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United States Patent [19]

Oka et al.

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[45] Date of Patent: Apr. 28, 1998

[54] **APPARATUS FOR MEASURING PULSE-WAVE PROPAGATION VELOCITY**

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[73] Assignee: **Colin Corporation**, Komaki, Japan

[21] Appl. No.: **718,715**

[22] Filed: **Sep. 24, 1996**

[30] **Foreign Application Priority Data**

Nov. 6, 1995	[JP]	Japan	7-287339
Nov. 27, 1995	[JP]	Japan	7-307353
Nov. 27, 1995	[JP]	Japan	7-307354
Jan. 25, 1996	[JP]	Japan	8-010619

[51] **Int. Cl.**[6] **A61B 5/02**

[52] **U.S. Cl.** **600/493**; 600/485

[58] **Field of Search** 128/672, 679, 128/680, 681; 600/485, 492, 493, 494

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

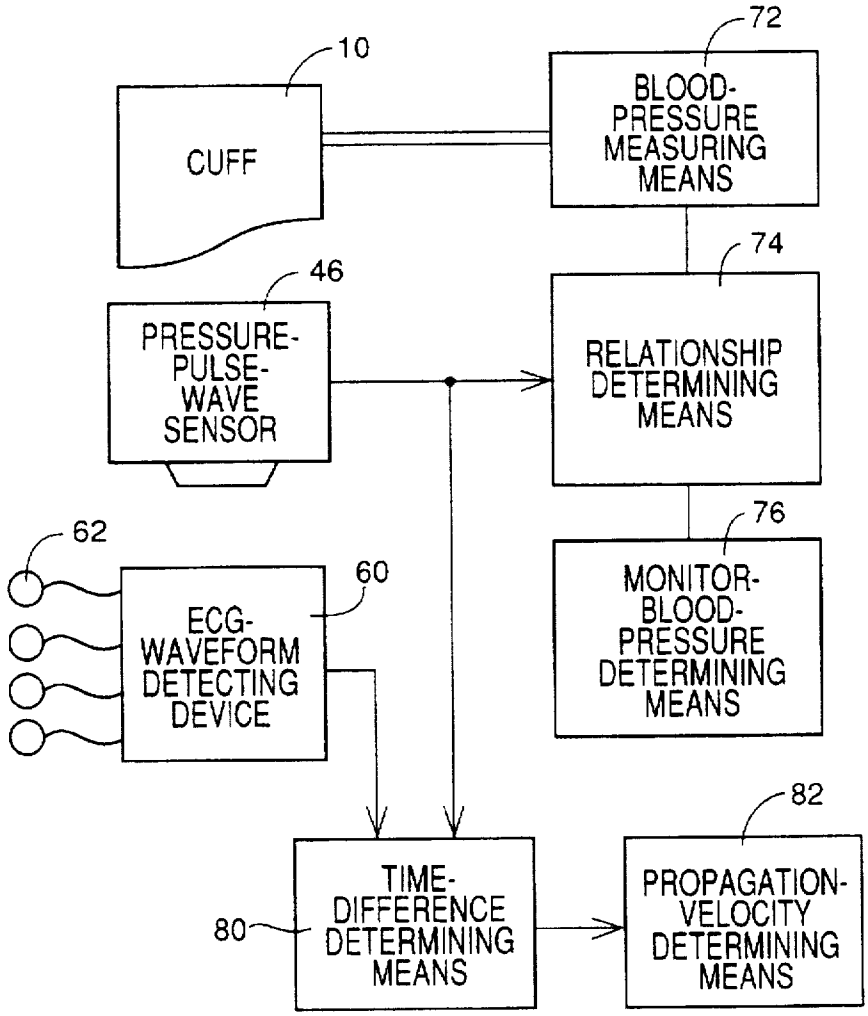
A-60-220037 11/1985 Japan .

Primary Examiner—William E. Kamm
Assistant Examiner—George R. Evanisko
Attorney, Agent, or Firm—Oliff & Berridge, PLC

[57] **ABSTRACT**

An apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, includes an electrocardiographic-waveform detecting device which detects an electrocardiographic waveform from the subject, a pulse-wave sensor which is adapted to be worn on the subject and which detects the pulse wave from the subject, a time-difference determining device for determining a time difference between a first periodic point relating to the detected electrocardiographic waveform and a second periodic point relating to the detected pulse wave, and a propagation-velocity determining device for determining the propagation velocity of the pulse wave based on the determined time difference.

14 Claims, 30 Drawing Sheets



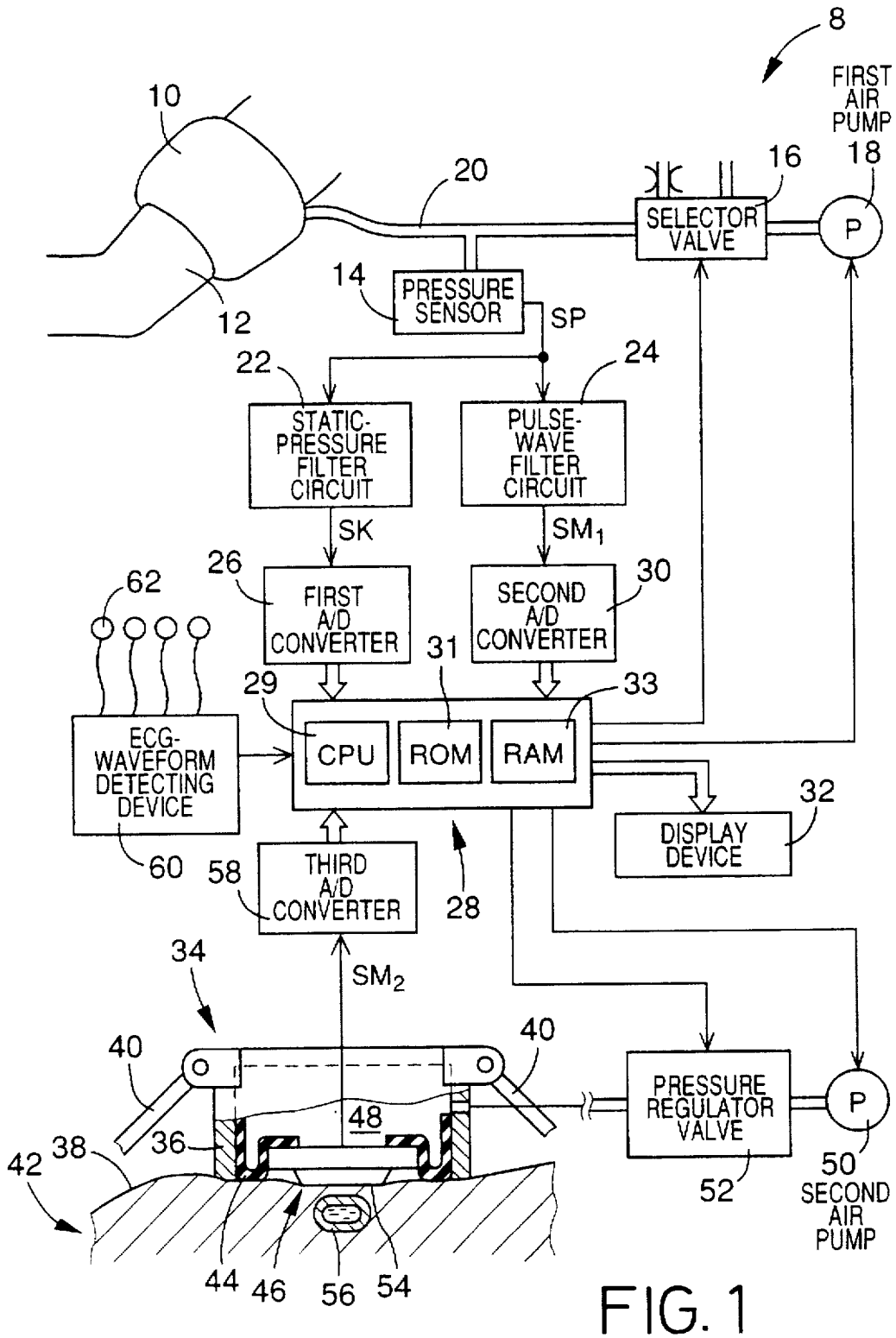

8
FIRST AIR PUMP
18
10
20
16
SELECTOR VALVE
P
14
PRESSURE SENSOR
SP
12
22
24
STATIC-PRESSURE FILTER CIRCUIT
PULSE-WAVE FILTER CIRCUIT
SK
SM1
26
30
62
FIRST A/D CONVERTER
SECOND A/D CONVERTER
31
29
33
ECG-WAVEFORM DETECTING DEVICE
CPU
ROM
RAM
32
DISPLAY DEVICE
60
58
THIRD A/D CONVERTER
28
34
SM2
40
40
48
PRESSURE REGULATOR VALVE
P
36
38
42
52
50
SECOND AIR PUMP
44
46
56
54

FIG. 1

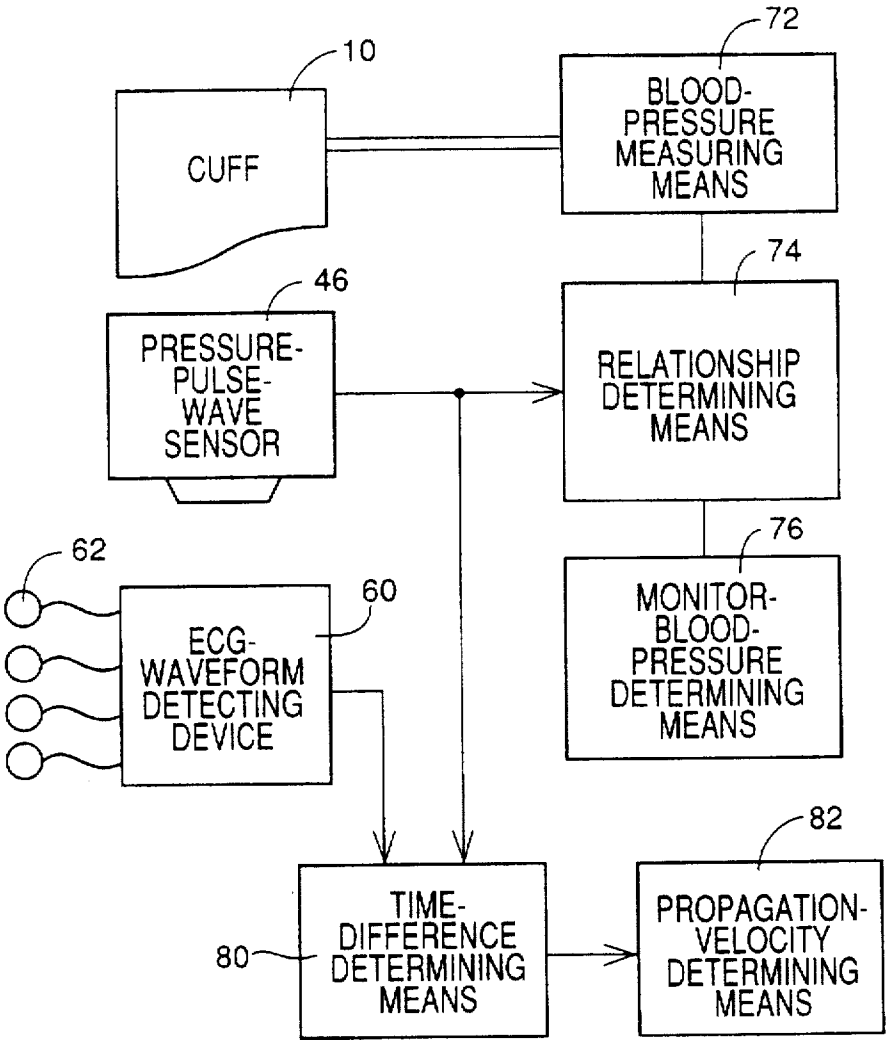

10
CUFF
72
BLOOD-PRESSURE MEASURING MEANS
74
RELATIONSHIP DETERMINING MEANS
46
PRESSURE-PULSE-WAVE SENSOR
62
60
ECG-WAVEFORM DETECTING DEVICE
76
MONITOR-BLOOD-PRESSURE DETERMINING MEANS
82
80
TIME-DIFFERENCE DETERMINING MEANS
PROPAGATION-VELOCITY DETERMINING MEANS

FIG. 2

FIG. 3

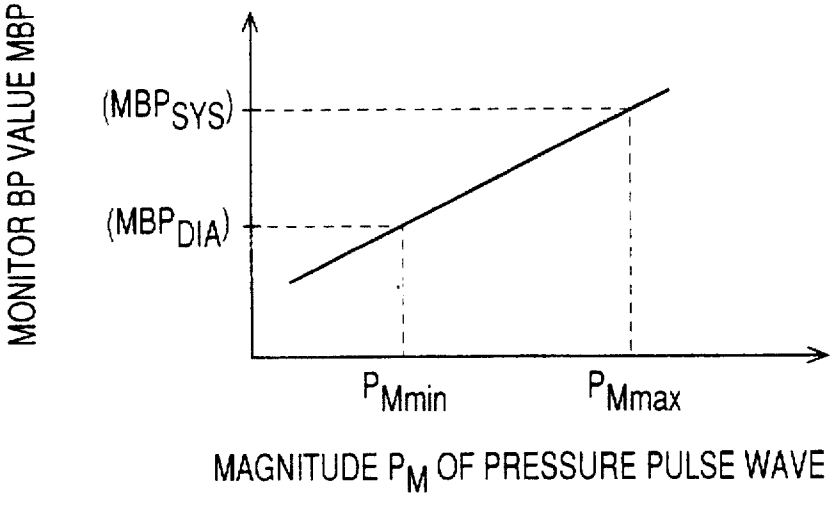

MONITOR BP VALUE MBP
(MBP$_{SYS}$)
(MBP$_{DIA}$)
P_{Mmin}
P_{Mmax}
MAGNITUDE P_M OF PRESSURE PULSE WAVE

FIG. 4

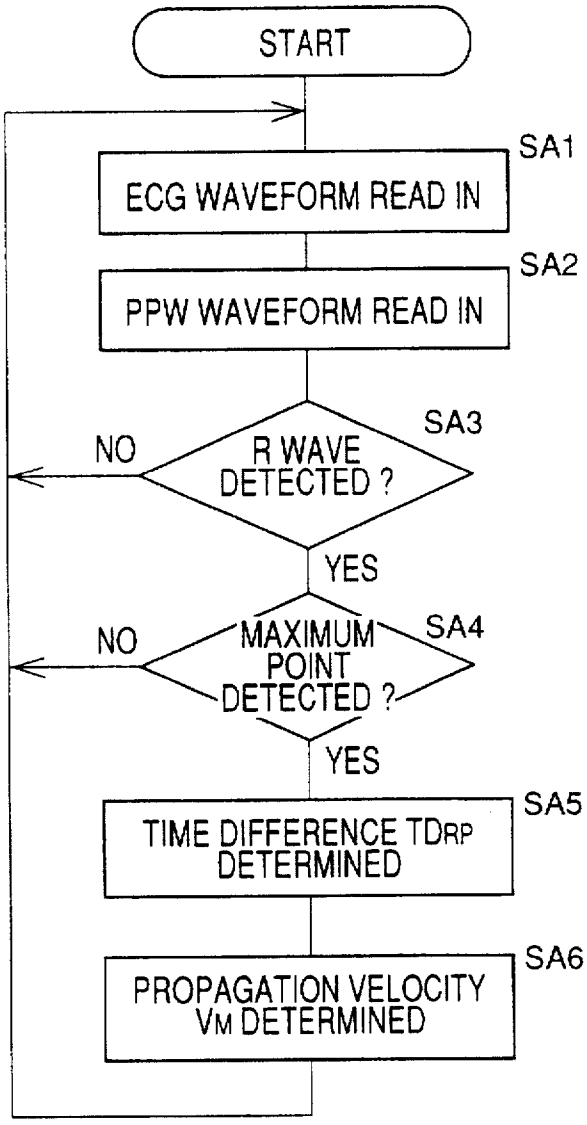
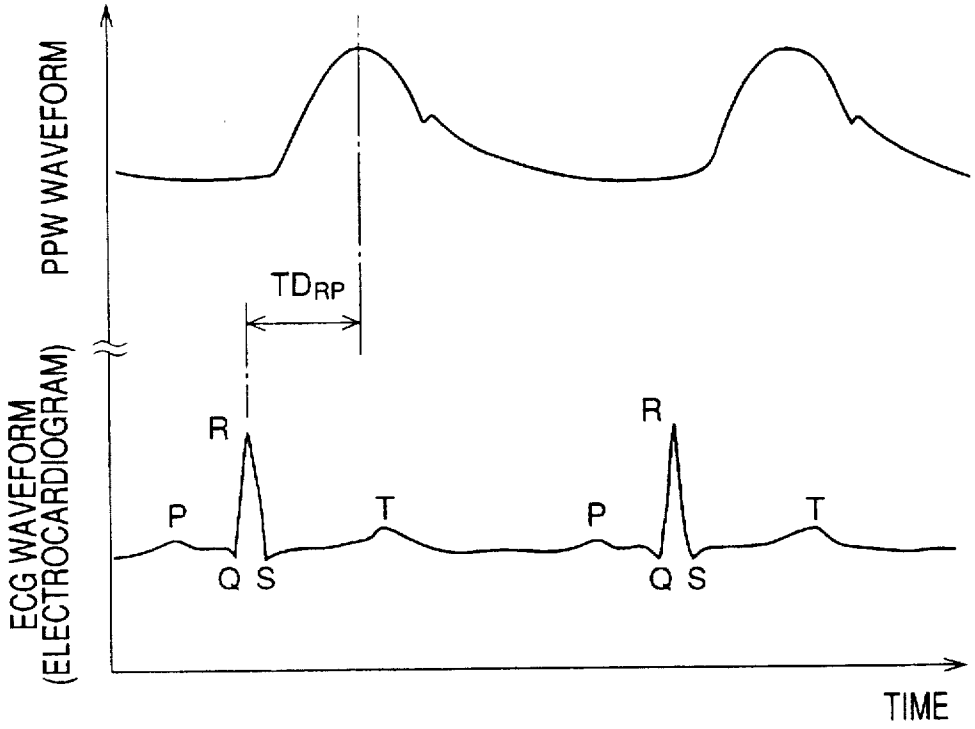

START
SA1
ECG WAVEFORM READ IN
SA2
PPW WAVEFORM READ IN
SA3
R WAVE DETECTED ?
NO
YES
SA4
MAXIMUM POINT DETECTED ?
NO
YES
SA5
TIME DIFFERENCE TDRP DETERMINED
SA6
PROPAGATION VELOCITY VM DETERMINED

FIG. 5


PPW WAVEFORM
TD$_{RP}$
ECG WAVEFORM
(ELECTROCARDIOGRAM)
R
P
T
Q S
R
P
T
Q S
TIME

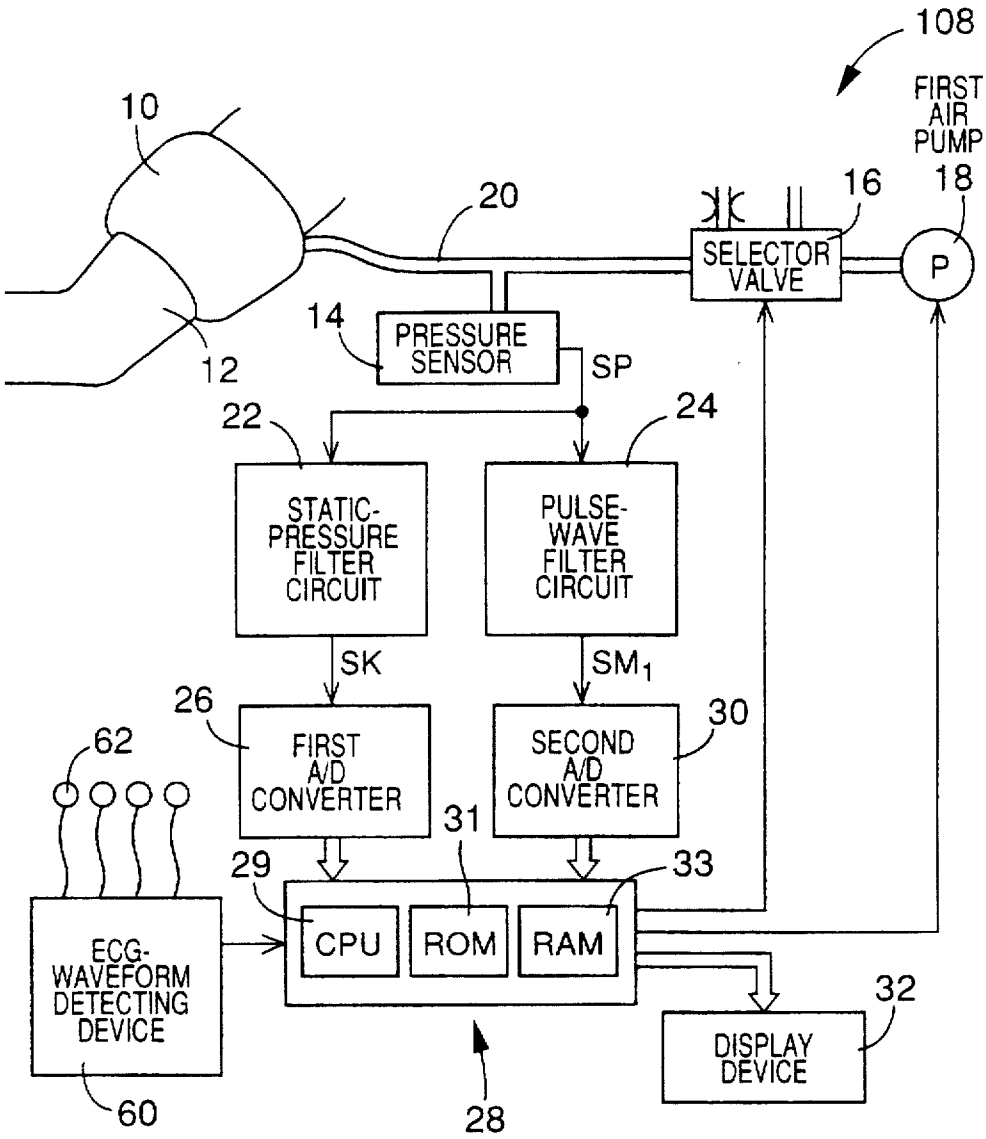

108
FIRST AIR PUMP
10
20
16
18
SELECTOR VALVE
P
14
PRESSURE SENSOR
SP
12
22
24
STATIC-PRESSURE FILTER CIRCUIT
PULSE-WAVE FILTER CIRCUIT
SK
SM1
26
30
62
FIRST A/D CONVERTER
SECOND A/D CONVERTER
31
29
33
CPU
ROM
RAM
ECG-WAVEFORM DETECTING DEVICE
32
DISPLAY DEVICE
60
28

