said maximum rate of change of said signal, said first difference, said second difference, said first time interval, and said second time interval; and

calculating the magnitude of the mean arterial pressure P_{mi} in accordance with the following expression:

$$\frac{1 - e^{-KTPP_i}}{1 - e^{kPP_i}} = R_i$$

where

PP_i=Pulse Pressure=P_s-P_d

P_s=Systolic blood pressure

P_d=Diastolic blood pressure

k=constant

K'=constant.

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