FIG. 6

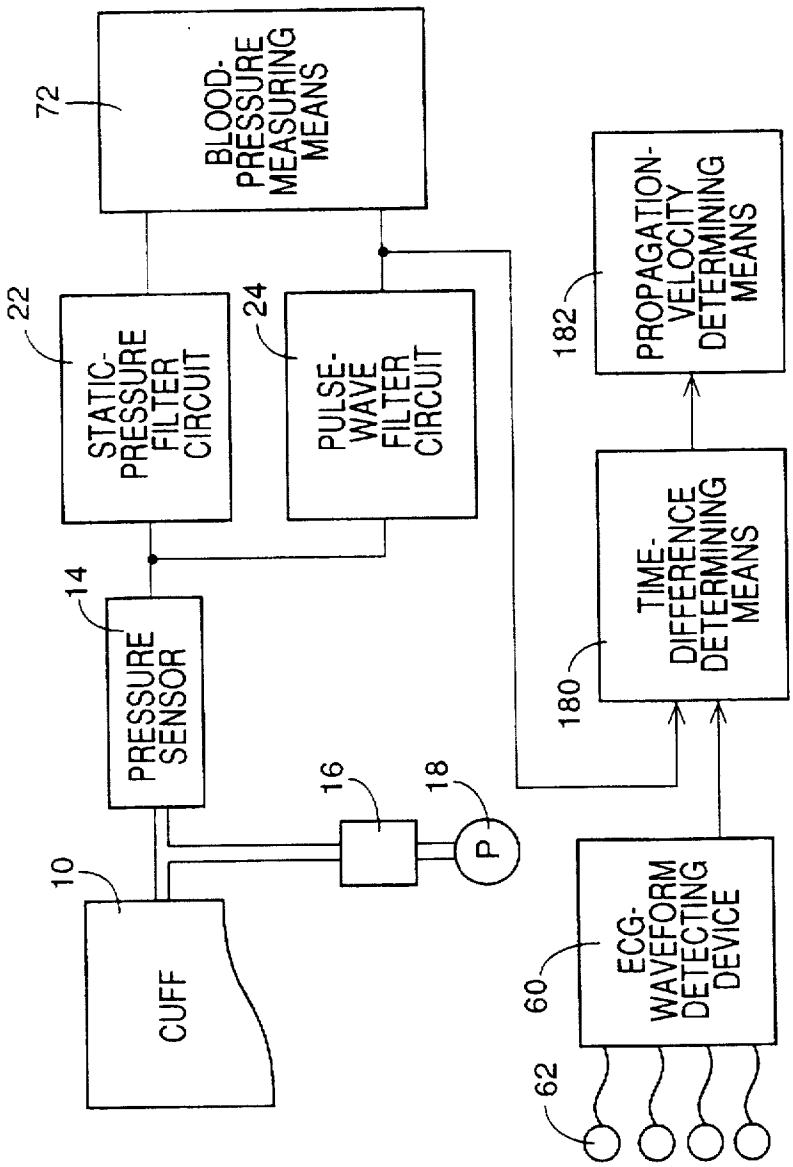

72
BLOOD-PRESSURE MEASURING MEANS
22
STATIC-PRESSURE FILTER CIRCUIT
24
PULSE-WAVE FILTER CIRCUIT
14
PRESSURE SENSOR
16
18
P
10
CUFF
182
PROPAGATION-VELOCITY DETERMINING MEANS
180
TIME-DIFFERENCE DETERMINING MEANS
60
ECG-WAVEFORM DETECTING DEVICE
62

FIG. 7

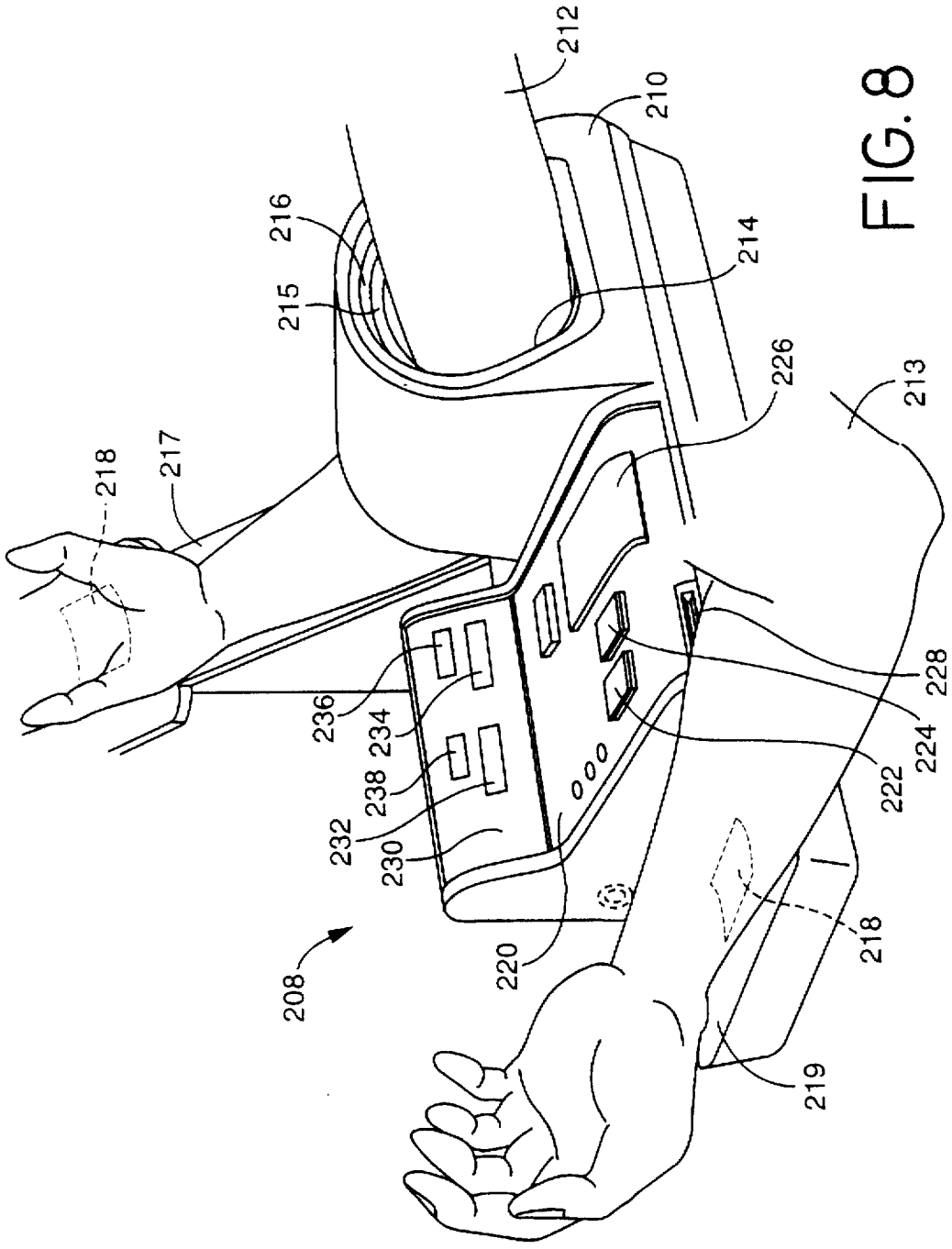

212
210
216
214
215
226
213
218
217
228
236
234
224
238
222
232
230
220
218
208
219

FIG. 8

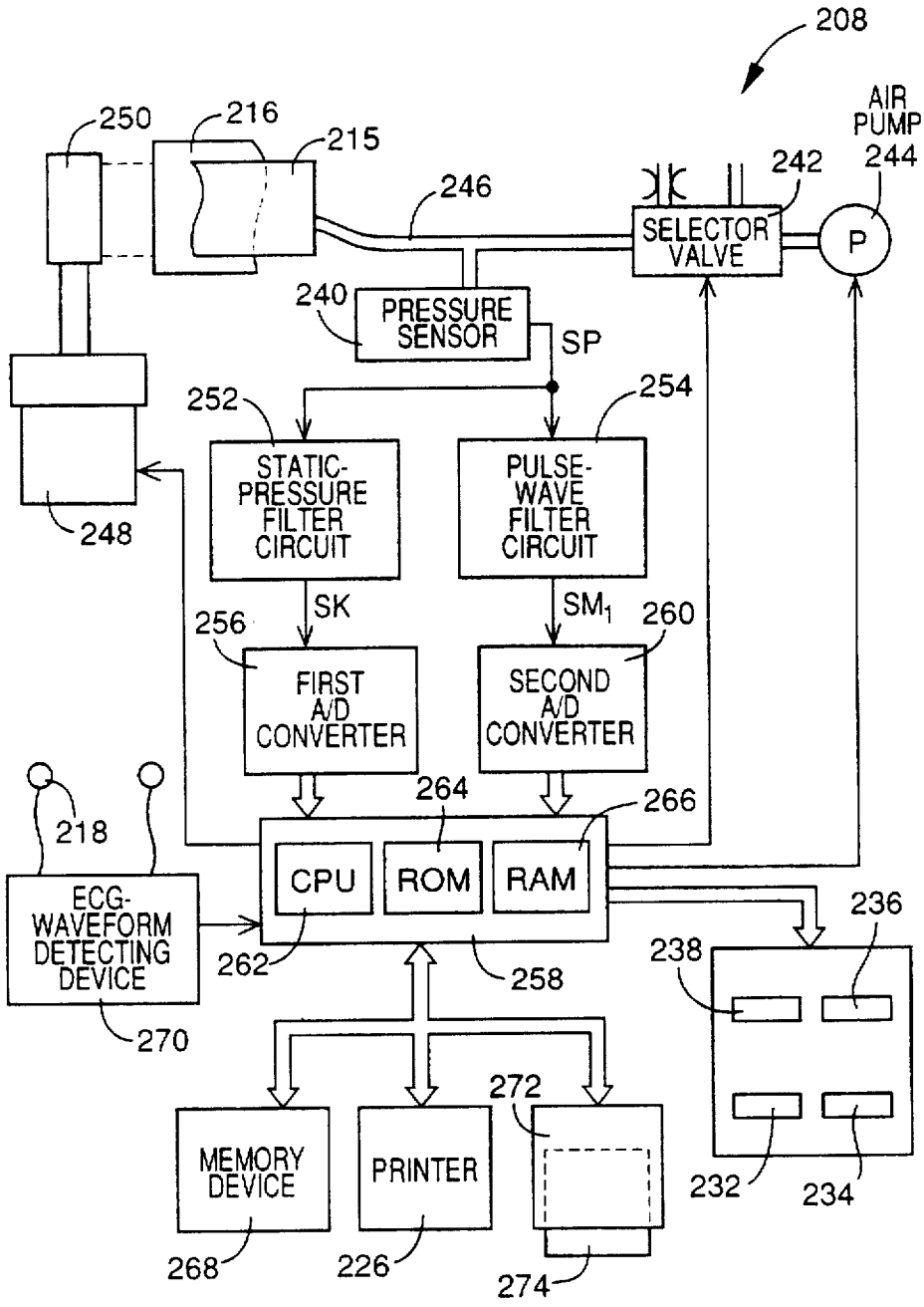

208
AIR PUMP
244
250
216
215
246
242
SELECTOR VALVE
P
240
PRESSURE SENSOR
SP
252
254
STATIC-PRESSURE FILTER CIRCUIT
PULSE-WAVE FILTER CIRCUIT
248
SK
SM1
256
260
FIRST A/D CONVERTER
SECOND A/D CONVERTER
264
266
218
CPU
ROM
RAM
236
ECG-WAVEFORM DETECTING DEVICE
262
258
238
270
272
MEMORY DEVICE
PRINTER
232
234
268
226
274

FIG. 9

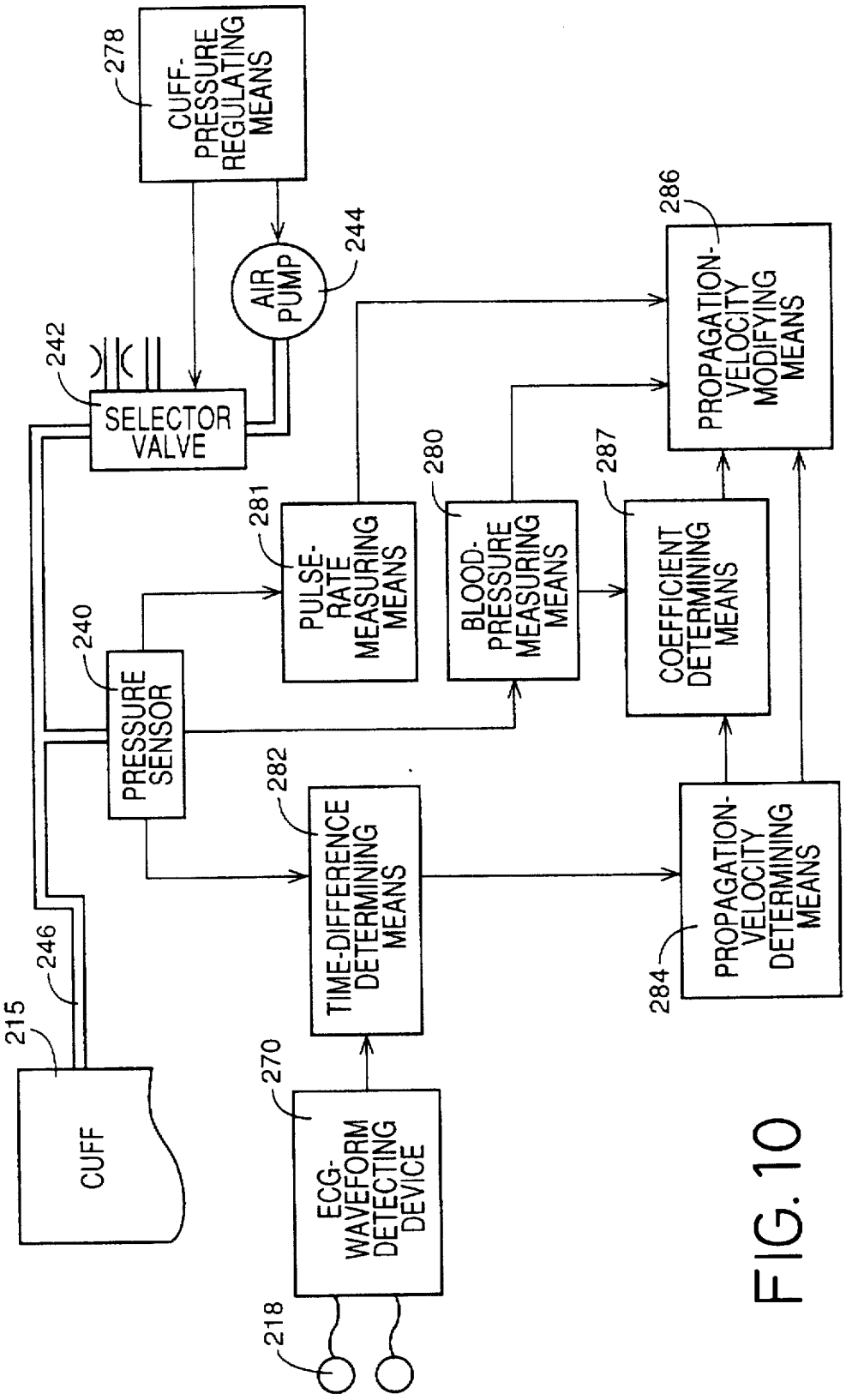

278
CUFF-PRESSURE REGULATING MEANS
244
AIR PUMP
242
SELECTOR VALVE
286
PROPAGATION-VELOCITY MODIFYING MEANS
281
PULSE-RATE MEASURING MEANS
280
BLOOD-PRESSURE MEASURING MEANS
287
COEFFICIENT DETERMINING MEANS
240
PRESSURE SENSOR
282
TIME-DIFFERENCE DETERMINING MEANS
284
PROPAGATION-VELOCITY DETERMINING MEANS
246
215
CUFF
270
ECG-WAVEFORM DETECTING DEVICE
218

FIG. 10

FIG. 11

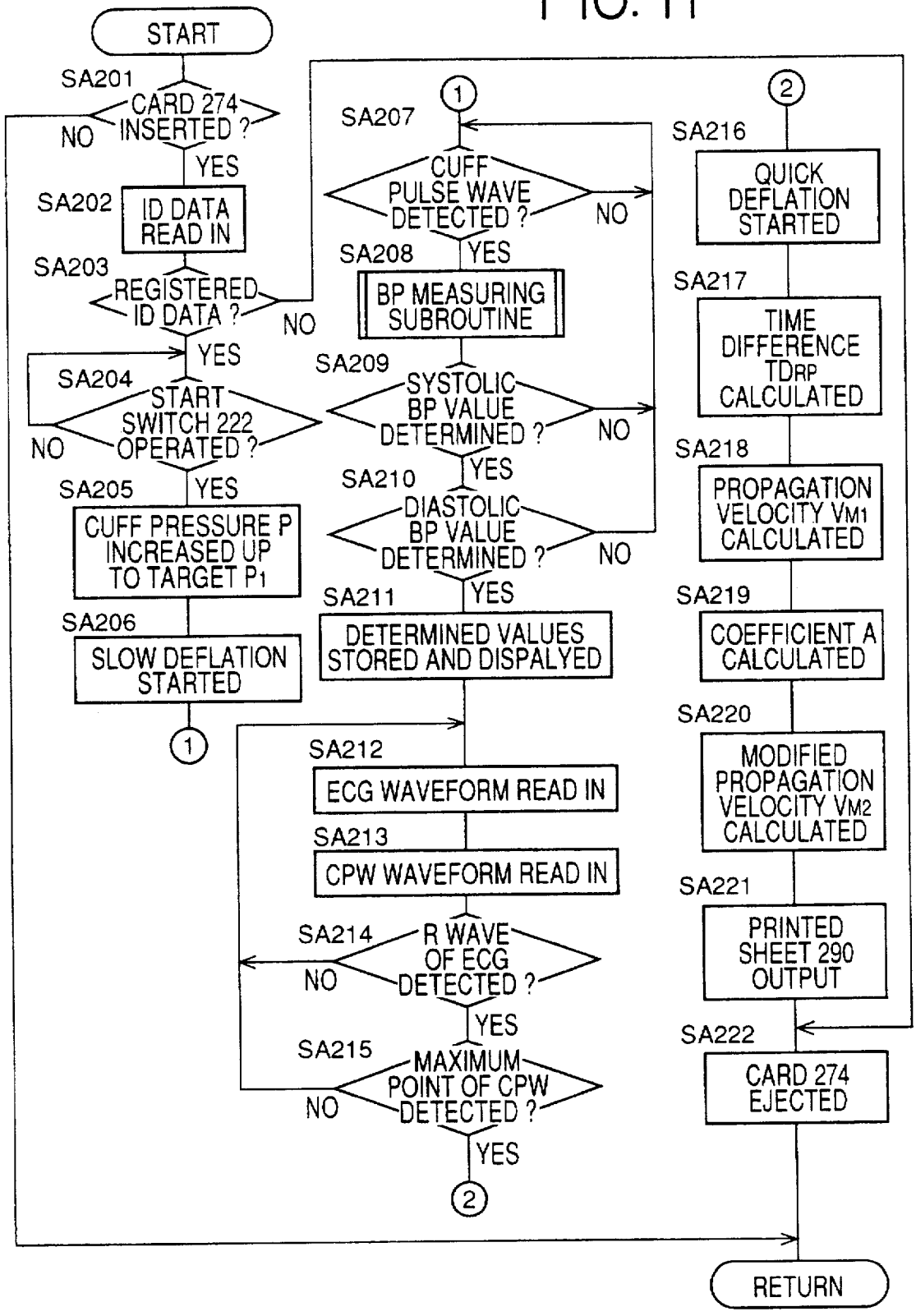

START
SA201
CARD 274 INSERTED ?
NO
YES
SA202
ID DATA READ IN
SA203
REGISTERED ID DATA ?
NO
YES
SA204
START SWITCH 222 OPERATED ?
NO
YES
SA205
CUFF PRESSURE P INCREASED UP TO TARGET P1
SA206
SLOW DEFLATION STARTED
1
SA207
CUFF PULSE WAVE DETECTED ?
NO
YES
SA208
BP MEASURING SUBROUTINE
SA209
SYSTOLIC BP VALUE DETERMINED ?
NO
YES
SA210
DIASTOLIC BP VALUE DETERMINED ?
NO
YES
SA211
DETERMINED VALUES STORED AND DISPALYED
SA212
ECG WAVEFORM READ IN
SA213
CPW WAVEFORM READ IN
SA214
R WAVE OF ECG DETECTED ?
NO
YES
SA215
MAXIMUM POINT OF CPW DETECTED ?
NO
YES
2
SA216
QUICK DEFLATION STARTED
SA217
TIME DIFFERENCE TDRP CALCULATED
SA218
PROPAGATION VELOCITY VM1 CALCULATED
SA219
COEFFICIENT A CALCULATED
SA220
MODIFIED PROPAGATION VELOCITY VM2 CALCULATED
SA221
PRINTED SHEET 290 OUTPUT
SA222
CARD 274 EJECTED
RETURN

FIG. 12

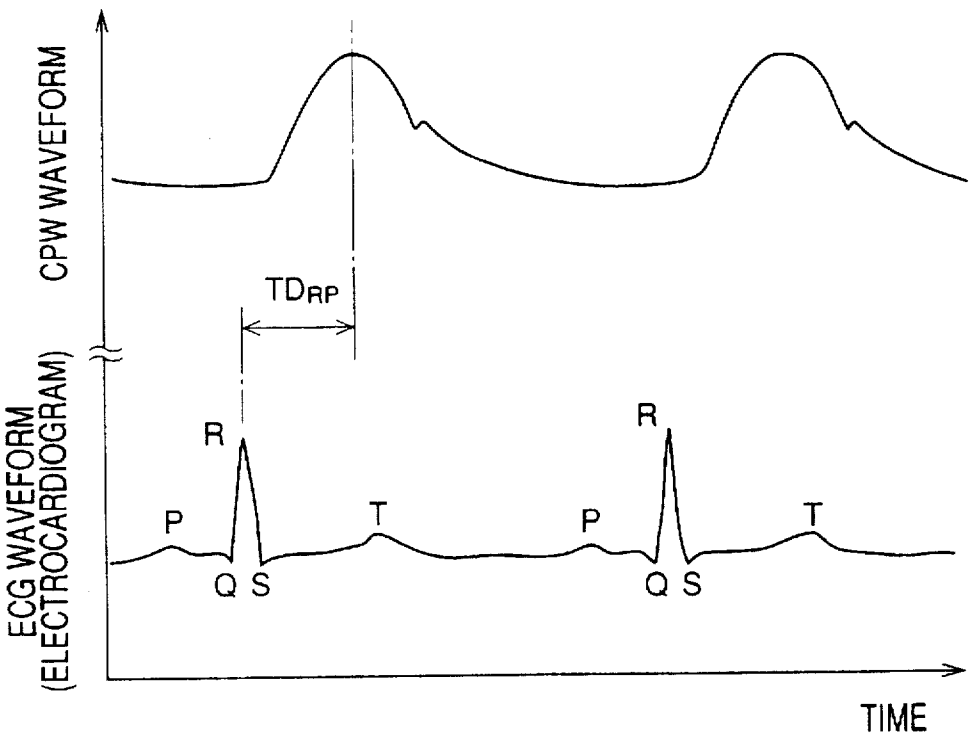

CPW WAVEFORM
TDRP
ECG WAVEFORM
(ELECTROCARDIOGRAM)
R
P
T
Q S
R
P
T
Q S
TIME

FIG. 13

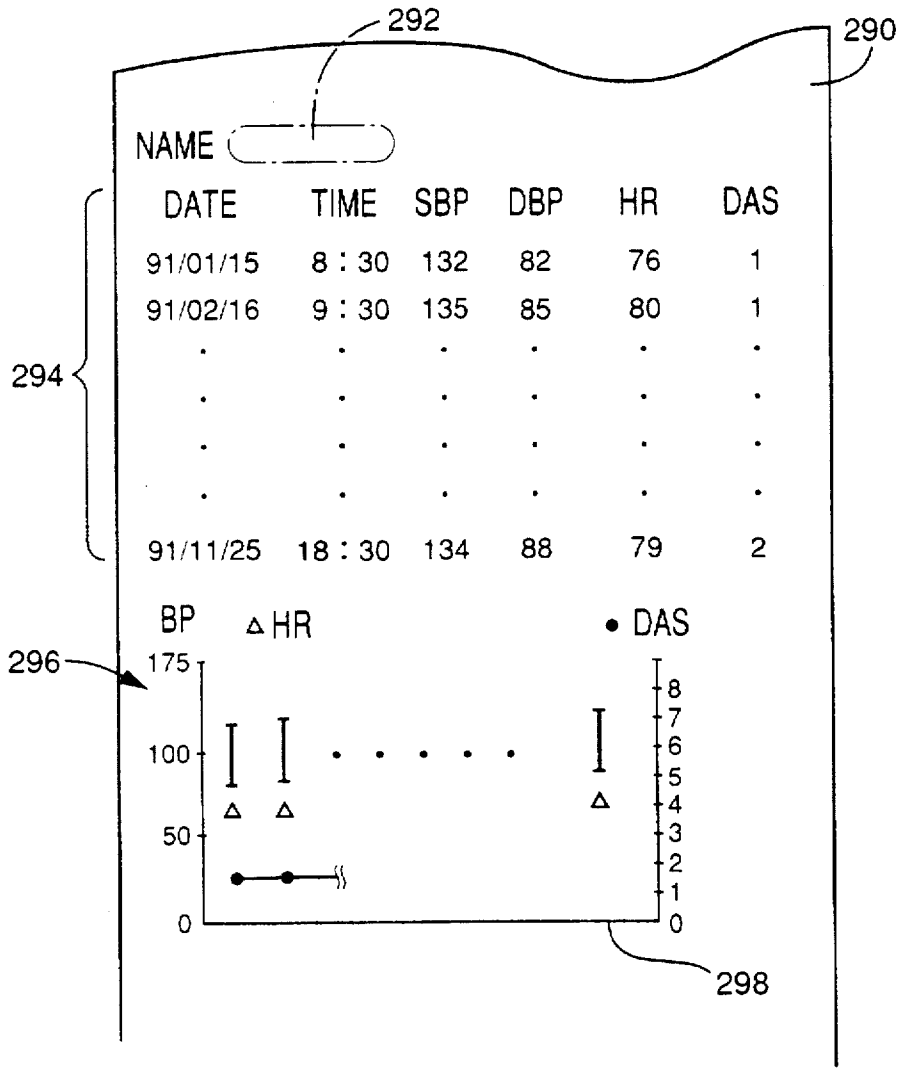
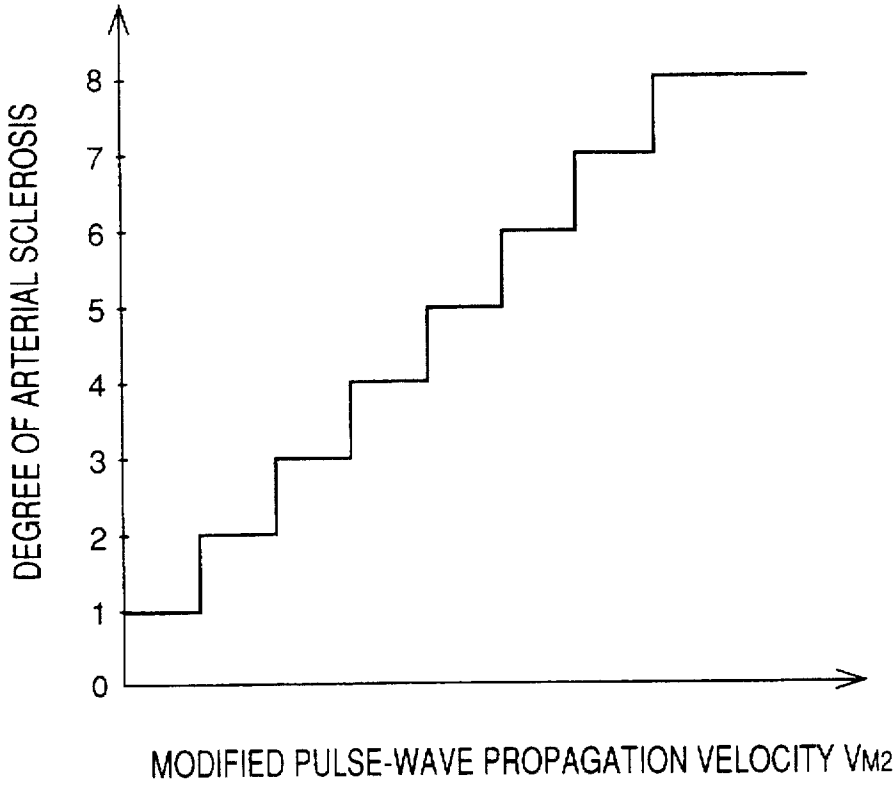

292
290
NAME
DATE TIME SBP DBP HR DAS
91/01/15 8 : 30 132 82 76 1
91/02/16 9 : 30 135 85 80 1
294
91/11/25 18 : 30 134 88 79 2
BP △HR •DAS
296
175
100
50
0
8
7
6
5
4
3
2
1
0
298

FIG. 14


DEGREE OF ARTERIAL SCLEROSIS
0
1
2
3
4
5
6
7
8
MODIFIED PULSE-WAVE PROPAGATION VELOCITY VM2

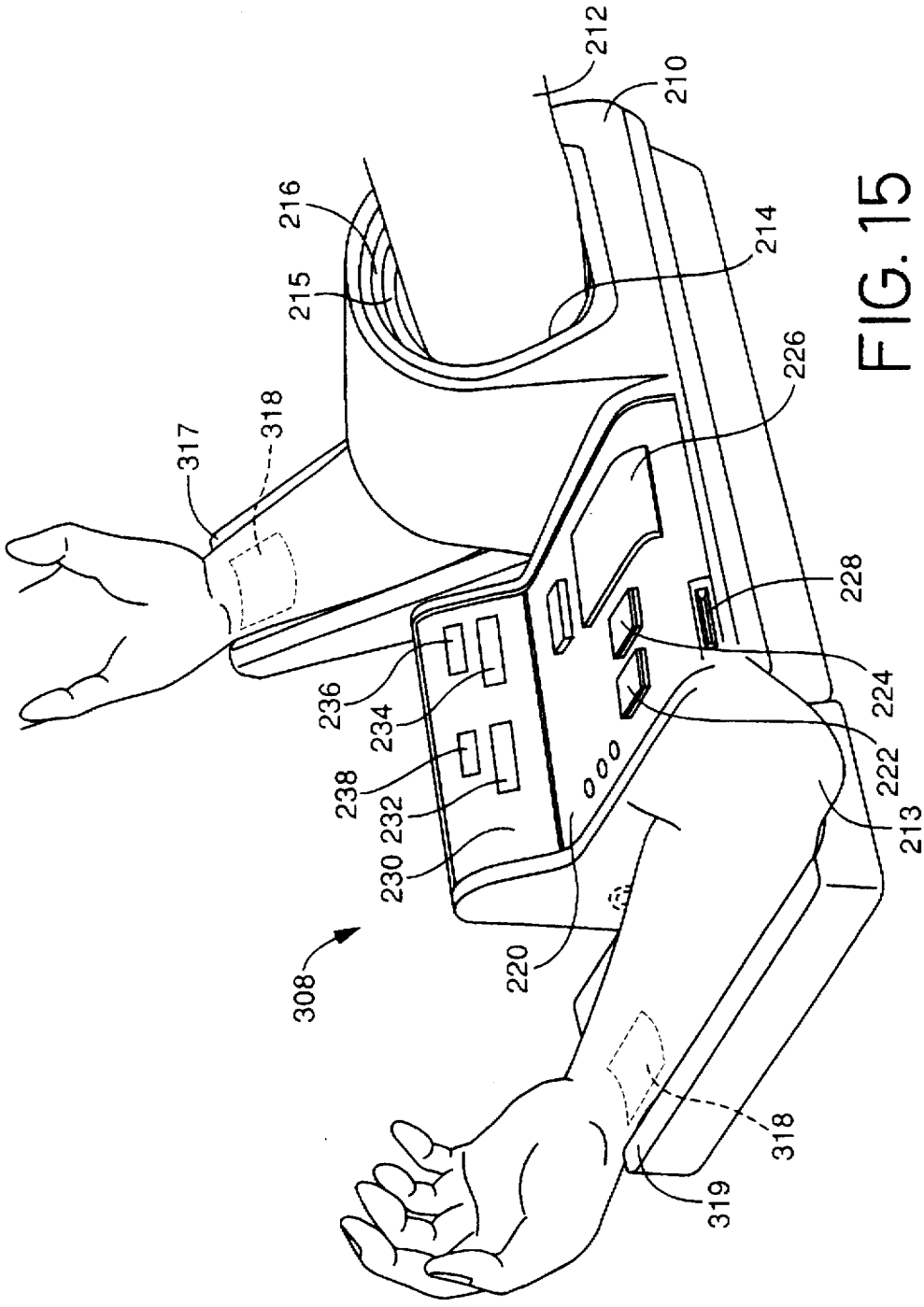

212
210
216
214
215
226
317
318
228
236
234
224
238
232
222
230
213
220
308
318
319

FIG. 15

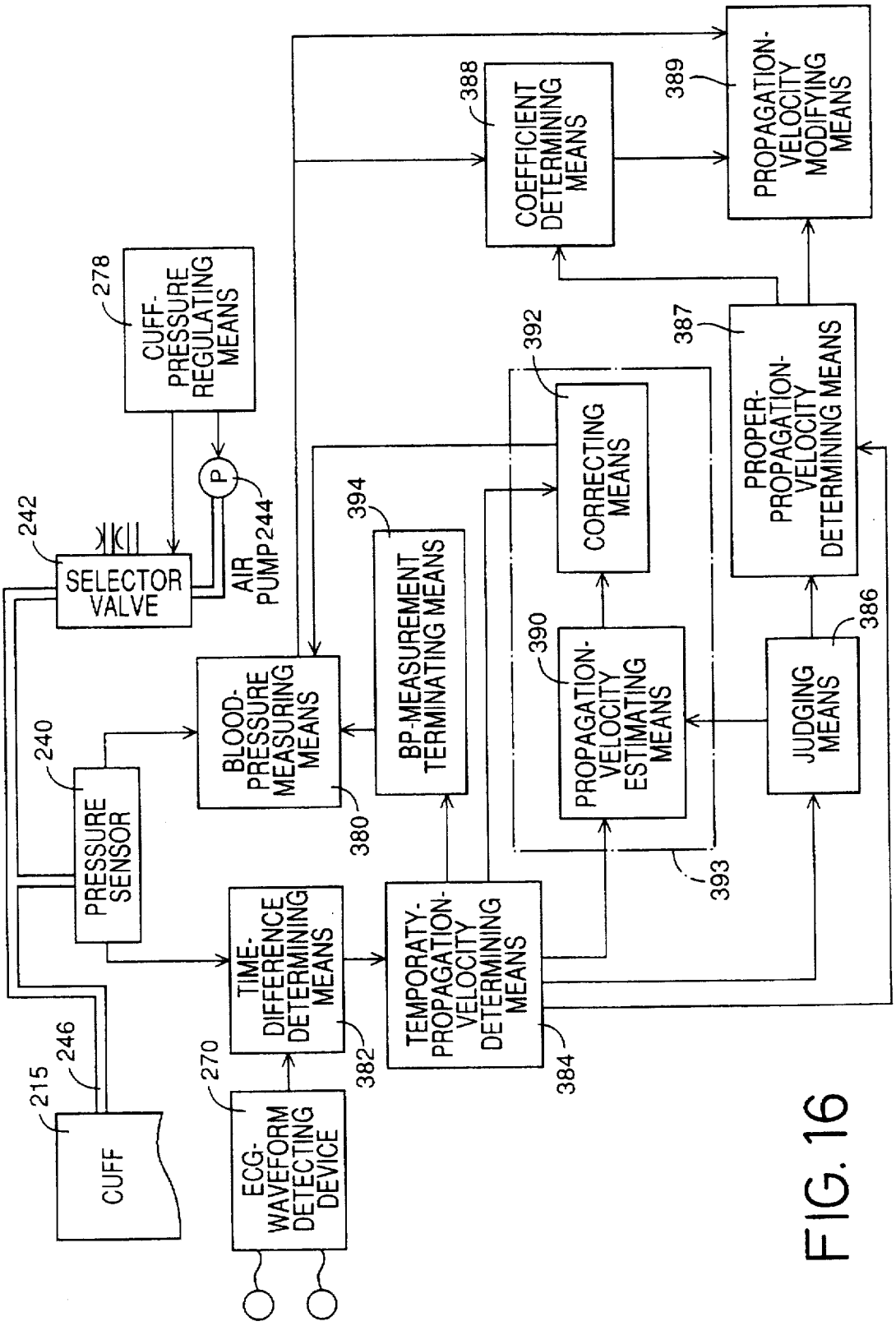

CUFF
215
246
ECG-WAVEFORM DETECTING DEVICE
270
TIME-DIFFERENCE DETERMINING MEANS
382
TEMPORATY-PROPAGATION-VELOCITY DETERMINING MEANS
384
PRESSURE SENSOR
240
BLOOD-PRESSURE MEASURING MEANS
380
BP-MEASUREMENT TERMINATING MEANS
394
SELECTOR VALVE
242
AIR PUMP
244
P
CUFF-PRESSURE REGULATING MEANS
278
CORRECTING MEANS
392
PROPAGATION-VELOCITY ESTIMATING MEANS
390
393
JUDGING MEANS
386
PROPER-PROPAGATION-VELOCITY DETERMINING MEANS
387
COEFFICIENT DETERMINING MEANS
388
PROPAGATION-VELOCITY MODIFYING MEANS
389

FIG. 16

FIG. 17

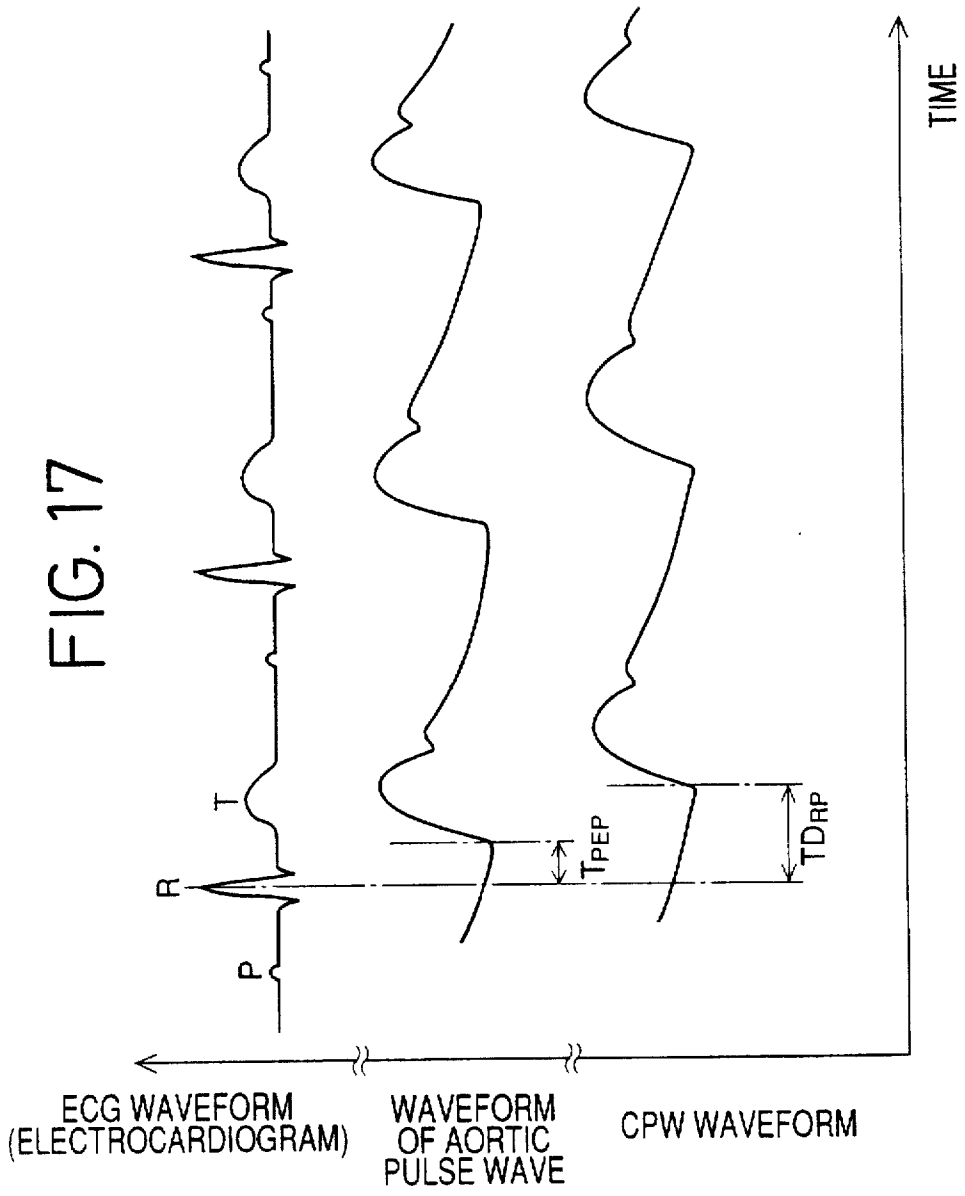

TIME
T
R
P
TPEP
TDRP
ECG WAVEFORM
(ELECTROCARDIOGRAM)
WAVEFORM
OF AORTIC
PULSE WAVE
CPW WAVEFORM

FIG. 18

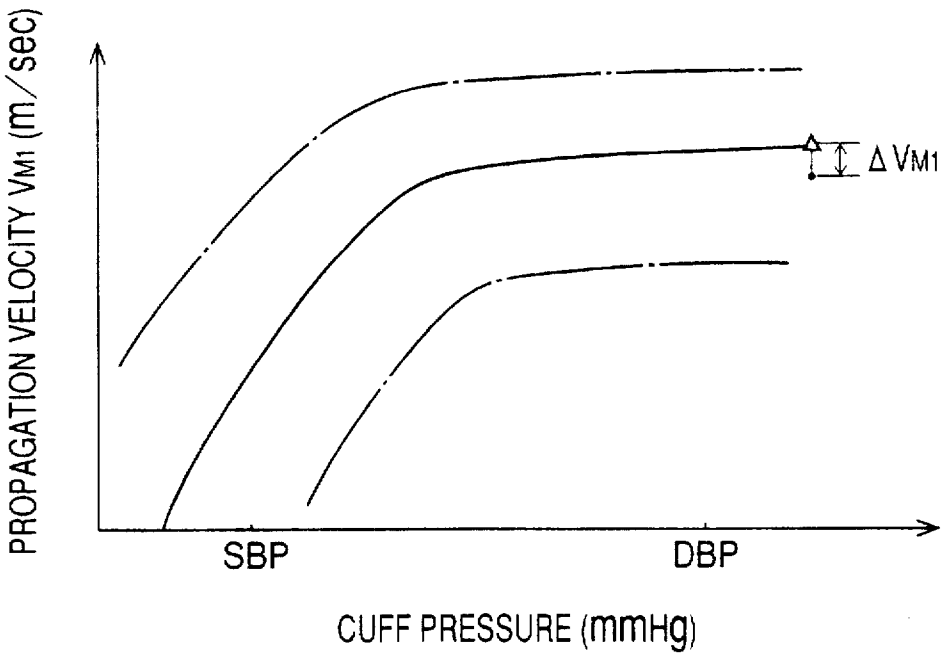

PROPAGATION VELOCITY VM1 (m/sec)
ΔVM1
SBP
DBP
CUFF PRESSURE (mmHg)

FIG. 19

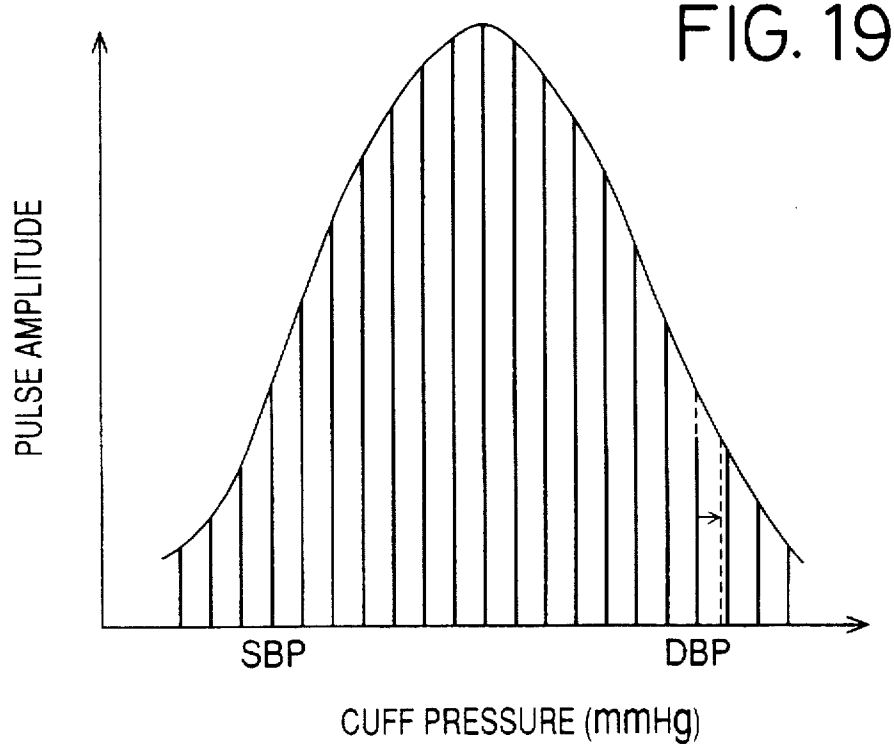

PULSE AMPLITUDE
SBP
DBP
CUFF PRESSURE (mmHg)

FIG. 20

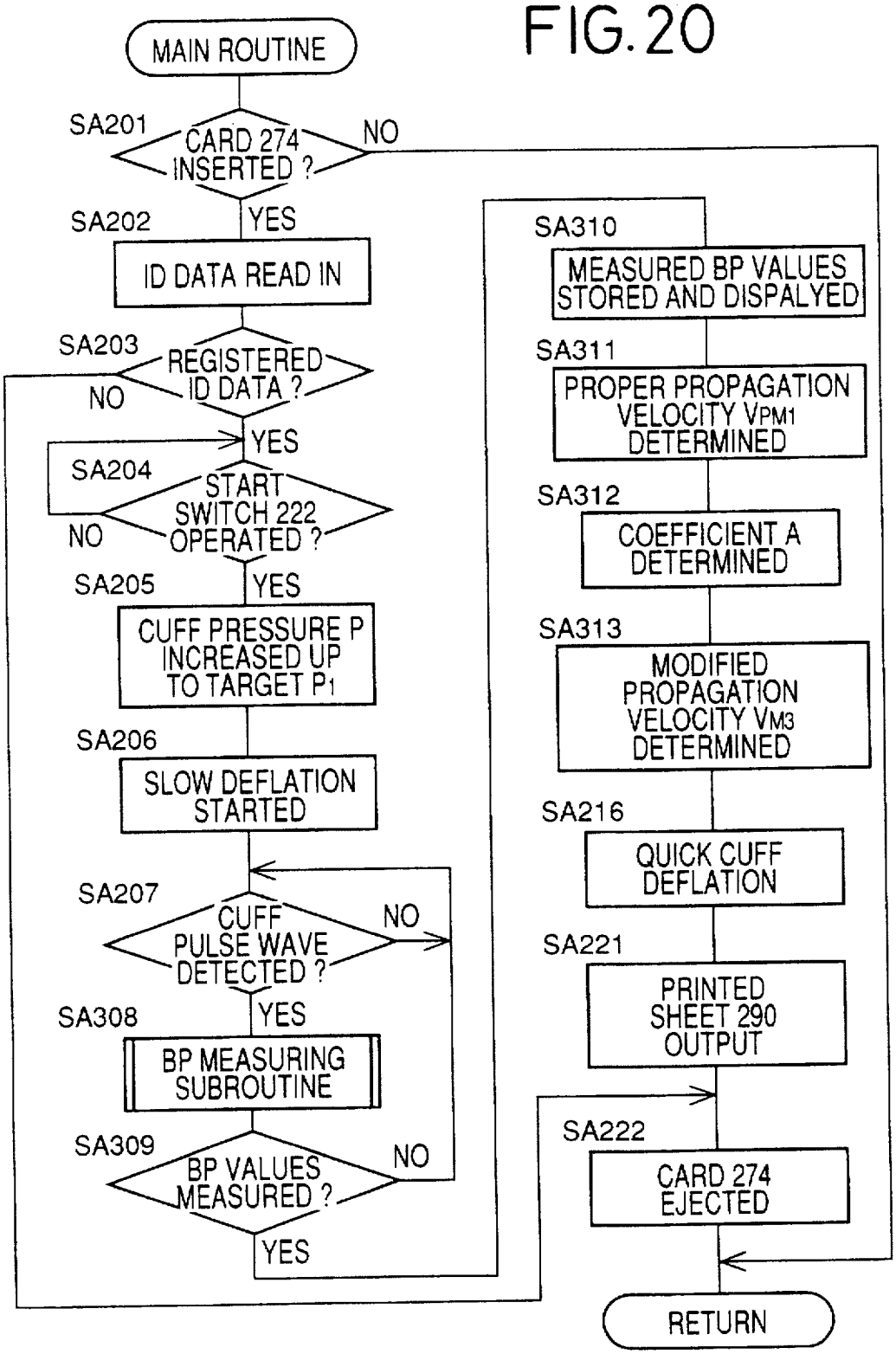

MAIN ROUTINE
SA201
CARD 274 INSERTED ?
NO
YES
SA202
ID DATA READ IN
SA203
REGISTERED ID DATA ?
NO
YES
SA204
START SWITCH 222 OPERATED ?
NO
YES
SA205
CUFF PRESSURE P INCREASED UP TO TARGET P1
SA206
SLOW DEFLATION STARTED
SA207
CUFF PULSE WAVE DETECTED ?
NO
YES
SA308
BP MEASURING SUBROUTINE
SA309
BP VALUES MEASURED ?
NO
YES
SA310
MEASURED BP VALUES STORED AND DISPALYED
SA311
PROPER PROPAGATION VELOCITY VPM1 DETERMINED
SA312
COEFFICIENT A DETERMINED
SA313
MODIFIED PROPAGATION VELOCITY VM3 DETERMINED
SA216
QUICK CUFF DEFLATION
SA221
PRINTED SHEET 290 OUTPUT
SA222
CARD 274 EJECTED
RETURN

FIG. 21

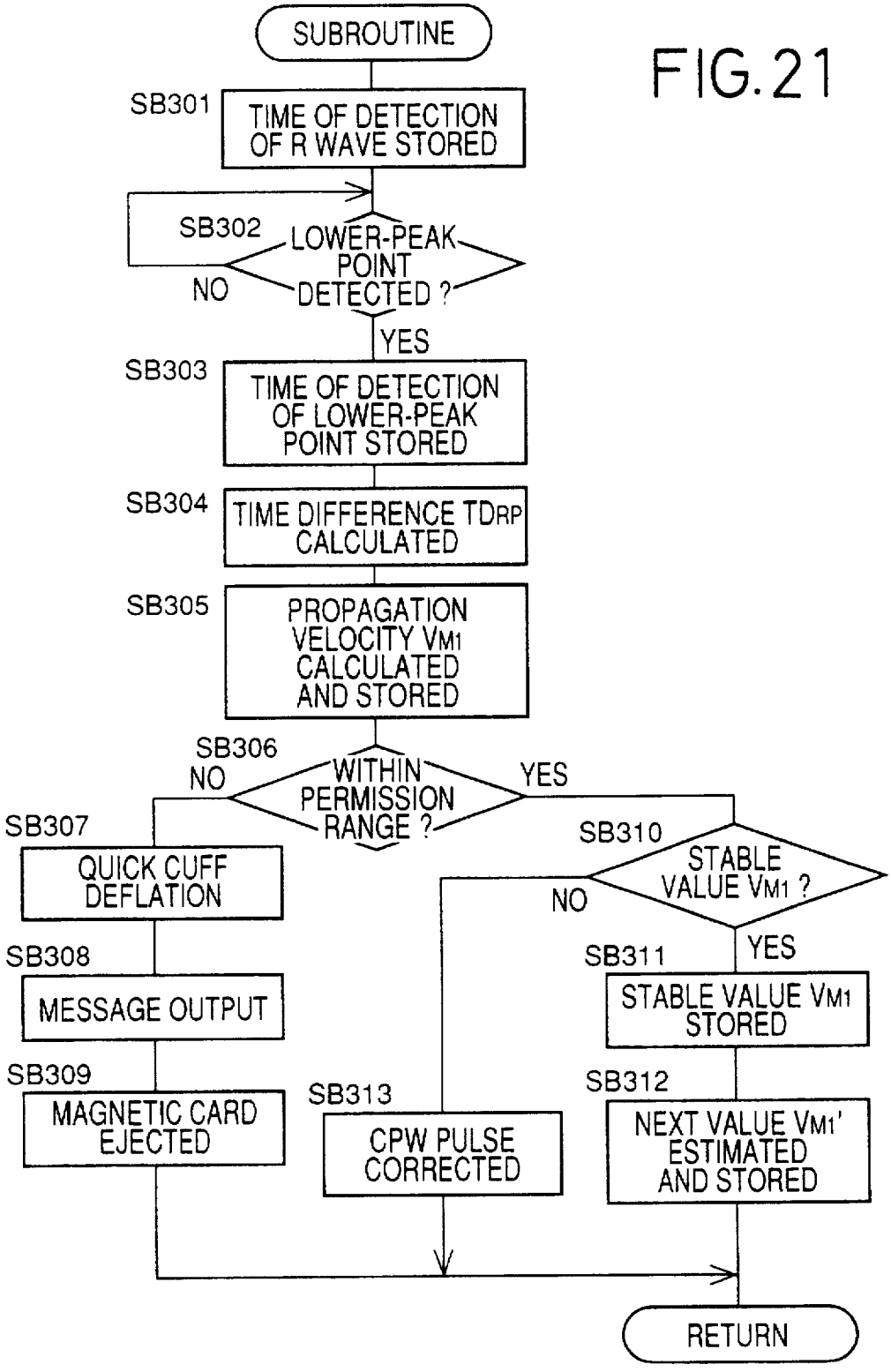
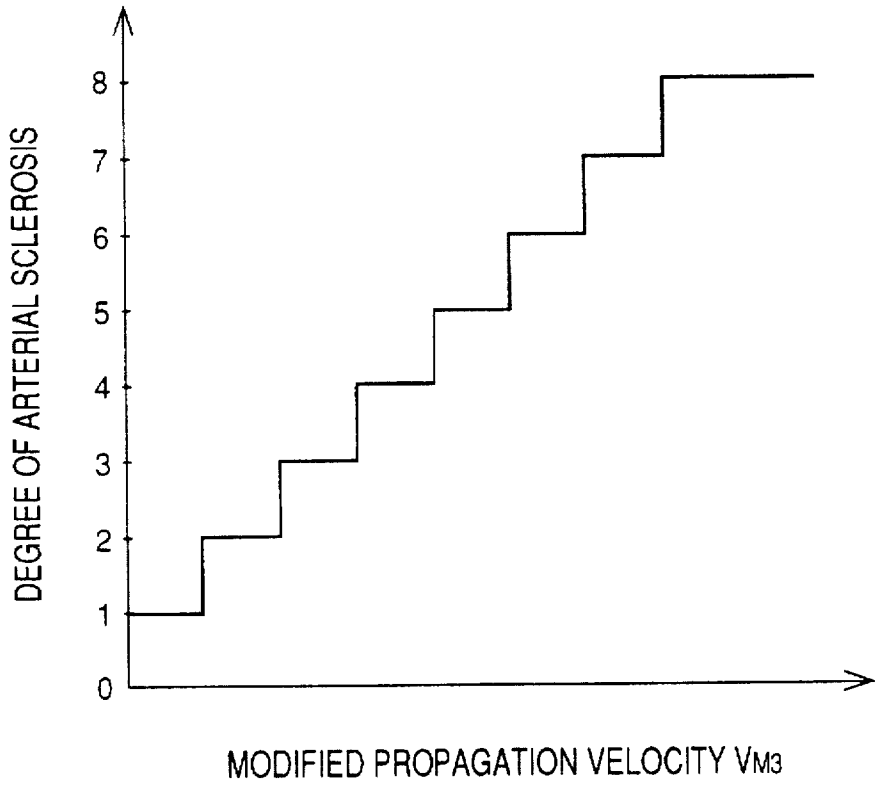

SUBROUTINE
SB301
TIME OF DETECTION OF R WAVE STORED
SB302
LOWER-PEAK POINT DETECTED ?
NO
YES
SB303
TIME OF DETECTION OF LOWER-PEAK POINT STORED
SB304
TIME DIFFERENCE TDRP CALCULATED
SB305
PROPAGATION VELOCITY VM1 CALCULATED AND STORED
SB306
WITHIN PERMISSION RANGE ?
NO
YES
SB307
QUICK CUFF DEFLATION
SB308
MESSAGE OUTPUT
SB309
MAGNETIC CARD EJECTED
SB310
STABLE VALUE VM1 ?
NO
YES
SB311
STABLE VALUE VM1 STORED
SB312
NEXT VALUE VM1' ESTIMATED AND STORED
SB313
CPW PULSE CORRECTED
RETURN

FIG. 22


DEGREE OF ARTERIAL SCLEROSIS
0
1
2
3
4
5
6
7
8
MODIFIED PROPAGATION VELOCITY VM3

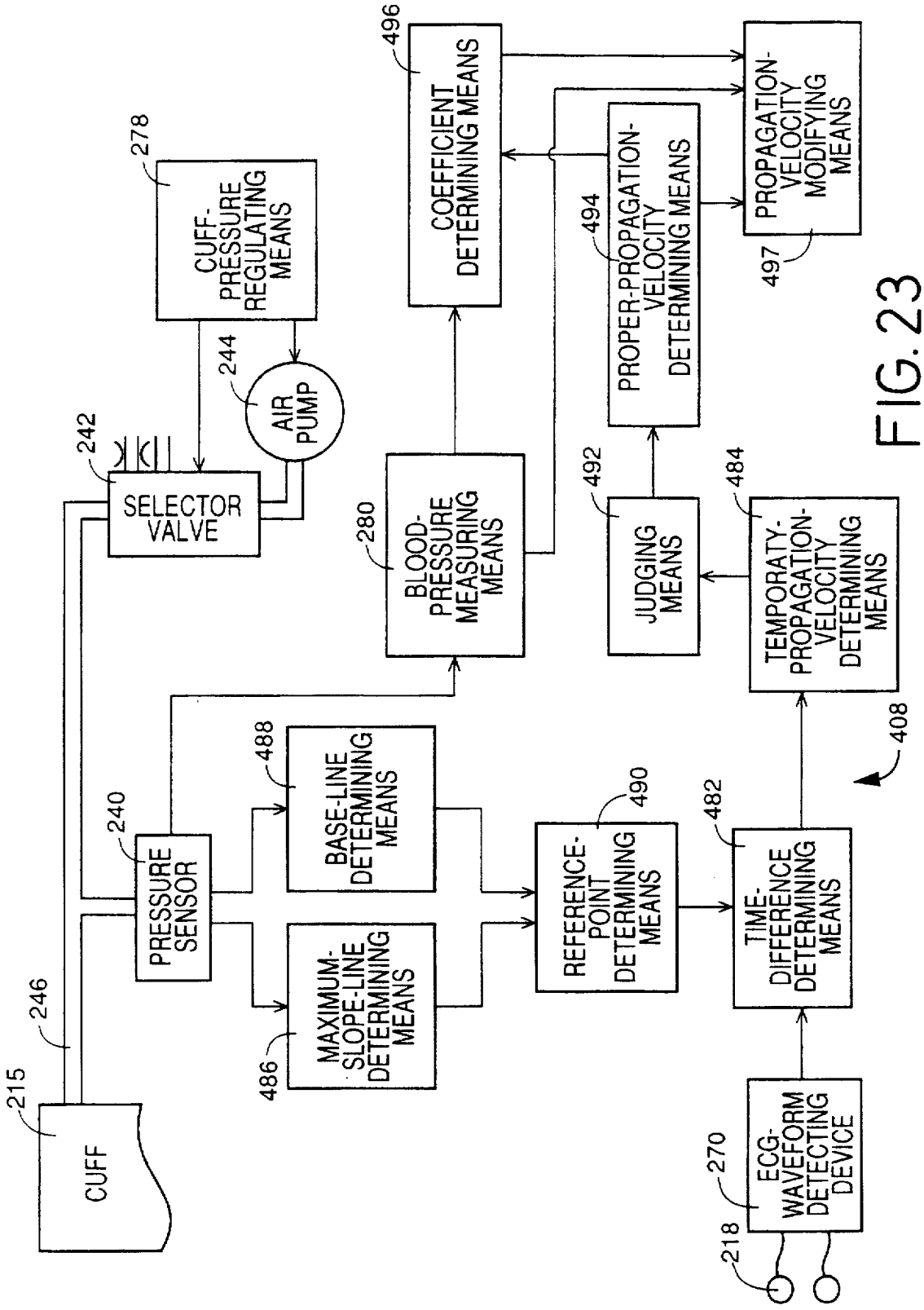

CUFF
215
246
PRESSURE SENSOR
240
SELECTOR VALVE
242
AIR PUMP
244
CUFF-PRESSURE REGULATING MEANS
278
BLOOD-PRESSURE MEASURING MEANS
280
BASE-LINE DETERMINING MEANS
488
MAXIMUM-SLOPE-LINE DETERMINING MEANS
486
REFERENCE-POINT DETERMINING MEANS
490
TIME-DIFFERENCE DETERMINING MEANS
482
ECG-WAVEFORM DETECTING DEVICE
270
218
TEMPORATY-PROPAGATION-VELOCITY DETERMINING MEANS
484
JUDGING MEANS
492
PROPER-PROPAGATION-VELOCITY DETERMINING MEANS
494
COEFFICIENT DETERMINING MEANS
496
PROPAGATION-VELOCITY MODIFYING MEANS
497
408

FIG. 23

FIG. 24

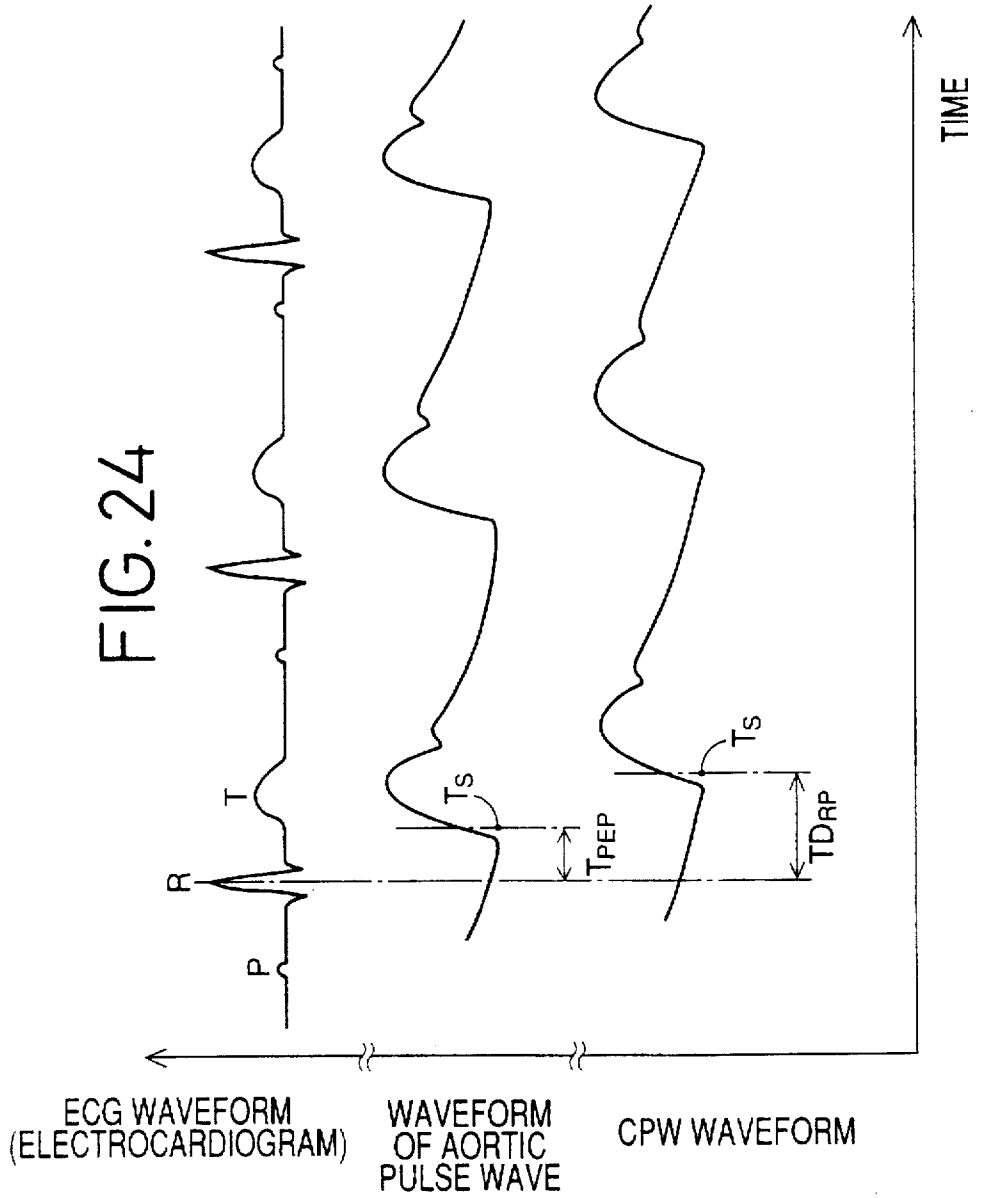

TIME
T
R
P
T_S
T_{PEP}
T_S
TD_{RP}
ECG WAVEFORM (ELECTROCARDIOGRAM)
WAVEFORM OF AORTIC PULSE WAVE
CPW WAVEFORM

FIG. 25

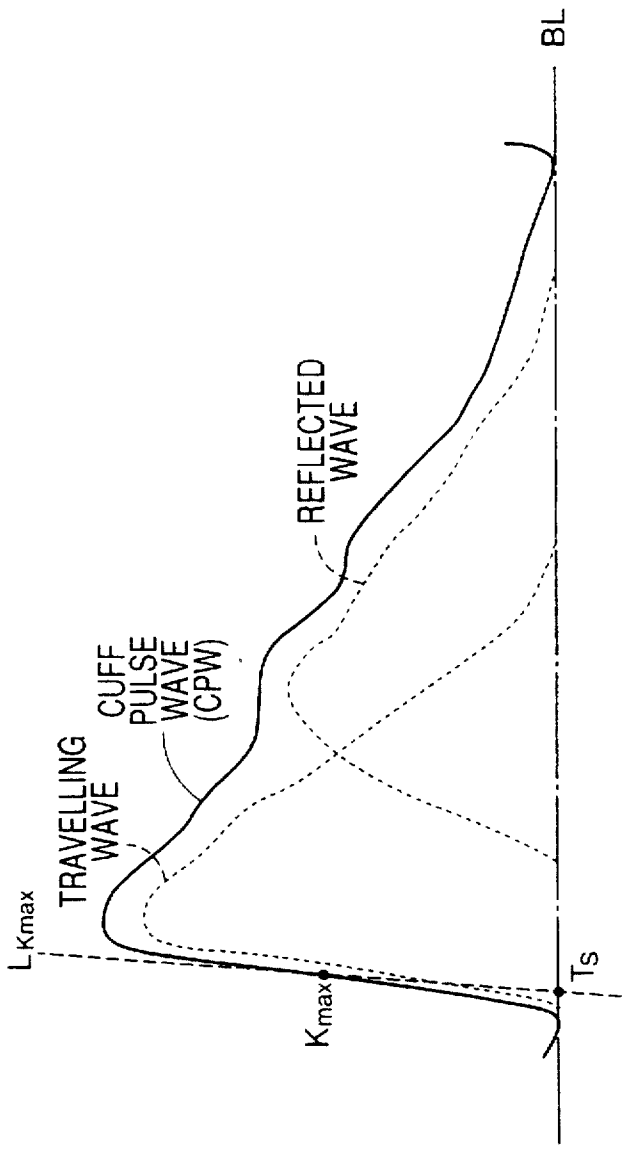

BL
REFLECTED WAVE
CUFF PULSE WAVE (CPW)
TRAVELLING WAVE
L_{Kmax}
K_{max}
T_S

FIG. 26

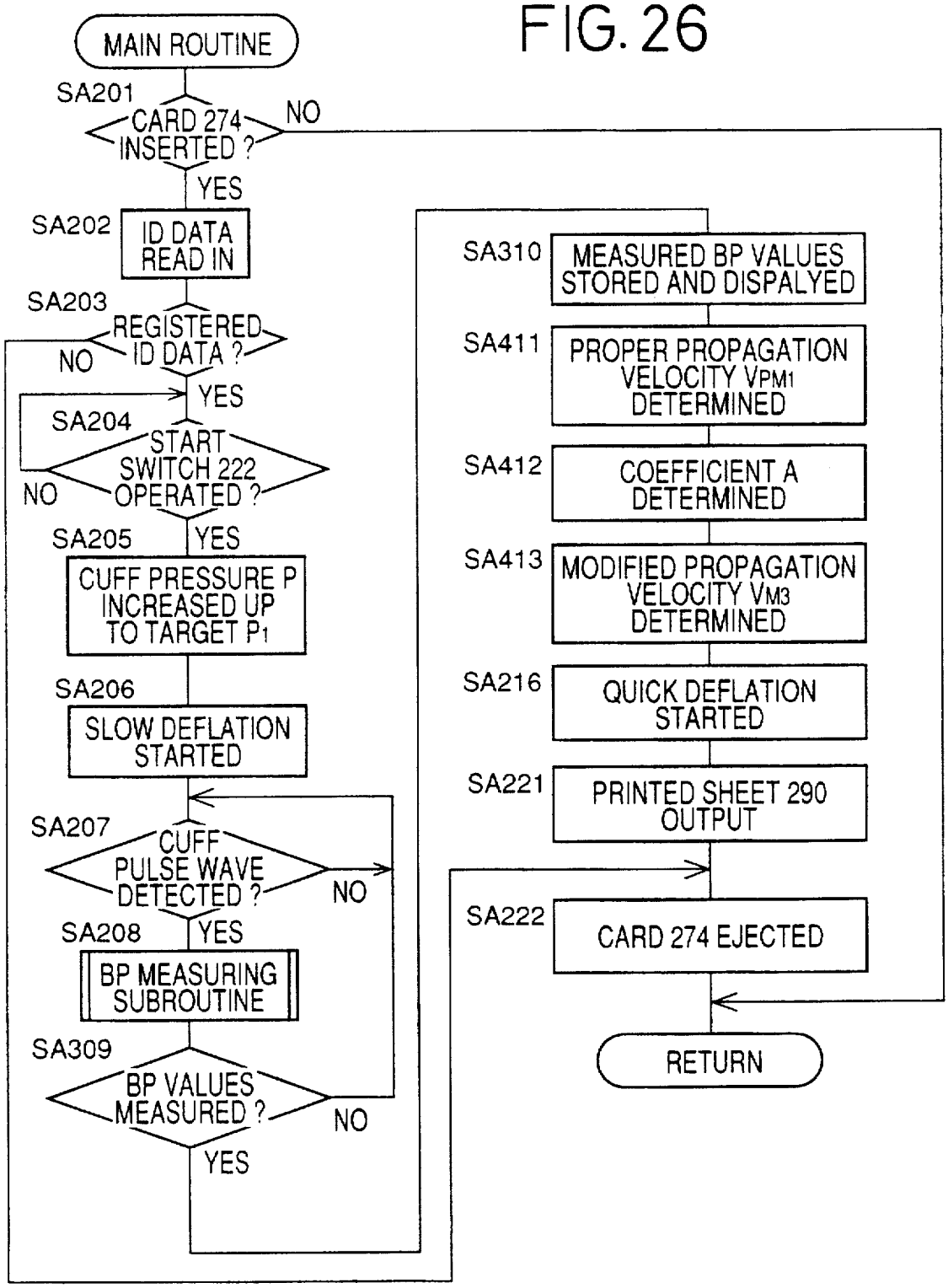
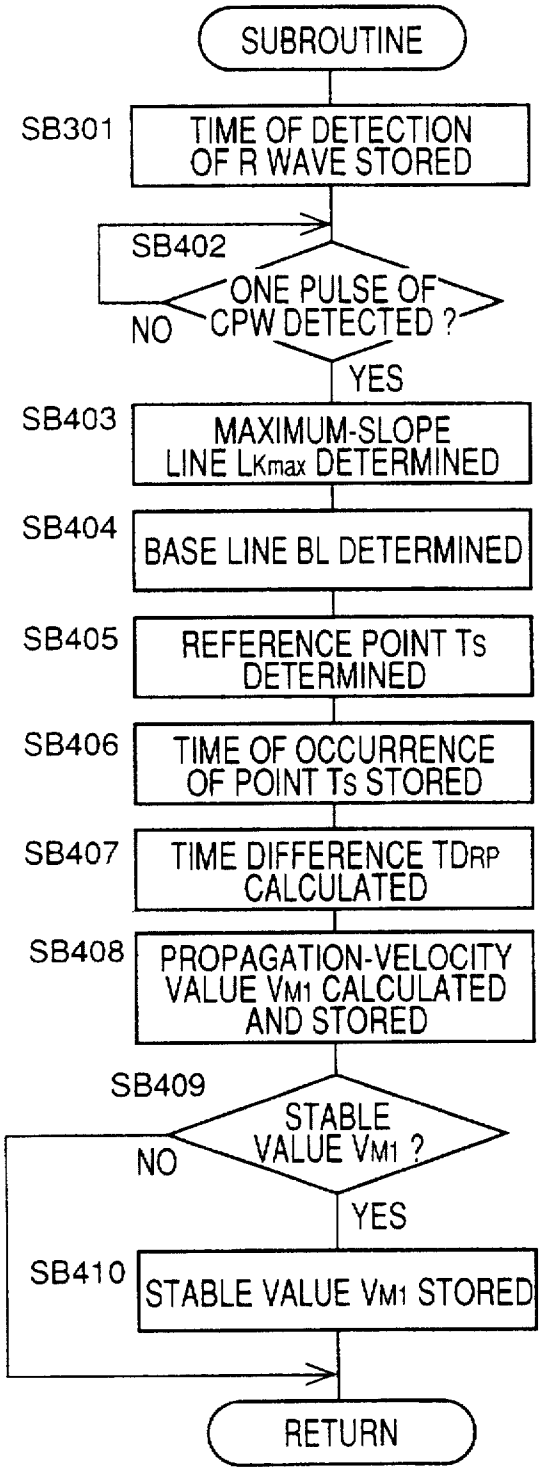

MAIN ROUTINE
SA201
CARD 274 INSERTED ?
NO
YES
SA202
ID DATA READ IN
SA203
REGISTERED ID DATA ?
NO
YES
SA204
START SWITCH 222 OPERATED ?
NO
YES
SA205
CUFF PRESSURE P INCREASED UP TO TARGET P1
SA206
SLOW DEFLATION STARTED
SA207
CUFF PULSE WAVE DETECTED ?
NO
YES
SA208
BP MEASURING SUBROUTINE
SA309
BP VALUES MEASURED ?
NO
YES
SA310
MEASURED BP VALUES STORED AND DISPALYED
SA411
PROPER PROPAGATION VELOCITY VPM1 DETERMINED
SA412
COEFFICIENT A DETERMINED
SA413
MODIFIED PROPAGATION VELOCITY VM3 DETERMINED
SA216
QUICK DEFLATION STARTED
SA221
PRINTED SHEET 290 OUTPUT
SA222
CARD 274 EJECTED
RETURN

FIG. 27


SUBROUTINE
SB301
TIME OF DETECTION OF R WAVE STORED
SB402
ONE PULSE OF CPW DETECTED ?
NO
YES
SB403
MAXIMUM-SLOPE LINE LKmax DETERMINED
SB404
BASE LINE BL DETERMINED
SB405
REFERENCE POINT Ts DETERMINED
SB406
TIME OF OCCURRENCE OF POINT Ts STORED
SB407
TIME DIFFERENCE TDRP CALCULATED
SB408
PROPAGATION-VELOCITY VALUE VM1 CALCULATED AND STORED
SB409
STABLE VALUE VM1 ?
NO
YES
SB410
STABLE VALUE VM1 STORED
RETURN

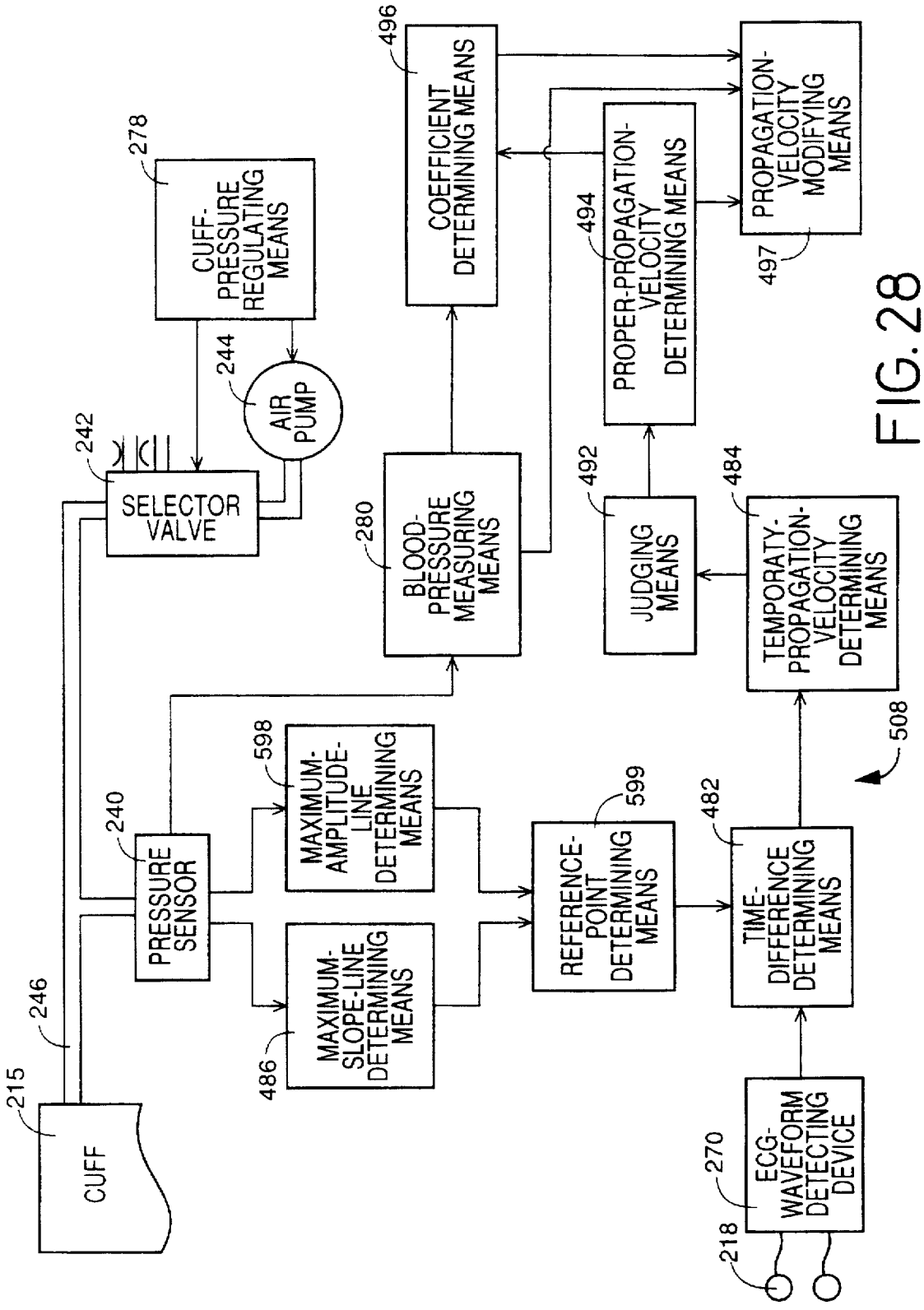

CUFF
215
246
PRESSURE SENSOR
240
SELECTOR VALVE
242
AIR PUMP
244
CUFF-PRESSURE REGULATING MEANS
278
MAXIMUM-SLOPE-LINE DETERMINING MEANS
486
MAXIMUM-AMPLITUDE-LINE DETERMINING MEANS
598
BLOOD-PRESSURE MEASURING MEANS
280
COEFFICIENT DETERMINING MEANS
496
REFERENCE-POINT DETERMINING MEANS
599
TIME-DIFFERENCE DETERMINING MEANS
482
ECG-WAVEFORM DETECTING DEVICE
270
218
PROPER-PROPAGATION-VELOCITY DETERMINING MEANS
494
JUDGING MEANS
492
TEMPORATY-PROPAGATION-VELOCITY DETERMINING MEANS
484
PROPAGATION-VELOCITY MODIFYING MEANS
497
508

FIG. 28

FIG. 29

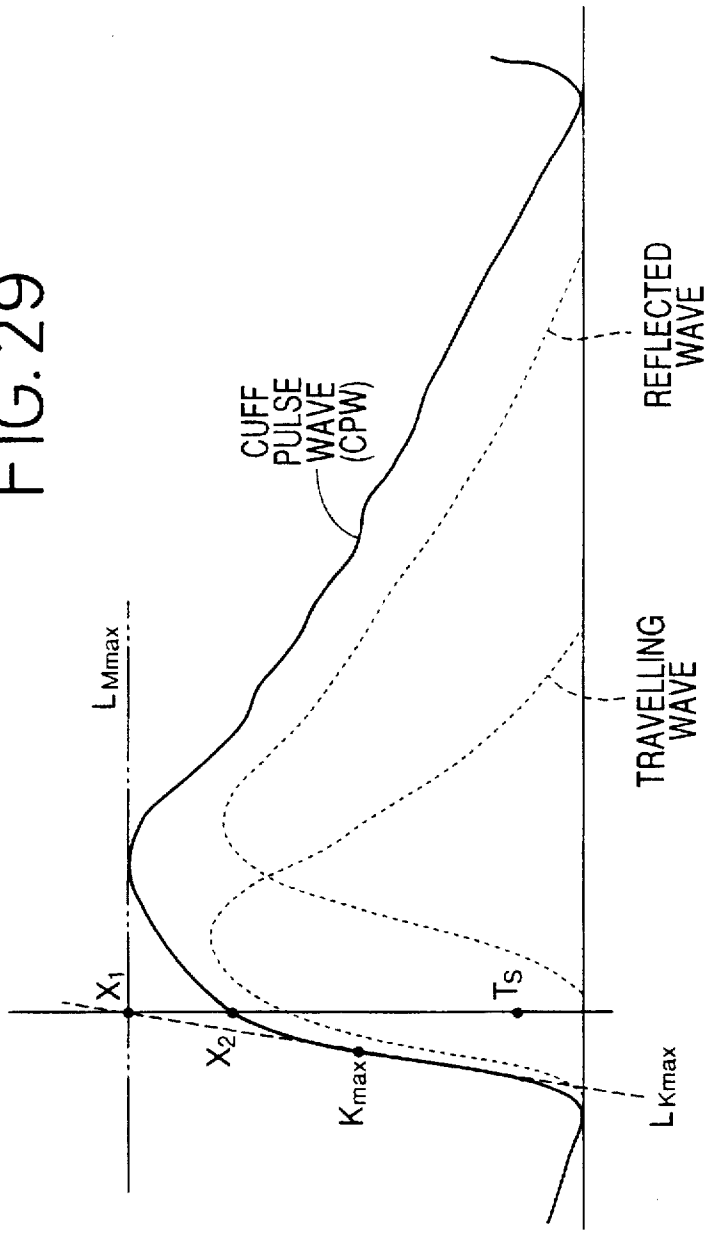

CUFF PULSE WAVE (CPW)
REFLECTED WAVE
TRAVELLING WAVE
L_{Mmax}
X_1
X_2
K_{max}
T_S
L_{Kmax}

FIG. 30

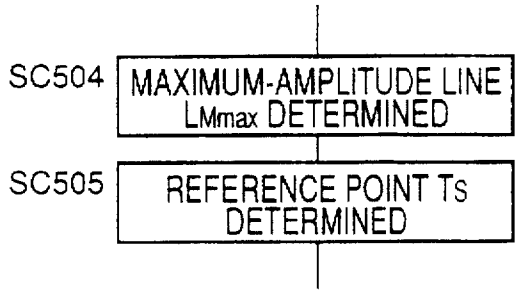
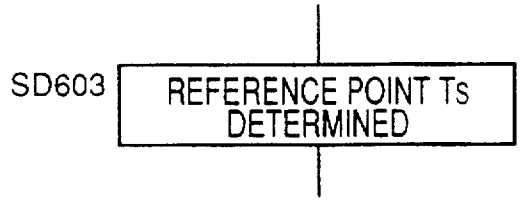

SC504
MAXIMUM-AMPLITUDE LINE LMmax DETERMINED
SC505
REFERENCE POINT Ts DETERMINED

FIG. 32


SD603
REFERENCE POINT Ts DETERMINED

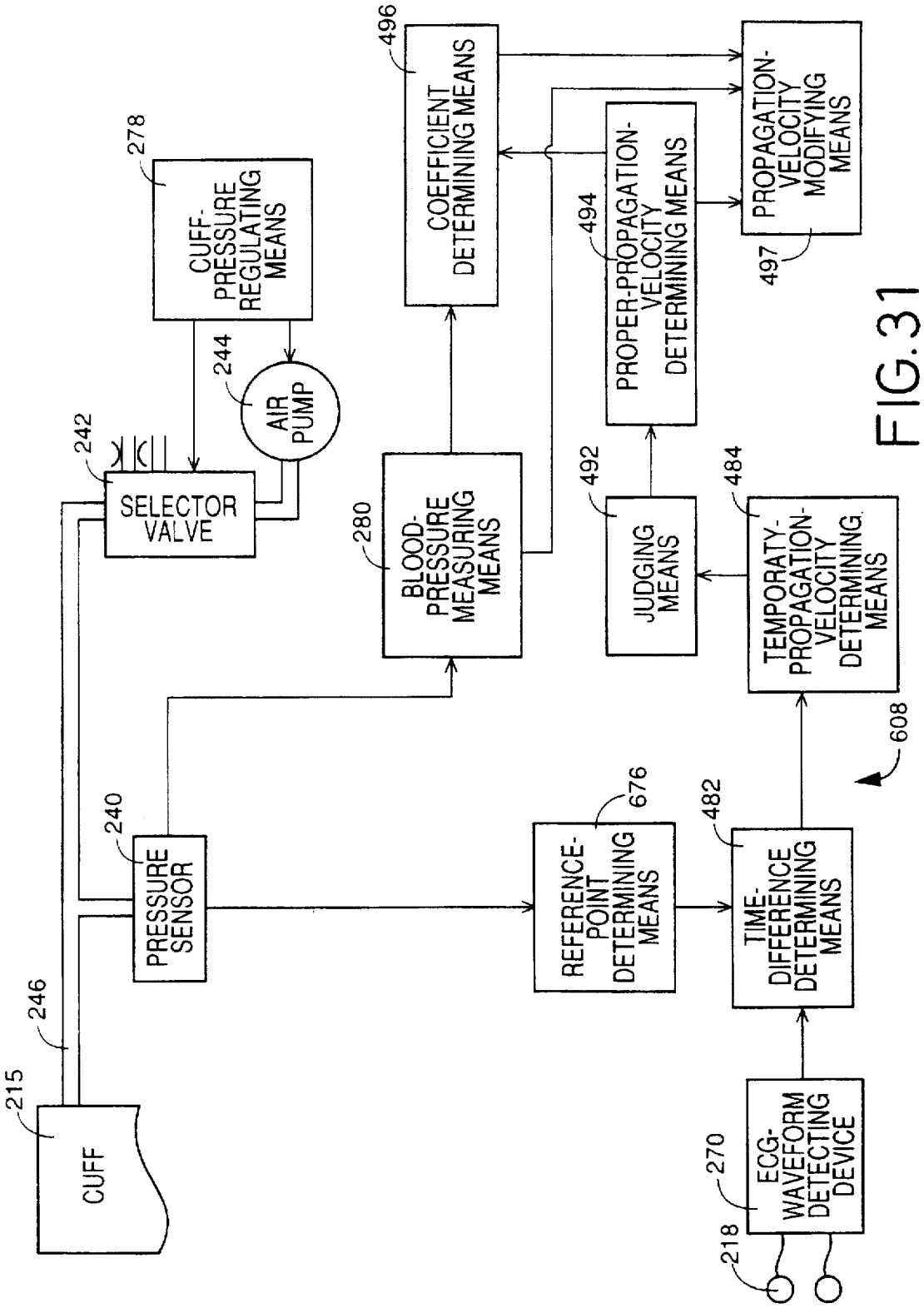

CUFF
215
246
PRESSURE SENSOR
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CUFF-PRESSURE REGULATING MEANS
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496
PROPER-PROPAGATION-VELOCITY DETERMINING MEANS
494
PROPAGATION-VELOCITY MODIFYING MEANS
497
JUDGING MEANS
492
TEMPORATY-PROPAGATION-VELOCITY DETERMINING MEANS
484
608
REFERENCE-POINT DETERMINING MEANS
676
TIME-DIFFERENCE DETERMINING MEANS
482
ECG-WAVEFORM DETECTING DEVICE
270
218

FIG. 31

APPARATUS FOR MEASURING PULSE-WAVE PROPAGATION VELOCITY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an apparatus for measuring the velocity of propagation of a pulse wave which is propagated through an artery of a living subject.

2. Related Art Statement

The blood pressure, degree of arterial sclerosis, peripheral resistance, etc. of a living subject can be estimated based on the velocity of propagation of a pulse wave which is propagated through an artery of the subject. There is known a pulse-wave propagation velocity measuring apparatus including a pair of pulse-wave sensors which are put on different locations on the skin of a living subject to press different portions of an artery of the subject via the skin and detect respective pulse waves from the artery. The measuring apparatus determines a pulse-wave propagation velocity based on the phase difference of the two pulse waves detected through the two sensors. The measuring apparatus is disclosed in, e.g., Unexamined Japanese Patent Application laid open for inspection purposes under Publication No. 60(1985)-220037.

The prior measuring apparatus measures the pulse-wave propagation velocity through the pulse-wave sensors being pressed against two portions of a superficial artery, such as carotid artery, radial artery, or dorsal pedal artery, that is adjacent to the skin of the subject. In this case, however, the time difference between the time of occurrence or detection of a heartbeat-synchronous pulse of one of the two pulses waves and the time of occurrence or detection of a corresponding heartbeat-synchronous pulse of the other pulse wave is small, because the length or distance between the two portions of the superficial artery is short. Thus, the time difference may not be relied upon for providing a very accurate pulse-wave propagation velocity.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an apparatus for measuring a very accurate pulse-wave propagation velocity.

The above object has been achieved by the present invention. According to a first aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising an electrocardiographic-waveform detecting device which detects an electrocardiographic waveform from the subject, a pulse-wave sensor which is adapted to be worn on the subject and which detects the pulse wave from the subject, time-difference determining means for determining a time difference between a first periodic point relating to the detected electrocardiographic waveform and a second periodic point relating to the detected pulse wave, and propagation-velocity determining means for determining the propagation velocity of the pulse wave based on the determined time difference.

In the pulse-wave measuring apparatus in accordance with the first aspect of the invention, the time difference determined by the time-difference determining means contains a time duration when the pulse wave is propagated through the aorta directly connected to the heart of the subject. Therefore, the length of the artery through which the pulse wave is propagated is increased and accordingly the time difference is increased. In addition, since the diameter of the aorta is large and accordingly the velocity of the pulse wave being propagated through the aorta is decreased, the time difference is increased. Thus, the present apparatus provides a very accurate pulse-wave propagation velocity. Therefore, the degree of arterial sclerosis, or the blood pressure, of the subject can be estimated with high accuracy based on the thus determined pulse-wave propagation velocity.

According to a preferred feature of the first aspect of the invention, the pulse-wave sensor comprises a pressure sensor which is adapted to be pressed against a portion of the artery of the subject via a skin of the subject and which detects, as the pulse wave, a heartbeat-synchronous pressure oscillation which is transmitted thereto from the portion of the artery via the skin. In the case where the present invention is applied to a BP monitor apparatus including an identical pressure sensor for monitoring BP values of a subject, the pressure sensor is used for the two purposes, one for detecting a pulse wave and thereby measuring a pulse-wave propagation velocity and the other for monitoring BP values. The BP monitor apparatus having the pulse-wave propagation velocity measuring function enjoys a reduced production cost.

According to another feature of the first aspect of the invention, the pulse-wave sensor comprises an inflatable cuff which is adapted to be wound around a body portion of the subject, and a pressure sensor which detects, as the pulse wave, a heartbeat-synchronous pressure oscillation which is produced in the cuff. In the case where the present invention is applied to a BP measuring apparatus including identical cuff and pressure sensor for measuring a BP value of a subject, the cuff and pressure sensor are used for the two purposes, one for detecting a pulse wave and thereby measuring a pulse-wave propagation velocity and the other for measuring a BP value. The BP measuring apparatus having the pulse-wave propagation velocity measuring function enjoys a reduced production cost.

According to another feature of the first aspect of the invention, the pulse-wave sensor comprises a photoelectric sensor including a light source which emits a light toward a body portion of the subject, and a light detecting element which detects the light transmitted through, or reflected from, the body portion. In the case where the present invention is applied to a blood-oxygen-saturation measuring apparatus (e.g., so-called pulse oximeter) having an identical photoelectric sensor for measuring a blood oxygen saturation of a subject, the photoelectric sensor is used for the two purposes, one for detecting a pulse wave and thereby measuring a pulse-wave propagation velocity and the other for measuring a blood oxygen saturation. The oxygen-saturation measuring apparatus having the pulse-wave propagation velocity measuring function enjoys a reduced production cost.

According to a second aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising a blood-pressure measuring device which measures a blood pressure value of the subject, an electrocardiographic-waveform detecting device which includes a plurality of electrodes adapted to contact a body surface of the subject and which detects an electrocardiographic waveform from the subject through the electrodes, a pulse-wave sensor which is adapted to be worn on the subject and which detects the pulse wave from the subject, time-difference determining means for determining a time difference between a first

periodic point relating to the detected electrocardiographic waveform and a second periodic point relating to the detected pulse wave, propagation-velocity determining means for determining the propagation velocity of the pulse wave based on the determined time difference, and propagation-velocity modifying means for modifying the determined propagation-velocity value to a modified propagation-velocity value corresponding to a predetermined blood pressure value, based on the measured blood pressure value, according to a predetermined relationship between modified propagation velocity, and determined propagation velocity and measured blood pressure.

While the pulse-wave propagation velocity is influenced by the degree of arterial sclerosis, it is also influenced by the blood pressure and/or the pulse rate of the subject. However, the blood pressure (BP) values of the subject will change more or less in different measurements. Therefore, the propagation velocity measured by the prior apparatus may not directly be used as an index indicative of a degree of arterial sclerosis. In the pulse-wave propagation velocity measuring apparatus in accordance with the second aspect of the invention, however, the modified pulse-wave propagation velocity provided by the propagation-velocity modifying means can directly be used as an index indicative of a degree of arterial sclerosis. Thus, even if the BP or pulse-rate values obtained from the subject in different measurements may differ from each other, the present apparatus modifies each measured propagation velocity value to a modified propagation velocity corresponding to the predetermined BP value. Accordingly, a series of modified propagation-velocity values can directly be used as an index indicative of a time-wise change of the degree of arterial sclerosis of the subject.

According to a preferred feature of the second aspect of the invention, the propagation velocity measuring apparatus further comprises a pulse-rate measuring device which measures a pulse rate value of the subject, and the propagation-velocity modifying means comprises means for modifying the determined propagation-velocity value to the modified propagation-velocity value corresponding to the predetermined blood pressure value and a predetermined pulse rate value, based on the measured blood pressure value and the measured pulse rate value, according to the predetermined relationship between modified propagation velocity, and determined propagation velocity, measured blood pressure value, and measured pulse rate. Since the thus modified propagation-velocity value corresponds to both the predetermined BP and pulse-rate values, it is more accurate than a modified value corresponding to only the predetermined BP value, because the former value is free from influences from the fluctuation of the pulse rate whereas the latter value is subject to them.

According to another feature of the second aspect of the invention, the propagation velocity measuring apparatus further comprises coefficient determining means for determining a coefficient which is variable with the propagation velocity determined by the propagation-velocity determining means and with the blood pressure measured by the blood-pressure measuring device, and the propagation-velocity modifying means comprises means for modifying the determined propagation-velocity value to the modified propagation-velocity value corresponding to the predetermined blood pressure value, such that the modified propagation-velocity value is equal to a product of the determined coefficient and a difference between the predetermined blood pressure value and the measured blood pressure value. Thus, the modified propagation velocity is determined using the coefficient which is determined based on the propagation velocity and the diastolic BP value each obtained from the subject. Owing to the coefficient, the modified value is free from influences or fluctuations due to the differences of individual persons regarding the degree of arterial sclerosis. Therefore, the modified propagation-velocity values obtained from different subjects can be compared with each other for comparing the respective degrees of arterial sclerosis of those subjects.

According to another feature of the second aspect of the invention, the propagation velocity measuring apparatus further comprises means for determining a degree of arterial sclerosis based on the modified propagation-velocity value according to a predetermined relationship between degree of arterial sclerosis and modified propagation velocity.

According to a third aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising a blood-pressure measuring device which includes an inflatable cuff adapted to be wound around a body portion of the subject, a pulse-wave sensor which detects the pulse wave transmitted from the artery of the subject to the cuff when a pressure in the cuff is changed, and means for determining a blood pressure value of the subject based on the detected pulse wave, an electrocardiographic-waveform detecting device which includes a plurality of electrodes adapted to contact a body surface of the subject and which detects an electrocardiographic waveform from the subject through the electrodes, time-difference determining means for successively determining a time difference between a first periodic point relating to the detected electrocardiographic waveform and a second periodic point relating to the detected pulse wave, temporary-propagation-velocity determining means for successively determining a temporary propagation velocity of the pulse wave based on each of the successively determined time-difference values, judging means for judging whether the change of each of the successively determined temporary propagation-velocity values with respect to the change of the cuff pressure is smaller than a reference value, and proper-propagation-velocity determining means for determining a proper propagation velocity from at least one temporary propagation-velocity value for which a positive judgment is made by the judging means.

There is known a BP measuring device which includes an inflatable cuff adapted to be wound around a body portion of the subject, a pulse-wave sensor which detects the pulse wave transmitted from the artery of the subject to the cuff when a pressure in the cuff is changed, and means for determining a blood pressure value of the subject based on the detected pulse wave. The BP measuring device is disclosed in, e.g., U.S. patent application Ser. No. 08/273,929. In the case where the present invention is embodied with the BP measuring device, however, the (temporary) propagation-velocity values determined by the (temporary) propagation-velocity determining means gradually increase as the pressure of the cuff gradually decreases, when the cuff pressure is changed in a range above a mean BP value of the subject. In the pulse-wave propagation velocity measuring apparatus in accordance with the third aspect of the invention, the judging means judges whether the change of each of the determined temporary propagation-velocity values with respect to the change of the cuff pressure is smaller than a reference value, and the proper-propagation-velocity determining means determines a proper propagation velocity from at least one temporary propagation-velocity value for which a positive judgment is made by the judging means.

Since the proper propagation-velocity value is determined from the temporary propagation value or values that is or are stable independent of the change of cuff pressure, the accuracy of measurement of pulse-wave propagation velocity is improved.

According to a preferred feature of the third aspect of the invention, the proper-propagation-velocity determining means comprises means for determining, as the proper propagation velocity, an average of a plurality of temporary propagation-velocity values for each of which the positive judgment is made by the judging means. The thus determined proper propagation velocity enjoys a higher accuracy than a proper propagation velocity as one of a plurality of temporary propagation-velocity values for each of which the positive judgment is made by the judging means. However, the proper-propagation-velocity determining means may comprise means for determining, as the proper propagation velocity, a temporary propagation-velocity values for which a positive judgment is made by the judging means.

According to another feature of the third aspect of the invention, the propagation velocity measuring apparatus further comprises proper-propagation-velocity modifying means for modifying the determined proper propagation-velocity value to a modified proper propagation-velocity value corresponding to a predetermined blood pressure value, based on the measured blood pressure value, according to a predetermined relationship between modified proper propagation velocity, and determined proper propagation velocity and measured blood pressure.

According to another feature of the third aspect of the invention, the propagation velocity measuring apparatus further comprises means for determining a degree of arterial sclerosis of the subject based on the modified proper propagation-velocity value according to a predetermined relationship between degree of arterial sclerosis and modified proper propagation velocity.

According to a fourth aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising a blood-pressure measuring device which includes an inflatable cuff adapted to be wound around a body portion of the subject, a pulse-wave sensor which detects a plurality of heartbeat-synchronous pulses of the pulse wave transmitted from the artery of the subject to the cuff when a pressure in the cuff is changed, and means for determining a blood pressure value of the subject based on variation of respective amplitudes of the detected heartbeat-synchronous pulses of the pulse wave, an electrocardiographic-waveform detecting device which includes a plurality of electrodes adapted to contact a body surface of the subject and which detects an electrocardiographic waveform from the subject through the electrodes, time-difference determining means for successively determining a time difference between a first periodic point relating to each of heartbeat-synchronous pulses of the detected electrocardiographic waveform and a second periodic point relating to a corresponding one of the detected heartbeat-synchronous pulses of pulse wave, propagation-velocity determining means for successively determining a propagation velocity of the pulse wave based on each of the successively determined time-difference values, judging means for judging whether the change of each of the successively determined propagation-velocity values with respect to the change of the cuff pressure is smaller than a reference value, and correcting means for correcting at least one first pulse of the heartbeat-synchronous pulses of the pulse wave which is deviated from at least one second pulse for which a positive judgment is made by the judging means, based on the deviation of the first pulse from the second pulse, so that the blood-pressure measuring device measures the blood pressure value of the subject based on the variation of the respective amplitudes of the heartbeat-synchronous pulses including the corrected first pulse.

In the case where the present invention is embodied with the BP measuring device which determines a BP value of the subject based on variation of respective amplitudes of heartbeat-synchronous pulses of the pulse wave obtained when the cuff pressure is changed, the relationship of correspondence of pulse amplitude and cuff pressure (or blood pressure) may break for a certain reason during each BP measuring operation of the BP measuring device. Hence, if a first pulse of the heartbeat-synchronous pulses of the pulse wave is deviated from one or more second pulses corresponding to one or more propagation-velocity values for each of which a positive judgment is made by the judging means, the correcting means corrects the first pulse, e.g., amplitude of the first pulse, or value of the cuff pressure at the time of detection of the first pulse, so that the BP measuring device measures a BP value of the subject based on the variation of respective amplitudes of heartbeat-synchronous pulses including the corrected first pulse. Thus, the accuracy of measurement of BP values is improved.

According to a preferred feature of the fourth aspect of the invention, the correcting means comprises estimating means for estimating, based on a plurality of the determined propagation-velocity values for each of which the positive judgment is made by the judging means, a next propagation-velocity value which will be determined by the propagation-velocity determining means, and difference determining means for determining a difference between the estimated next propagation-velocity value and an actual next propagation-velocity actually determined by the propagation-velocity determining means.

According to another feature of the fourth aspect of the invention, the correcting means further comprises means for determining a correction value based on the determined difference according to a predetermined expression, and adding the correction value to an amplitude of the first pulse. Thus, the first pulse is corrected.

According to another feature of the fourth aspect of the invention, the correcting means further comprises means for determining a correction value based on the determined difference according to a predetermined expression, and adding the correction value to a value of the cuff pressure at a time of detection of the first pulse. Thus, the first pulse is corrected.

According to a fifth aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising, a blood-pressure measuring device which includes an inflatable cuff adapted to be wound around a body portion of the subject, a pulse-wave sensor which detects the pulse wave transmitted from the artery of the subject to the cuff when a pressure in the cuff is changed, and means for determining a blood pressure value of the subject based on the detected pulse wave, an electrocardiographic-waveform detecting device which includes a plurality of electrodes adapted to contact a body surface of the subject and which detects an electrocardiographic waveform from the subject through the electrodes, time-difference determining means for determining a time difference between a first periodic point relating to the detected electrocardiographic waveform and a second

periodic point on relating to the detected pulse wave, propagation-velocity determining means for determining a propagation velocity of the pulse wave based on the determined time-difference value, and terminating means for terminating a blood pressure measurement of the blood-pressure measuring device when the determined propagation-velocity value does not fall within a permission range.

In the case where the present invention is embodied with the BP measuring device which determines a BP value of the subject based on the pulse wave obtained when the cuff pressure is changed, the relationship of correspondence of pulse wave and cuff pressure (or blood pressure) may break for a certain reason during each BP measuring operation of the BP measuring device. Hence, if an abnormal event occurs during each BP measurement and the propagation velocity excessively changes, i.e., increases or decreases, the BP measurement is forcedly terminated. Thus, an inaccurate BP measurement or value is effectively avoided.

According to a preferred feature of the fifth aspect of the invention, the propagation velocity measuring apparatus further comprises a memory which stores data indicative of a plurality of the permission ranges corresponding to a plurality of values of the cuff pressure at which a plurality of propagation-velocity values are determined by the propagation-velocity determining means.

According to a sixth aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising, a first and a second heartbeat-synchronous-wave sensor which detect, as the pulse wave, a first and a second heartbeat-synchronous wave, respectively, each of which is produced from the artery of the subject in synchronism with a heartbeat of the subject, maximum-slope-line determining means for determining, with respect to at least one of the first and second waves, a maximum-slope line which passes through a maximum-slope point where a heartbeat-synchronous pulse of the one wave takes a maximum slope, such that the maximum-slope line has the maximum slope, base-line determining means for determining, with respect to the one wave, a base line which passes through respective minimum points on both sides of a maximum point of the heartbeat-synchronous pulse of the one wave, reference-point determining means for determining, as a reference point, a point of intersection of the maximum-slope line and the base line, and propagation-velocity determining means for determining the propagation velocity of the pulse wave based on a time difference between the reference point determined with respect to the heartbeat-synchronous pulse of the one wave and a corresponding heartbeat-synchronous pulse of the other of the first and second waves.

The pulse wave propagated through the artery of the subject contains, as a primary component, a travelling wave and additionally contains, as a secondary component, a reflected wave produced when the travelling wave is reflected by the wall of the artery, e.g., bifurcate wall, as illustrated in FIG. **25**. Since, generally, the component of the reflected wave is weak relative to the component of the travelling wave, the maximum point of each travelling wave can be estimated as the maximum point of each pulse wave. However, as the arterial sclerosis becomes worse, the component of the reflected wave becomes stronger, and the maximum point of each pulse wave is more influenced by the component of the reflected wave, as shown in FIG. **29**. If the maximum point of the pulse wave is used as a reference point for determining a pulse-wave propagation velocity, then the propagation velocity may largely change depending upon the degree of arterial sclerosis of the subject and/or the shape of the artery wall where the pulse wave is detected. In the pulse-wave propagation velocity measuring apparatus in accordance with the sixth aspect of the invention, however, the reference-point determining means determines, as the reference point, a point of intersection of the maximum-slope line and the base line. This reference point (T_S) is free from the influences of the reflected wave, as illustrated in FIG. **25**. Thus, the reference point does not change or move relative to the pulse wave even if the subject may have a serious arterial sclerosis. Accordingly, the present apparatus measures, with high accuracy, the propagation velocity of the pulse wave.

According to a seventh aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising, a first and a second heartbeat-synchronous-wave sensor which detect, as the pulse wave, a first and a second heartbeat-synchronous wave, respectively, each of which is produced from the artery of the subject in synchronism with a heartbeat of the subject, maximum-slope-line determining means for determining, with respect to at least one of the first and second waves, a maximum-slope line which passes through a maximum-slope point where a heartbeat-synchronous pulse of the one wave takes a maximum slope, such that the maximum-slope line has the maximum slope, maximum-point-line determining means for determining, with respect to the one wave, a maximum-point line which passes through a maximum point where the heartbeat-synchronous pulse of the one wave takes a maximum amplitude, such that the maximum-point line is parallel to a base line which passes through respective minimum points on both sides of the maximum point of the heartbeat-synchronous pulse of the one wave, reference-point determining means for determining a reference point from a point of intersection of the one wave and a line which passes through a point of intersection of the maximum-slope line and the maximum-point line and is perpendicular to the maximum-point line, and propagation-velocity determining means for determining the propagation velocity of the pulse wave based on a time difference between the reference point determined with respect to the heartbeat-synchronous pulse of the one wave and a corresponding heartbeat-synchronous pulse of the other of the first and second waves.

In the pulse-wave propagation velocity measuring apparatus in accordance with the seventh aspect of the invention, the reference-point determining means determines the reference point from a point of intersection of the one wave and a line which passes through a point of intersection of the maximum-slope line and the maximum-point line and is perpendicular to the maximum-point line. The reference point may be determined as being equal to the point of intersection of the one wave and the line or otherwise be determined based on the intersection point. This reference point (T_S) is free from the influences of the reflected wave, as illustrated in FIG. **29**. Thus, the reference point does not change or move relative to the pulse wave even if the subject may have a serious arterial sclerosis. Accordingly, the present apparatus measures, with high accuracy, the propagation velocity of the pulse wave.

According to an eighth aspect of the present invention, there is provided an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising a first and a second heartbeat-synchronous-wave sensor which

detect, as the pulse wave, a first and a second heartbeat-synchronous wave, respectively, each of which is produced from the artery of the subject in synchronism with a heartbeat of the subject, reference-point determining means for determining, with respect to at least one of the first and second waves, a maximum-slope point where a heartbeat-synchronous pulse of the one wave takes a maximum slope, and determining the determined maximum-slope point as a reference point, and propagation-velocity determining means for determining the propagation velocity of the pulse wave based on a time difference between the reference point determined with respect to the heartbeat-synchronous pulse of the one wave and a corresponding heartbeat-synchronous pulse of the other of the first and second waves.

In the pulse-wave propagation velocity measuring apparatus in accordance with the eighth aspect of the invention, the reference-point determining means determines, as the reference point, a maximum-slope point where the pulse wave takes a maximum slope. This reference point (K_{max}) is free from the influences of the reflected wave, as illustrated in FIG. **25** or **29**. Thus, the reference point does not change or move relative to the pulse wave even if the subject may have a serious arterial sclerosis. Accordingly, the present apparatus measures, with high accuracy, the propagation velocity of the pulse wave.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and optional objects, features, and advantages of the present invention will better be understood by reading the following detailed description of the preferred embodiments of the invention when considered in conjunction with the accompanying drawings, in which:

FIG. **1** is a diagrammatic view of a blood pressure (BP) monitor apparatus providing a pulse-wave propagation velocity measuring apparatus as a first embodiment of the present invention;

FIG. **2** is a block diagram for illustrating essential functions of an electronic control device of the apparatus of FIG. **1**;

FIG. **3** is a graph showing a relationship which is determined by the control device of the apparatus of FIG. **1**;

FIG. **4** is a flow chart representing a control program according to which the apparatus of FIG. **1** is controlled;

FIG. **5** is a time chart for illustrating a time difference, TD_{RP}, which is determined by the control device of the apparatus of FIG. **1**;

FIG. **6** is a diagrammatic view corresponding to FIG. **1**, showing a BP measuring apparatus providing another pulse-wave propagation velocity measuring apparatus as a second embodiment of the present invention;

FIG. **7** is a block diagram corresponding to FIG. **2**, for illustrating essential functions of an electronic control device of the apparatus of FIG. **6**;

FIG. **8** is a perspective view of a BP measuring apparatus providing another pulse-wave propagation velocity measuring apparatus as a third embodiment of the present invention;

FIG. **9** is a diagrammatic view corresponding to FIG. **1**, for showing the construction of of the apparatus of FIG. **8**;

FIG. **10** is a block diagram corresponding to FIG. **2**, for illustrating essential functions of an electronic control device of the apparatus of FIG. **8**;

FIG. **11** is a flow chart representing a control program according to which the apparatus of FIG. **8** is controlled;

FIG. **12** is a time chart for illustrating a time difference, TD_{RP}, which is determined by the control device of the apparatus of FIG. **8**;

FIG. **13** is a view of a printed sheet output from a printer of the apparatus of FIG. **8**;

FIG. **14** is a map representing a relationship between degree of arterial sclerosis and modified pulse-wave propagation velocity V_{M2} which is used for determining a degree of arterial sclerosis from a modified pulse-wave propagation velocity V_{M2};

FIG. **15** is a perspective view corresponding to FIG. **8**, showing another BP measuring apparatus providing another pulse-wave propagation velocity measuring apparatus as a fourth embodiment of the present invention;

FIG. **16** is a block diagram corresponding to FIG. **10**, for illustrating essential functions of an electronic control device of the apparatus of FIG. **15**;

FIG. **17** is a time chart for illustrating a time difference, TD_{RP}, which is determined by the control device of the apparatus of FIG. **15**;

FIG. **18** is a graph showing the change of the propagation-velocity values V_{M1} determined by the apparatus of FIG. **15**, with respect to the pressure of an inflatable cuff of the same;

FIG. **19** is a graph showing the change of respective amplitudes of heartbeat-synchronous pulses of a pulse wave transmitted to the cuff, with respect to the cuff pressure;

FIG. **20** is a flow chart representing a control program according to which the apparatus of FIG. **15** is controlled;

FIG. **21** is a flow chart representing an interrupt subroutine according to which the apparatus of FIG. **15** is controlled;

FIG. **22** is a map representing a relationship between degree of arterial sclerosis and modified propagation velocity V_{M3} that is used for determining a degree of arterial sclerosis from a modified propagation velocity V_{M3};

FIG. **23** is a block diagram corresponding to FIG. **10**, for illustrating essential functions of an electronic control device of another BP measuring apparatus providing another propagation-velocity measuring apparatus as a fifth embodiment of the present invention;

FIG. **24** is a time chart for illustrating a time difference TD_{RP} which is determined by the control device of the apparatus of FIG. **23**;

FIG. **25** is an enlarged view for illustrating a reference point, T_S, determined by the control device of the apparatus of FIG. **23**;

FIG. **26** is a flow chart representing a control program according to which the apparatus of FIG. **23** is controlled;

FIG. **27** is a flow chart representing an interrupt subroutine according to which the apparatus of FIG. **23** is controlled;

FIG. **28** is a block diagram corresponding to FIG. **23**, for illustrating essential functions of an electronic control device of another BP measuring apparatus providing another propagation-velocity measuring apparatus as a sixth embodiment of the present invention;

FIG. **29** is an enlarged view corresponding to FIG. **25**, for illustrating a reference point T_S determined by the control device of the apparatus of FIG. **28**;

FIG. **30** is a flow chart representing an interrupt subroutine according to which the apparatus of FIG. **28** is controlled;

FIG. **31** is a block diagram corresponding to FIG. **23**, for illustrating essential functions of an electronic control device of another BP measuring apparatus providing another propagation-velocity measuring apparatus as a seventh embodiment of the present invention; and

FIG. 32 is a flow chart representing an interrupt subroutine according to which the apparatus of FIG. 31 is controlled.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIGS. 1 through 7, there will be described a first embodiment of the present invention which relates to a blood-pressure (BP) monitor apparatus 8 which monitors the blood pressure of a living subject and which also functions as an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of the subject.

In FIG. 1, the BP monitor apparatus 8 includes a cuff 10 which has a belt-like cloth bag and a rubber bag accommodated in the cloth bag and which is adapted to be wound around, e.g., an upper arm 12 of a patient, and a pressure sensor 14, a selector valve 16, and a first air pump 18 each of which is connected to the cuff 10 via piping 20. The selector valve 16 is selectively placed in an inflation position in which the selector valve 16 permits a pressurized air to be supplied from the air pump 18 to the cuff 10, a slow-deflation position in which the selector valve 16 permits the pressurized air to be discharged slowly from the cuff 10, and a quick-deflation position in which the selector valve 16 permits the pressurized air to be discharged quickly from the cuff 10.

The pressure sensor 14 detects an air pressure in the cuff 10, and supplies a pressure signal, SP, representing the detected pressure to each of a static-pressure filter circuit 22 and a pulse-wave filter circuit 24. The static-pressure filter circuit 22 includes a low-pass filter and extracts, from the pressure signal SP, a static component contained in the signal SP, i.e., cuff-pressure signal, SK, representing the static cuff pressure. The cuff-pressure signal SK is supplied to an electronic control device 28 via a first A/D converter 26.

The pulse-wave filter circuit 24 includes a band-pass filter and extracts, from the pressure signal SP, an oscillatory component having frequencies in a predetermined range, i.e., cuff-pulse-wave (CPW) signal, SM_1. The CPW signal SM_1 is supplied to the control device 28 via a second A/D converter 30. The CPW signal SM_1 represents a cuff pulse wave, i.e., oscillatory pressure wave which is produced from a brachial artery (not shown) of the patient in synchronism with the heartbeat of the patient and is propagated to the cuff 10.

The electronic control device 28 is provided by a so-called microcomputer including a central processing unit (CPU) 29, a read only memory (ROM) 31, a random access memory (RAM) 33, and an input and output (I/O) port (not shown). The CPU 29 processes input signals according to the control programs pre-stored in the ROM 31 by utilizing the temporary-storage function of the RAM 33, and supplies drive signals via the I/O port to the selector valve 16 and the first air pump 18.

The BP monitor apparatus 8 further includes a pressure-pulse-wave detecting probe 34. The detecting probe 34 has a container-like housing 36 which is detachably worn, with the help of bands 40, on a body surface 38 of a wrist 42 downstream of an upper arm of the patient different from the upper arm 12 around which the cuff 10 is wound, or wrist downstream of the upper arm 12, such that an opening of the housing 36 is opposed to the body surface 38. A pressure-pulse-wave (PPW) sensor 46 is supported by the housing 36 via a diaphragm 44, such that the PPW sensor 46 is movable relative to the housing 36 and is advanceable through the opening of the housing 36. The housing 36, the diaphragm 44, and the PPW sensor 46 cooperate with one another to define a pressure chamber 48, to which a pressurized air is supplied from a second air pump 50 via a pressure regulator valve 52. Thus, the PPW sensor 46 is pressed against a radial artery 56 via the body surface or skin 38 with a pressing force, P_{HD}, corresponding to the air pressure in the pressure chamber 48.

The PPW sensor 46 includes a number of semiconductor pressure-sensing elements (not shown) which are arranged in a pressing surface 54 of a semiconductor chip formed of, e.g., monocrystalline silicon. The PPW sensor 46 is pressed against the radial artery 56 via the body surface 38 of the wrist 42 to detect a pressure pulse wave (PPW), i.e., oscillatory pressure wave which is produced from the radial artery 56 and is transmitted thereto via the body surface 38, and generates a pressure-pulse-wave (PPW) signal, SM_2, representing the detected PPW. The PPW signal SM_2 is supplied to the control device 28 via a third A/D convertor 58. In the present embodiment, the PPW sensor 46 provides a pulse-wave sensor which detects a pulse wave propagated through an artery of a living subject.

The CPU 29 of the control device 28 operates, according to the control programs pre-stored in the ROM 31, for supplying drive signals to the second air pump 50 and the pressure regulator value 52, and thereby regulating the air pressure in the pressure chamber 48, that is, pressing force P_{HD} of the PPW sensor 46 applied to the radial artery 56 via the body surface 38. Based on respective magnitudes of heartbeat-synchronous pulses of the PPW detected through the PPW sensor 46 while the air pressure of the chamber 48 is changed, the CPU 29 determines an optimum pressing force, P_{HDP}, of the PPW sensor 46, in a known manner, and controls the pressure regulator valve 52 to maintain the optimum pressing force or pressure P_{HDP}, for each continuous BP monitoring operation.

The BP monitor apparatus 8 additionally includes an electrocardiographic-waveform (ECG-waveform) detecting device 60. The ECG-waveform detecting device 60 continuously detects an electrocardiographic (ECG) waveform indicating the time-wise change of electric potential of the cardiac muscle of a living subject, through a plurality of electrodes 62 which are placed at predetermined positions on the subject. The ECG-waveform detecting device 60 may be provided by an electrocardiograph, and the ECG waveform may be an electrocardiogram detected by the electrocardiograph. The ECG-waveform detecting device 60 supplies an electric signal representing the detected ECG waveform, to the electronic control device 28, so that the CPU 29 of the control device 28 processes the electric signal in a manner described later. A display device 32 may, not may not, record the ECG waveform on a recording sheet (not shown).

In an upper and a lower portion of the graph of FIG. 5, a waveform as an example of a pressure pulse wave (PPW) detected by the PPW sensor 46, and an example (electrocardiogram) of an ECG waveform detected by the ECG-waveform detecting device 60 are shown, respectively.

FIG. 2 illustrates essential control functions of the electronic control device 28 of the BP monitor apparatus 8. First, the control device 28 cooperates with the pressure sensor 14, the filter circuits 22, 24, and the A/D converters 26, 30 to function as a BP measuring means 72 which measures a systolic BP value, SBP, and a diastolic BP value, DBP, of the patient, according to a well-known oscillometric method

(e.g., JIS T 1115; JIS is Japanese Industrial Standard), based on the variation of respective amplitudes of heartbeat-synchronous pulses of the cuff pressure wave (i.e., CPW signal SM_1) obtained through the pulse-wave filter circuit **24** while the pressure of the cuff **10** is slowly increased or decreased. The measured BP values are displayed on a screen of a cathode ray tube (CRT) of the display device **32**.

The PPW sensor **46** is preferably pressed on the body surface **38** of the wrist **42** downstream of the upper arm different from the upper arm **12** on which the cuff **10** is worn, and detects a pressure pulse wave (PPW) produced from the radial artery **56** of the wrist **42**. The control device **28** functions as a relationship determining means **74** which determines, in advance, a relationship between BP value (i.e., monitor BP value, MBP) and magnitude, P_M, of pressure pulse wave, based on at least one BP value measured by the BP measuring means **72** and at least one magnitude of the PPW (i.e., PPW signal SM_2) detected by the PPW sensor **46**, for each patient and each BP monitoring operation. This relationship may be one, shown in FIG. **3**, which is defined by the following linear function: $MBP = A \cdot P_M + B$, where A is a constant indicative of the slope of the linear function and B is a constant indicative of an intercept of the linear function. The control device **28** also functions as a monitor BP determining means **76** which successively determines, according to the relationship, a systolic and a diastolic BP value, MBP_{SYS}, MBP_{DIA}, (monitor BP values MBP), based on magnitudes P_M of each heartbeat-synchronous pulse of the pressure pulse wave (i.e., PPW signal SM_2) detected by the PPW sensor **46**, that is, maximum (upper-peak) and minimum (lower-peak) magnitudes, P_{Mmax}, P_{Mmin}, of each heartbeat-synchronous pulse of the pressure pulse wave, and successively outputs the determined monitor BP values MBP to the display device **32** so that the display device **32** successively displays the monitor BP values MBP for each heartbeat-synchronous pulse of the PPW.

The control device **28** also functions as a time-difference determining means **80** which determines a time difference between a predetermined periodic point relating to the ECG waveform of each of heartbeat-synchronous pulses of the electric signal supplied from the ECG-waveform detecting device **60**, and a predetermined periodic point relating to the PPW waveform of a corresponding one of heartbeat-synchronous pulses of the PPW signal SM_2 supplied from the PPW sensor **46**. For example, the determining means **80** determines a time difference, TD_{RP}, between the time of occurrence or detection of an R wave of each pulse of the ECG waveform and the time of occurrence or detection of a maximum (upper-peak) point of a corresponding pulse of the PPW waveform, as shown in FIG. **5**. The maximum or upper-peak point has a maximum magnitude, i.e., maximum electric voltage.

The control device **28** additionally functions as a propagation-velocity determining means **82** which determines a propagation velocity, V_M, (m/sec) of the pressure pulse wave (PPW) which is propagated through the artery of the patient including the radial artery **56**, based on the determined time difference TD_{RP}, according to the following expression (1) pre-stored in the ROM **31**:

$$V_M = L/(TD_{RP} - T_{PEP}) \quad (1)$$

where

L is the length of the artery of the patient from the left ventricle to the position of pressing of the PPW sensor **46** via the aorta, brachial artery, and radial artery **56**; and

T_{PEP} is the pre-ejection period between a Q wave or point of the ECG waveform and a minimum point (i.e., rising point) of the PPW waveform.

The values L, T_{PEP} occurring in the expression (1) are experimentally determined, in advance.

Next, there will be described the operation of the BP monitor apparatus **8** constructed as described above, by reference to the flow chart of FIG. **4**.

First, at Step SA1, the CPU **29** of the control device **28** reads in one heartbeat-synchronous pulse of the ECG waveform detected by the ECG-waveform detecting device **60** and, at Step SA2, the CPU **29** reads in a corresponding heartbeat-synchronous pulse of the PPW waveform detected by the PPW sensor **46**.

Subsequently, at Step SA3, the CPU **29** judges whether the CPU **29** has read in an R wave (or R point) of the heartbeat-synchronous pulse of the ECG waveform. If a negative judgment is made at Step SA3, the control of the CPU **29** goes back to Step SA1. Meanwhile, if a positive judgment is made at Step SA3, the control of the CPU **29** goes to Step SA4 to judge whether the CPU **29** has read in a maximum point of the corresponding heartbeat-synchronous pulse of the PPW waveform.

If a negative judgment is made at Step SA4, the control of the CPU **29** goes back to Step SA1. Meanwhile, if a positive judgment is made at Step SA4, the control of the CPU **29** goes to Step SA5 to determine a time difference TD_{RP} from the R wave of one pulse of the ECG waveform to the maximum point of corresponding pulse of the PPW waveform, as shown in FIG. **5**. Step SA5 corresponds to the time-difference determining means **80**. Step SA5 is followed by Step SA6 to determine a propagation velocity V_M of PPW, based on the time difference TD_{RP} determined at Step SA5, according to the above expression (1). Step SA6 corresponds to the propagation-velocity determining means **82**. The PPW propagation velocity V_M determined at Step SA6 may be used to estimate a degree of arterial sclerosis, a peripheral resistance, or a BP value of the patient according to an algorithm (not shown). The thus estimated BP value may be utilized by the relationship determining means **74** when the means **74** operates for updating the MBP-P_M relationship shown in FIG. **3**.

As is apparent from the foregoing description, in the first embodiment shown in FIGS. **1** to **5**, the CPU **29** of the control device **28** determines, at Step SA5, the time difference TD_{RP} between the predetermined periodic point (R wave) of each heartbeat-synchronous pulse of the ECG waveform and the predetermined periodic point (maximum point) of a corresponding heartbeat-synchronous pulse of the PPW waveform and determines, at Step SA6, the velocity V_M of propagation of the PPW through the artery of the patient, based on the time difference TD_{RP} determined at Step SA5, according to the above expression (1). This propagation velocity V_M is calculated based on the greatest length L of patient's artery including the aorta directly connected to patient's heart. In addition, since the aorta has the greatest diameter, the velocity V_M of propagation of the PPW becomes the lowest when the PPW passes through the aorta. That is, it needs a long time for the PPW to pass through the aorta. Thus, the time difference TD_{RP} is maximized. Therefore, the present BP monitor apparatus **8**, i.e., pulse-wave propagation velocity measuring apparatus **8** measures the propagation velocity V_M of the PPW with higher accuracy than the prior apparatus which measures a propagation velocity of a pulse wave based on a smaller time difference. In addition, the propagation velocity V_M may be relied upon for estimating, with higher accuracy, a degree of arterial sclerosis and/or a BP value of the patient.

In addition, in the first embodiment, the PPW sensor **46** is used for the two purposes, i.e., one for detecting, from the radial artery **56**, the magnitudes P_M of each pulse of the PPW which are used by the monitor BP determining means **76** for successively determining the monitor BP values MBP according to the relationship shown in FIG. **3** and the other for detecting the time of occurrence of the maximum point of each pulse of the PPW which is used by the time-difference determining means **80** for determining the time difference TD_{RP}. Accordingly, the total number of elements or parts of the present apparatus **8** is decreased and the production cost of the same **8** is reduced.

Referring next to FIGS. **6** and **7**, there will be described a second embodiment of the present invention. The second embodiment relates to a blood pressure (BP) measuring apparatus **108** which has basically the same hardware construction as that of the BP monitor apparatus **108** shown in FIGS. **1** and **2** but does not include the PPW detecting probe **34**, the third A/D converter **58**, the second air pump **50**, or the pressure regulator valve **52**. The same reference numerals as used in FIGS. **1** and **2** are used to designate the corresponding elements or parts of the BP measuring apparatus **108** shown in FIGS. **6** and **7**, and the description thereof is omitted.

In the second embodiment, a cuff **10**, a pressure sensor **14**, a pulse-wave filter circuit **24**, etc. cooperate with one another to provide a pulse-wave sensor which detects a pulse wave propagated through an artery of a patient. The pulse-wave sensor **10**, **14**, **24** detects, as the pulse wave, a cuff pulse wave (CPW) which is propagated through a brachial artery of an upper arm **12** of the patient and transmitted to the cuff **10**, and supplies a cuff-pulse-wave (CPW) signal, SM_1, representing the detected CPW waveform, to an electronic control device **28** via a second A/D converter **30**. An example of the CPW waveform is shown in an upper portion of the graph of FIG. **12**.

As shown in FIG. **7**, the control device **28** functions as a time-difference determining means **180** which determines a time difference, TD_{RP}, between an R wave of each heartbeat-synchronous pulse of an ECG waveform detected by an ECG-waveform detecting device **60** and a maximum (upper-peak) point of a corresponding heartbeat-synchronous pulse of the cuff pulse wave (i.e., CPW signal SM_1) detected by the pulse-wave sensor **10**, **14**, **24**. The control device **28** also functions as a propagation-velocity determining means **182** which determines a velocity, V_{MCPW}, of the CPW propagated through patient's artery including the brachial artery, based on the time difference TD_{RP} determined by the time-difference determining means **180**, according to the same expression as the previously-indicated expression (1).

Like the propagation velocity V_M determined by the BP monitor apparatus **8**, the propagation velocity V_{MCPW} is determined based on the great length L of patient's artery including the aorta directly connected to patient's heart. In addition, since the aorta has the great diameter, the velocity V_{MCPW} of propagation of the CPW becomes very low when the CPW passes through the aorta. That is, it needs a long time for the CPW to pass through the aorta. Thus, the time difference TD_{RP} is maximized. Therefore, the present BP measuring apparatus **108**, i.e., pulse-wave propagation velocity measuring apparatus **108** measures the propagation velocity V_{MCPW} of the CPW with higher accuracy than the prior apparatus which measures a propagation velocity of a pulse wave based on a small time difference. In addition, the propagation velocity V_{MCPW} can be relied upon for estimating, with higher accuracy, a degree of arterial sclerosis and/or a BP value of the patient.

In the second embodiment shown in FIGS. **6** and **7**, the pulse-wave sensor, i.e., cuff **10**, pressure sensor **14**, pulse-wave filter circuit **24**, etc. are used for the two purposes, i.e., one for cooperating with a BP measuring means **72** to measure a systolic and a diastolic BP value of the patient and the other for detecting the time of occurrence of the maximum point of each pulse of the CPW which is used by the time-difference determining means **180** for determining the time difference TD_{RP}. Accordingly, the total number of elements or parts of the present apparatus **108** is decreased and the production cost of the same **108** is reduced.

In each of the first and second embodiments, the time difference TD_{RP} is calculated as the difference of the time of occurrence of R wave of each pulse of the ECG waveform and the time of occurrence of maximum point of a corresponding pulse of the PPW or CPW. However, it is possible to determine a time difference, TD, between a Q wave or a S wave of each pulse of the ECG waveform and a maximum or a minimum (lower-peak) point of a corresponding pulse of the PPW or CPW, or between the R wave of each pulse of the ECG waveform and the minimum point of a corresponding pulse of the PPW or CPW. The propagation velocity V_M, V_{MCPW} may be determined based on the time difference TD according to the expression (1).

In the expression (1) employed in each of the first and second embodiments, the pre-ejection period T_{PEP} is defined as the difference of the time of occurrence of Q wave (Q point) of each pulse of the ECG waveform and the time of occurrence of minimum point (rising point) of a corresponding pulse of the PPW or CPW. However, it is possible to define the pre-ejection period T_{PEP} as a time difference between the R wave (R point) or S wave (S point) of each pulse of the ECG waveform and the minimum point of a corresponding pulse of the PPW or CPW, because the Q, R, and S waves of each pulse are very near to one another in time on the ECG waveform. Alternatively, it is possible to define the pre-ejection period T_{PEP} as a time difference between a periodic point relating to each pulse of the ECG waveform and a periodic point relating to a corresponding pulse of an aortic pulse wave, as shown in FIG. **17**. In the last case, too, the value T_{PEP} may be experimentally determined and stored in the ROM **31**, in advance.

In each of the first and second embodiments, the pressure pulse wave (PPW) or the cuff pulse wave (CPW) is detected as the pulse wave of the patient. However, the pulse-wave sensor may be provided by a known photoelectric sensor including a light source which emits a light toward a body surface or skin tissue of a patient, and a light detecting element which detects the light transmitted through, or reflected from, the skin tissue of the patient and produces an electric signal representing, as a photoelectric pulse wave, the time-wise change of intensity of the detected light. The intensity of the light transmitted through, or reflected from, the skin tissue changes as the volume of blood flowing through the artery running in the skin tissue changes in synchronism with the heartbeat of the patient. For example, a so-called pulse oximeter that measures a blood oxygen saturation of a living subject includes a photoelectric sensor including a light source which emits two lights having different wavelengths, respectively, toward skin tissue of the subject and a light detecting element which detects the two lights each transmitted through, or reflected from, the skin tissue. The pulse oximeter determines a blood oxygen saturation of the subject based on the detected lights. In the latter case, the photoelectric sensor is used for the two purposes, i.e., one for detecting the two lights which are utilized for determining the blood oxygen saturation of the patient and

the other for detecting the time of occurrence of a periodic point of each pulse of the photoelectric pulse wave which is utilized for determining a time difference TD based on the time of occurrence of the periodic point. Accordingly, the total number of elements or parts of the pulse oximeter is decreased and the production cost of the same is reduced, like the apparatus **8**, **108**.

Referring next to FIGS. **8** to **14**, there will be described a third embodiment of the present invention which relates to an automatic blood pressure (BP) measuring apparatus **208** which automatically measures a BP value of a living subject and which also functions as an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of the subject.

In FIG. **8**, reference numeral **210** designates a housing of the BP measuring apparatus **208**. The housing **210** includes a tunnel-like, cylindrical hollow portion which provides an arm receiver **214** into which a right arm **212** of the subject is inserted for measurement of his or her BP value or values. Inside the arm receiver **214**, an elongate belt **216** is supported such that the belt **216** takes a generally cylindrical shape. An inflatable cuff **215** which is provided by a flexible cloth bag and a rubber bag accommodated in the cloth bag, is secured to the inner surface of the elongate belt **216**.

In rear of the arm receiver **214**, a first arm rest **217** is provided at a tilt to support the forearm of the right arm **212**. A first electrode **218** of an electrocardiographic-waveform detecting device **270** (FIG. **9**) is provided on an end portion of the arm rest **217** such that the electrode **218** contacts the back of the hand of the right arm **212**. The upper surface of the arm rest **217** has a shape suitable for supporting the entire forearm of the arm **212** such that the muscles between the elbow and the back of the hand are kept relaxed for detecting an accurate electrocardiographic waveform. A second arm rest **219** is provided on the left-hand side of the housing **210**, for supporting a left arm **13** of the subject, and a second electrode **218** is provided on a middle portion of the arm rest **219** such that the second electrode **18** contacts the left arm **13**. The two electrodes **18** cooperate with each other to detect the electrocardiographic waveform from the subject. Like the first arm rest **217**, the upper surface of the second arm rest **219** has a shape suitable for supporting the entire forearm of the left arm **213** such that the muscles between the elbow and the back of the hand are kept relaxed for detecting an accurate electrocardiographic waveform.

The BP measuring apparatus **208** has an operation panel **220** including a START switch **222**, a STOP switch **224**, a printer **226**, and a card insertion slot **228**. The BP measuring apparatus **208** further has a display panel **230** including a SBP display **232**, a DBP display **234**, a HR display **236**, and a date and time display **238**. The abbreviations "SBP", "DBP", and "HR" represent a systolic BP value, a diastolic BP value, and a heart-rate or pulse-rate value, respectively.

FIG. **9** shows the construction of the BP measuring apparatus **208**. In the figure, the inflatable cuff **215** is connected via piping **246** to a pressure sensor **240**, a selector valve **242**, and an air pump **244**. The selector valve **242** is selectively placed in an inflation position in which the selector valve **242** permits a pressurized air to be supplied from the air pump **244** to the cuff **215**, a slow-deflation position in which the selector valve **242** permits the pressurized air to be discharged slowly from the cuff **215**, and a quick-deflation position in which the selector valve **242** permits the pressurized air to be discharged quickly from the cuff **215**. The elongate belt **216** which takes a cylindrical shape in the arm receiver **214** and to which the inflatable cuff **215** is secured, is fixed at one of longitudinal ends thereof to the housing **210** and is connected at the other longitudinal end to a rotatable drum **250** which is driven or rotated by a direct-current (DC) motor **248** via reduction gears. The elongate belt **216** or the inflatable cuff **215** is tightened, and loosened, by the DC motor **248**.

The pressure sensor **214** detects an air pressure in the cuff **215**, and supplies a pressure signal, SP, representing the detected pressure to each of a static-pressure filter circuit **252** and a pulse-wave filter circuit **254**. The static-pressure filter circuit **252** includes a low-pass filter and extracts, from the pressure signal SP, a static component contained in the signal SP, i.e., cuff-pressure signal, SK, representing the static cuff pressure. The cuff-pressure signal SK is supplied to an electronic control device **258** via a first A/D converter **256**.

The pulse-wave filter circuit **254** includes a band-pass filter and extracts, from the pressure signal SP, an oscillatory component having frequencies in a predetermined range, i.e., cuff-pulse-wave (CPW) signal, SM_1. The CPW signal SM_1 is supplied to the control device **258** via a second A/D converter **260**. The CPW signal SM_1 represents a cuff pulse wave, i.e., oscillatory pressure wave which is produced from a brachial artery (not shown) of the subject in synchronism with the heartbeat of the subject and is propagated to the cuff **215**. In the present embodiment, the cuff **215**, pressure sensor **240**, pulse-wave filter circuit **254**, etc. cooperate with one another to provide a pulse-wave sensor which detects a pulse wave propagated through an artery of a living subject.

The electronic control device **258** is provided by a so-called microcomputer including a central processing unit (CPU) **262**, a read only memory (ROM) **264**, a random access memory (RAM) **266**, and an input and output (I/O) port (not shown). The CPU **262** processes input signals according to the control programs pre-stored in the ROM **264** by utilizing the temporary-storage function of the RAM **266**, outputs a drive signal to the printer **226**, and outputs display signals to the displays **232–238**. When a BP measurement is carried out, the CPU **262** supplies a drive signal to the DC motor **248** to wind the cuff **215** around the right arm **212** of the subject being inserted in the arm receiver **214**, subsequently supplies a drive signal to the air pump **244** to inflate the cuff **215** and thereby press the upper arm **212**, and then supplies a drive signal to the selector valve **242** to reduce gradually or slowly the pressure of the cuff **215**, so that the CPU **262** obtains the pulse-wave signal SM_1 and the cuff-pressure signal SK from the pressure sensor **240** via the respective filters **252**, **254** during this cuff-pressure reducing operation, determines a systolic and a diastolic BP value SBP, DBP of the subject according to a known oscillometric BP measuring method based on the obtained signals SM, SK, and supplies display signals to the SBP and DBP displays **232**, **234** to display the determined BP values SBP, DBP, respectively.

In addition, the CPU **262** produces a set of BP data which represents the thus determined BP values SBP, DBP and a date and a time when those BP values are obtained, and stores the set of BP data in a BP-data storing area of a memory device **268**. The memory device **268** accumulatively stores a plurality of sets of BP data produced in a plurality of BP measuring operations. The memory device **268** may be provided by a well-known data storing device such as a magnetic disk, a magnetic tape, a volatile semiconductor memory, or a non-volatile semiconductor memory.

The BP measuring apparatus **208** includes the electrocardiographic-waveform (ECG-waveform) detecting device **270**. The ECG-waveform detecting device **270** con-

tinuously detects an electrocardiographic (ECG) waveform indicating the change of electric potential of the cardiac muscle of the subject, through the pair of electrodes **218** one of which contacts the back of the right hand **212** of the subject and the other of which contacts the left arm **213** of the same. The ECG-waveform detecting device **270** may be provided by an electrocardiograph, and the ECG waveform may be an electrocardiogram detected by the electrocardiograph. The detecting device **270** supplies an electric signal representing the detected ECG waveform, to the control device **258**, so that the CPU **262** of the control device **258** processes the electric signal. The printer **226** may, not may not, print out the ECG waveform on a recording sheet **290** (FIG. **13**).

In an upper and a lower portion of the graph of FIG. **12**, a waveform as an example of a cuff pulse wave (CPW) detected by the pulse-wave sensor **215**, **240**, **254**, and an example (electrocardiogram) of an ECG waveform detected by the ECG-waveform detecting device **270** are shown, respectively.

FIG. **10** illustrates essential control functions of the electronic control device **258** of the BP measuring apparatus **208**. First, the control device **258** functions as a cuff-pressure regulating means **278** which switches the selector valve **242** to the inflation position and drives the air pump **244**, so as to increase quickly the pressure of the cuff **215** up to a predetermined target value, P_1, (e.g., 180 mmHg), subsequently switches the valve **242** to the slow-deflation position so as to decrease slowly the cuff pressure and, after a BP measurement, switches the valve **242** to the quick-deflation position so as to decrease quickly the cuff pressure. In addition, the control device **258** functions as a BP measuring means **280** which cooperates with the cuff **215**, the pressure sensor **240**, etc. to measure a systolic BP value SBP and a diastolic BP value DBP of the subject, according to a well-known oscillometric method, based on the variation of respective amplitudes of heartbeat-synchronous pulses of the cuff pressure wave (i.e., CPW signal SM_1) obtained through the pulse-wave filter circuit **254** while the pressure of the cuff **215** is slowly decreased. The control device **258** additionally functions as a pulse-rate measuring means **281** which cooperates with the cuff **215**, the pressure sensor **240**, etc. to measure a pulse-rate value HR of the subject from the interval of successive two heartbeat-synchronous pulses of the CPW.

The control device **258** also functions as a time-difference determining means **282** which determines a time difference between a predetermined periodic point relating to the ECG waveform of each of heartbeat-synchronous pulses of the electric signal supplied from the ECG-waveform detecting device **270**, and a predetermined periodic point relating to the waveform of a corresponding one of heartbeat-synchronous pulses of the CPW signal SM_1 which is supplied from the pressure sensor **240** when the pressure of the cuff **215** is around the diastolic BP value DBP of the subject. For example, the determining means **282** determines a time difference, TD_{RP}, between the time of occurrence or detection of an R wave of each pulse of the ECG waveform and the time of occurrence or detection of a maximum point (upper-peak point) of a corresponding pulse of the CPW waveform, as shown in FIG. **12**.

The control device **258** additionally functions as a propagation-velocity determining means **284** which determines a propagation velocity, V_{M1}, (m/sec) of the cuff pulse wave (CPW) which is propagated through the artery of the subject including the brachial artery of the right arm **212**, based on the determined time difference TD_{RP}, according to a predetermined expression (2):

$$V_{M1}=L/(TD_{RP}-T_{PEP}) \quad (2)$$

where

L is the length (m) of the artery of the subject from the left ventricle to the position of pressing of the cuff **215** via the aorta and the brachial artery; and

T_{PEP} is the pre-ejection period between a Q wave or point of the ECG waveform and a minimum point (i.e., rising point) of the CPW waveform.

The values L, T_{PEP} occurring in the expression (2) are experimentally determined, in advance. The expression (2) is pre-stored in the ROM **264**.

The control device **258** also functions as a propagation-velocity modifying means **286** which modifies the propagation velocity V_{M1} determined by the propagation-velocity determining means **284**, to a modified propagation velocity, V_{M2}, (m/sec) corresponding to a predetermined BP value, BP_t, and a predetermined pulse rate, HR_t, based on the diastolic BP value DBP measured by the BP measuring means **280** and the pulse rate HR measured by the pulse-rate measuring means **281**, according to a predetermined expression (3):

$$V_{M2}=V_{M1}+A(BP_t-DBP)+E(HR_t-HR) \quad (3)$$

where

$$A=B\cdot V_{M1}+C\cdot DBP+D \quad (4);$$

and

B, C, D, and E are constants.

The coefficient, A, occurring in the expression (3) is determined by a coefficient determining means **287** according to the above expression (4). The coefficient A increases as the propagation velocity V_{M1} increases, and decreases as the diastolic BP value DBP increases. The control device **258** functions as the coefficient determining means **288**. The constant E occurring in the expression (3) and the constants B, C, D occurring in the expression (4) are experimentally pre-determined. The constant B is positive and the constant C is negative.

Hereinafter, there will be described the operation of the BP measuring apparatus **208** constructed as described above, by reference to the flow chart of FIG. **11**.

First, at Step SA**201**, the CPU **262** judges whether a magnetic card **274** has been inserted in a card reader **272** through the insertion slot **228** by a living person. If a negative judgment is made at Step SA**201**, the current cycle of this routine is ended. On the other hand, if a positive judgment is made at Step SA**201**, the control of the CPU **262** goes to Step SA**202** to read identification (ID) data which are magnetically recorded on the magnetic card **274** and which identify the person who carries the card **274**.

Step SA**202** is followed by Step SA**203** to judge whether the ID data read from the magnetic card **274** are identical with ID data registered in an ID-data storing area of the memory device **268**. The ID-data storing area has the memory capacity to store a number of sets of ID data corresponding to a number of magnetic cards **274**, i.e., a number of living persons. If a negative judgment is made at Step SA**203**, the control of the CPU **262** goes to Step SA**222** to eject the card **274** from the card reader **272** through the slot **228**. On the other hand, if a positive judgment is made at Step SA**203**, i.e., the ID data read from the card **274** are identical with registered ID data, the control of the CPU **262** goes to Step SA**204** to judge whether the START switch **222** has been operated to start a blood pressure (BP) measurement.

If the judgment made at Step SA204 is negative, Step SA204 is repeated until a positive judgment is made. Meanwhile, if a positive judgment is made at Step SA204, the control of the CPU 262 goes to Step SA205 to switch the selector valve 242 to the inflation position thereof and drive the air pump 244 so as to increase the pressure, P, of the cuff 215 up to a predetermined target value (e.g., 180 mmHg) and subsequently stop the air pump 244. Step SA205 is followed by Step SA206 to switch the valve 242 to the slow-deflation position so as to start the slow deflation of the cuff, i.e., slow decreasing of the cuff pressure P. Steps SA205 and SA206 correspond to the cuff-pressure regulating means 278.

Step SA206 is followed by Step SA207 to judge whether the CPU 262 has read in one heartbeat-synchronous pulse of the CPW signal SM_1. Step SA207 is repeated until a positive judgment is made. Meanwhile, if a positive judgment is made at Step SA207, the control of the CPU 262 goes to Step SA208 to effect a BP measuring subroutine in which a systolic, a diastolic, and a mean BP value SBP_1, DBP_1, MBP_1, and a pulse-rate value HR_1, of the person are measured. More specifically described, the BP values SBP_1, DBP_1, MBP_1 of the person are determined based on the signals SM_1, SK obtained during the slow decreasing of the cuff pressure P, in the known oscillometric method. The systolic and diastolic BP values SBP_1, DBP_1 are determined based on the variation of respective magnitudes of heartbeat-synchronous pulses of the CPW signal SM_1 obtained during the slow cuff-pressure decreasing. The mean BP value MBP_1 is determined as being equal to the cuff pressure at the time of occurrence or detection of a heartbeat-synchronous pulse having the greatest or maximum amplitude. The pulse-rate value HR_1 is determined from the time interval between the respective times of detection of two successive heartbeat-synchronous pulses of the CPW signal SM_1. Step SA208 corresponds to the BP measuring means 280.

Step SA208 is followed by Step SA209 to judge whether a systolic BP value SBP_1 has been determined at Step SA208. If a negative judgment is made at Step SA209, the control of the CPU 262 goes back to Step SA207. On the other hand, if a positive judgment is made at Step SA209, the control of the CPU 262 goes to Step SA210 to judge whether a diastolic BP value DBP_1 has been determined at Step SA208. If a negative judgment is made at Step SA210, the control of the CPU 262 goes back to Step SA207. Meanwhile, if a positive judgment is made at Step SA210, the control of the CPU 262 goes to Step SA211 to store a set of BP data which represents the BP and pulse-rate values SBP_1, DBP_1, MBP_1, HR_1 determined at Step SA208 and the date and time of measurement of those values, in association with the ID data for the person, in the BP-data storing area of the memory device 268. In addition, at Step SA211, the determined BP and pulse-rate values SBP_1, DBP_1, HR_1 are displayed on the SBP, DBP, and HR displays 232, 234, 236, respectively.

Subsequently, at Step SA212, the CPU 262 of the control device 258 reads in one heartbeat-synchronous pulse of the ECG waveform detected by the ECG-waveform detecting device 270 and, at Step SA213, the CPU 262 reads in a corresponding heartbeat-synchronous pulse of the CPW waveform detected by the pressure sensor 240. Next, at Step SA214, the CPU 262 judges whether the CPU 262 has read in an R wave (or R point) of the heartbeat-synchronous pulse of the ECG waveform. If a negative judgment is made at Step SA214, the control of the CPU 262 goes back to Step SA212. Meanwhile, if a positive judgment is made at Step SA214, the control of the CPU 262 goes to Step SA215 to judge whether the CPU 262 has read in a maximum point of the corresponding heartbeat-synchronous pulse of the CPW waveform.

If a negative judgment is made at Step SA215, the control of the CPU 262 goes back to Step SA212. Meanwhile, if a positive judgment is made at Step SA215, the control of the CPU 262 goes to Step SA216 to switch the selector valve 242 to the quick-deflation position so as to start the quick decreasing of the cuff pressure P. Step SA216 corresponds to the cuff-pressure regulating means 278. Step SA216 is followed by Step SA217 to determine a time difference TD_{RP} between the R wave of one pulse of the ECG waveform and the maximum point of corresponding pulse of the CPW waveform, as shown in FIG. 12. Step SA217 corresponds to the time-difference determining means 282. Step SA217 is followed by Step SA218 to determine a propagation velocity V_{M1} of CPW, based on the time difference TD_{RP} determined at Step SA217, according to the expression (2). Step SA218 corresponds to the propagation-velocity determining means 284.

Subsequently, at Step SA219, the CPU 262 determines a coefficient A occurring in the expression (3), based on the propagation velocity V_{M1} determined at Step SA218 and the diastolic BP value DBP_1 determined at Step SA208, according to the expression (4). Step SA219 corresponds to the coefficient determining means 288. Step SA219 is followed by Step SA220 to modify the propagation velocity V_{M1} determined at Step SA218 to a modified, i.e., normalized propagation velocity V_{M2} corresponding to the predetermined BP value BP_t and the predetermined pulse rate HR_t, based on the diastolic BP value DBP_1 and the pulse rate HR_1 measured at Step SA208, according to the expression (3). Step SA220 corresponds to the propagation-velocity modifying means 286.

In addition, at Step SA220, the CPU 262 of the control device 258 determines a degree of arterial sclerosis, DAS, of the person based on the modified propagation velocity V_{M2} according to a predetermined relationship between degree of arterial sclerosis and modified propagation velocity V_{M2}, shown in FIG. 14, and store data indicative of the determined degree of arterial sclerosis DAS, together with the set of BP data stored at Step SA211, in the memory device 268. The relationship shown in FIG. 14 is experimentally predetermined and is pre-stored in the ROM 264. As the degree of arterial sclerosis increases, the flexibility or softness of the arteries of the person decreases.

Step SA220 is followed by Step SA221 to command the printer 226 to output or record, on a recording sheet 290, the sets of BP data stored in the BP-data storing area of the memory device 268, as shown in FIG. 13. More specifically described, in an upper, left-hand portion of the sheet 290, the printer 226 records a name 292 of the person identified by the ID data or card 274. The name 292 of the person is represented by the registered ID data identifying the person. Bellow the name 292, the printer 226 records (a) a data list 294 showing the dates and times of measurements, the measured BP and pulse-rate values SBP, DBP, HR, and the determined degrees of arterial sclerosis DAS which have accumulatively been stored in the memory device 268; and (b) a graphic representation 296 of the sets of BP data and the sets of arterial-sclerosis data accumulatively stored in the memory device 268. The graphic representation 296 shows, along a common axis of abscissa 298 indicative of time, a series of vertical bars each of which has a top and a bottom horizontal segment which represent a systolic and a diastolic BP value SBP, DBP, respectively, a series of white triangles each of which represents a pulse-rate value HR, and a series of black circles each of which represents a degree of arterial sclerosis DAS, in the order of measurement or determination. Step SA221 is followed by Step SA222 to eject the magnetic card 274 from the card reader 272.

As is apparent from the foregoing description, in the third embodiment shown in FIGS. **8** to **14**, the CPU **262** of the control device **258** determines, at Step SA**217**, the time difference TD_{RP} between the predetermined periodic point (R wave) of each heartbeat-synchronous pulse of the ECG waveform and the predetermined periodic point (maximum point) of a corresponding heartbeat-synchronous pulse of the CPW waveform and determines, at Step SA**218**, the velocity V_{M1} of propagation of the CPW through the artery of the subject, based on the time difference TD_{RP} determined at Step SA**217**, according to the expression (2). In addition, at Step SA**220**, the CPU **262** modifies the propagation velocity V_{M1} determined at Step SA**218** to the modified propagation velocity V_{M2} corresponding to the predetermined BP value BP_r and the predetermined pulse rate HR_r, based on the diastolic BP value DBP_1 and the pulse rate HR_1 measured at Step SA**208**, according to the expression (3). Thus, even if the BP or pulse-rate values obtained from a living person in a plurality of measurements may differ from each other, the present apparatus **208** modifies each measured propagation velocity V_{M1} to a modified propagation velocity V_{M2} corresponding to the predetermined BP and pulse-rate values. Therefore, a series of modified propagation velocities V_{M2} can directly be used as an index indicative of a time-wise change of the degree of arterial sclerosis of the person.

In addition, since the modified propagation velocity V_{M2} corresponds to both the predetermined BP and pulse-rate values BP_r, HR_r, the value V_{M2} is more accurate than a value, $V_{M2'}$, which corresponds to only the predetermined BP value BP_r and is obtained according to the following expression (5):

$$V_{M2}=V_{M1}+A(BP_r-DBP) \quad (5)$$

The value V_{M2} is free from the influences or fluctuations due to the change of pulse rate HR of the person, whereas the value $V_{M2'}$ is subject to those fluctuations.

In the present apparatus **208**, the modified propagation velocity V_{M2} is calculated using the coefficient A which is calculated, at Step SA**219**, based on the propagation velocity V_{M1} determined at Step SA**218** and the diastolic BP value DBP_1 determined at Step SA**208**, according to the expression (4). Owing to the coefficient A, the value V_{M2} is free from the influences or fluctuations due to the differences of individual persons with respect to the degree of arterial sclerosis. Therefore, the values V_{M2} obtained from different persons can be compared with each other for comparing the respective degrees of arterial sclerosis of those persons.

In the present apparatus **208**, the propagation velocity V_{M1} or the modified propagation velocity V_{M2} is obtained concurrently when the BP values SBP_1, DBP_1, MBP_1 are measured, and a series of values V_{M2} can directly be used as an index indicative of a time-wise change of the degree of arterial sclerosis DAS. Thus, the person is provided with more physical information, with which he or she can think about his or her physical condition from more points of view. In addition, since the present apparatus **208** outputs the graphical representation **296** including the time-wise trend of DAS values, the person can easily and accurately see the time-wise change of the same.

In a conventional method, the pulse-wave propagation velocity is measured using a pulse-wave sensor which is applied, with the help of an exclusive assisting member, to a carotid artery or a femoral artery of a living subject. Thus, only the skilled person can fix the best condition under which the pulse-wave sensor is pressed against the artery via the skin, and it is considerably difficult for the subject himself or herself to measure his or her own propagation velocity. On the other hand, the present apparatus **208** can easily be operated by the subject without any skill to do so.

In the third embodiment, the time difference TD_{RP} is determined, at Step SA**216**, based on the cuff pulse wave (i.e., CPW signal SM_1) detected through the pressure sensor **240** when the pressure of the cuff **215** is changed around the diastolic BP value DBP_1 of the person. Generally, in a time duration in which the cuff pressure is higher than the mean BP value MBP_1, the time difference TD_{RP} increases as the cuff pressure decreases, as shown in FIG. **18**. However, when the cuff pressure is around the diastolic BP value DBP_1, the time difference TD_{RP} is not influenced by the change of the cuff pressure. Thus, the present apparatus **208** calculates a very accurate time difference TD_{RP} and, accordingly, calculates a very accurate propagation velocity V_{M1}, V_{M2}.

In the third embodiment, the arm receiver **214** is adapted to receive the right arm **212** of the subject. However, it is possible to modify the arm receiver **214** to receive the left arm **213**. In the latter case, the receiver **214** and the first arm rest **217** are provided on a left half portion of the housing **210**, and the second arm rest **219** is provided on the right-hand side of the housing **210**. Although the first arm rest **217** is provided at a tilt, the rest **217** may be provided to extend in a horizontal direction. The second arm rest **219** may be provided at a tilt. In any case, the arm rests **217**, **219** are required to support the arms **212**, **213** such that the muscles of the arms **212**, **213** are kept relaxed.

Although, in the third embodiment, the first electrode **18** is provided on the free-end portion of the first arm rest **217** and the second electrode **18** is provided on the middle portion of the second arm rest **219**, it is possible to dispose the electrodes **18** at different positions depending upon the shapes and positions of the rests **217**, **219**. In any case, the electrodes **18** are required to detect a stable or accurate ECG waveform from the arms **212**, **213** of the person.

While in the third embodiment the degree of arterial sclerosis DAS is determined from the modified propagation velocity V_{M2} corresponding to both the predetermined BP value BP_r and the predetermined pulse rate HR_r, it is possible that the value DAS be determined from the modified propagation velocity $V_{M2'}$ which corresponds to only the predetermined BP value BP_r and is calculated according to the expression (5). Since the pulse rate HR less influences the propagation velocity V_{M1} than the blood pressure BP, the modified propagation velocity $V_{M2'}$ can be relied upon to determine the value DAS.

Although the BP measuring apparatus **208** employs the automatic winding device **216**, **248**, **250** which automatically winds the cuff **215** around the upper arm **212** of the person, the apparatus **208** may employ a different cuff which can be wound around the right arm **212** with the hand of the left arm **213** of the person.

The coefficient A calculated according to the expression (4) may be replaced by a coefficient, A', calculated according to the following expression (6):

$$A'=(B'\cdot V_{M1})/(C'\cdot DBP)+D' \quad (6)$$

The coefficient A' is variable in direct proportion to the propagation velocity V_{M1} determined at Step SA**218** and in reciprocal proportion to the diastolic BP value DBP_1 determined at Step SA**208**.

In the third apparatus **208**, the printer **226** records, on the recording sheet **290**, the data list **294** and the graphical representation **296** each of which contains the DAS (degree

of arterial sclerosis) values. However, the printer **206** may be modified to record, in place of the DAS values, the modified propagation-velocity values V_{M2} in one or each of the list **294** and the graph **296**.

Although the third apparatus **208** determines BP values based on the variation of respective amplitudes of heartbeat-synchronous pulses of the CPW obtained during the slow decreasing of the cuff pressure, it is possible to modify the apparatus **208** to determine BP values based on the variation of respective amplitudes of heartbeat-synchronous pulses of a CPW obtained during a low-rate increasing of the cuff pressure.

While the third apparatus **208** measures BP values according to an oscillometric method, the principle of the present invention may be applied to a BP measuring apparatus which measures BP values according to a well-known Korotkoff-sound method.

Referring next to FIGS. **15** to **22**, there will described a fourth embodiment of the present invention which relates to an automatic BP measuring apparatus **308** which automatically measures a BP value of a living subject and which also functions as an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of the subject.

The BP measuring apparatus **308** as the fourth embodiment has substantially the same hardware construction as the BP measuring apparatus **208** as the third embodiment shown in FIGS. **8** and **9**. The same reference numerals as used in FIGS. **8** and **9** are used to designate the corresponding elements or parts of the fourth apparatus **308**, and the description thereof is omitted from the following description.

However, the fourth apparatus **308** has a first and a second electrode **318**, **318** and a first and a second arm rest **317**, **318** which are different from those **218**, **218**, **217**, **219** of the third apparatus **208**.

In addition, as shown in FIG. **16**, an electronic control device **258** of the fourth apparatus **308** has different control functions **380**, **382**, **384**, **386**, **387**, **388**, **389**, **393** (**390**, **392**), **394** in addition to the same control function **278** as that **278** of the control device **258** of the third apparatus **208** shown in FIG. **10**. The fourth apparatus **308** is controlled according to the control program represented by the flow charts of FIGS. **20** and **21**, in place of the control program represented by the flow chart of FIG. **11**. However, the main routine represented by the flow chart of FIG. **20** has the same steps, Steps SA**201** through SA**207**, SA**216**, SA**221**, and SA**222**, as those SA**201**–SA**207**, SA**216**, SA**221**, SA**222** of the control program represented by the flow chart of FIG. **11**. The description of those steps is omitted from the following description.

The following description relates to only the differences of the fourth apparatus **308** from the third apparatus **208**.

In the fourth apparatus **308**, a first electrode **318** of an ECG-waveform detecting device **270** is provided on an end portion of a first arm rest **317** such that the first electrode **318** contacts the back of the wrist of a right arm **212** of a living subject. The upper surface of the arm rest **317** has a shape suitable for supporting the entire portion of the right arm **212** between the elbow and the wrist such that the muscles between the elbow and the wrist are kept relaxed for detecting an accurate ECG waveform from the subject. A second arm rest **319** is provided on the left-hand side of a housing **210**, for supporting a left arm **213** of the subject, and a second electrode **318** is provided on an end portion of the arm rest **319** such that the second electrode **318** contacts the wrist of the left arm **213**. The two electrodes **318** cooperate with each other to detect the electrocardiographic waveform from the subject. Like the first arm rest **317**, the upper surface of the second arm rest **319** has a shape suitable for supporting the entire portion of the left arm **213** between the elbow and the wrist such that the muscles between the elbow and the wrist are kept relaxed for detecting an accurate ECG waveform.

The ECG-wave detecting device **270** detects the ECG waveform of the subject through the two electrodes **318** held in contact with the respective wrists of the right and left arms **212**, **213** of the subject. An example of the ECG waveform detected through the electrodes **318** is shown in an upper portion of the graph of FIG. **17**. An example of a cuff pulse wave (CPW) waveform detected through a cuff **215** and a pressure sensor **240** is shown in a lower portion of the graph of FIG. **17**.

FIG. **16** illustrates essential control functions of the control device **258** of the fourth apparatus **308**. The control device **258** functions as a cuff-pressure regulating means **278** which is the same as the cuff-pressure regulating means **278** of the third apparatus **208** shown in FIG. **10**.

The control device **258** of the fourth apparatus **308** functions as a BP measuring means **380** which is basically the same as the BP measuring means **280** of the third apparatus **208** shown in FIG. **10**. However, one or more heartbeat-synchronous pulses of the CPW based on which the BP measuring means **380** measures BP values SBP, DBP, MBP of the subject, is or are corrected by a pulse correcting means **393** described later, as illustrated in FIG. **19**.

The control device **258** of the third apparatus **308** additionally functions as a time-difference determining means **382** which successively determines a time difference between a predetermined periodic point relating to the ECG waveform of each of heartbeat-synchronous pulses of an electric signal supplied from the ECG-waveform detecting device **270**, and a predetermined periodic point relating to the CPW waveform of a corresponding one of heartbeat-synchronous pulses of a CPW signal SM_1 which is supplied from the pressure sensor **240** when the pressure of the cuff **215** is changed around a diastolic BP value DBP of the subject. In the present embodiment, the determining means **382** determines a time difference, TD_{RP}, between the time of occurrence or detection of an R wave of each pulse of the ECG waveform and the time of occurrence or detection of a minimum point (lower-peak point) of a corresponding pulse of the CPW waveform, as shown in FIG. **17**. In the present embodiment, the predetermined periodic point relating to the CPW waveform is defined as a rising point of each heartbeat-synchronous pulse, and the rising point may be defined as the minimum point, i.e., lower-peak point of each pulse. However, the rising point may otherwise be defined as a point greater than a minimum point by a predetermined magnitude, or a point where the slope or differential of the CPW waveform takes a maximum value. In short, the rising point may be defined as any periodic point other than a maximum (i.e. upper-peak) point of each pulse that is used by the time-difference determining means **282** of the third apparatus **208**.

The control device **258** of the fourth apparatus **308** functions as a temporary-propagation-velocity determining means **384** which determines a temporary propagation velocity V_{M1} (m/sec) of CPW, based on each of the successively determined time-difference values TD_{RP}, according to the same expression as the previously-indicated expression (2): $V_{M1}=L/(TD_{RP}-T_{PEP})$. However, in the present embodiment, a pre-ejection period T_{PEP} is defined as the time interval between the R wave of each pulse of the ECG

waveform and the minimum point of a corresponding pulse of an aortic pulse wave produced from the aorta of the subject. This value T_{PEP} is experimentally pre-determined and pre-stored in the ROM **264**.

In addition, the control device **258** of the fourth apparatus **308** functions as a stability judging means **386** which judges whether the propagation-velocity values V_{M1} successively determined by the propagation-velocity determining means **384** have become stable, e.g., whether the amount or rate of change of the propagation-velocity values V_{M1} has become not higher than a first or a second reference value, e.g., 0.1 m/sec or 3%, respectively; and as a proper-propagation-velocity determining means **387** which determines, as a proper propagation velocity, V_{PM1}, of the subject, an average of a predetermined number of the propagation-velocity values V_{M1} (corresponding to the level portion of a curve indicated at solid line in FIG. **18**) which are determined by the propagation-velocity determining means **284** and are not higher than the first or second reference value. This number is counted by the CPU **262** from the first value V_{M1} that first becomes not higher than the first or second reference value. However, the first value V_{M1} itself may be determined as the proper propagation-velocity value V_{PM1}.

The control device **258** of the fourth apparatus **308** also functions as a propagation-velocity modifying means **389** which modifies the proper propagation velocity V_{PM1} determined by the proper-propagation-velocity determining means **387**, to a modified (i.e., normalized) proper propagation velocity V_{M3} (m/sec) corresponding to a predetermined (i.e., normalized) BP value BP_t (e.g., 80 mmHg) and a predetermined pulse rate HR_t (e.g., 70 BPM (beats per minute)), based on the diastolic BP value DBP measured by the BP measuring means **380** and a measured pulse rate HR, according to the following expression (7) similar to the expression (3):

$$V_{M3}=V_{PM1}+A(BP_t-DBP)+E(HR_t-HR) \quad (7)$$

where

$$A=B\cdot V_{PM1}+C\cdot DBP+D \quad (8);$$

and

B, C, D, and E are constants.

The coefficient A occurring in the expression (7) is determined by a coefficient determining means **388** according to the above expression (8). The coefficient A increases as the propagation velocity V_{PM1} increases, and decreases as the diastolic BP value DBP increases. The control device **258** of the fourth apparatus **308** functions as the coefficient determining means **388**. The constant E occurring in the expression (7) and the constants, B, C, D, occurring in the expression (8) are experimentally determined in advance. The constant B is positive and the constant C is negative.

In addition, the control device **258** of the fourth apparatus **308** functions as a propagation-velocity estimating means **390** which estimates, as the next propagation-velocity value, $V_{M1'}$ (corresponding to a white triangle shown in FIG. **18**) which will next be determined by the propagation-velocity determining means **384**, an average of a predetermined number of the propagation-velocity values V_{M1} (corresponding to the level portion of the curve indicated at solid line in FIG. **18**) which are determined by the propagation-velocity determining means **384** and are not higher than the first or second reference value, according to a predetermined expression (9):

$$V_{M1}=[(V_{M1})_{i-n}+\ldots+(V_{M1})_{i-1}+(V_{M1})_i]/(n+1)$$

This number is counted by the CPU **262** from the first value V_{M1} that first becomes not higher than the first or second reference value. However, the last value V_{M1} itself may be estimated as the next propagation-velocity value $V_{M1'}$.

Moreover, the control device **258** of the fourth apparatus **308** functions as a correcting means **392** which calculates a difference, ΔV_{M1}, of the next propagation-velocity value $V_{M1'}$ estimated by the estimating means **390** and the next, actual propagation-velocity value V_{M1} (corresponding to a black circle shown in FIG. **18**) which is actually determined by the determining means **384**, according to a predetermined expression (10):

$$\Delta V_{M1}=V_{M1}-V_{M1} \quad (10)$$

The correcting means **392** additionally calculates a first correction value, X_1, according to a predetermined expression (11):

$$X_1=F\cdot(\Delta V_{M1}) \quad (11)$$

where F is a positive constant which is experimentally determined in advance.

The first correction value X_1, indicated at broken line in FIG. **19**, is added to the amplitude, indicated at solid line, of one heartbeat-synchronous pulse of CPW from which the current propagation-velocity value V_{M1} (i.e., above-indicated next value V_{M1}) is determined.

Alternatively, the correcting means **392** calculates a second correction value, X_2, according to a predetermined expression (12):

$$X_2=-G\cdot(\Delta V_{M1}) \quad (12)$$

where G is a positive constant which is experimentally determined in advance.

The second correction value X_2 is added to the cuff-pressure value at the time of occurrence or detection of one heartbeat-synchronous pulse of CPW from which the current propagation-velocity value V_{M1} (i.e., above-indicated next value V_{M1}) is determined, so that the amplitude, indicated at solid line, of the pulse is moved to an amplitude indicated at broken line. The propagation-velocity estimating means **390** and the correcting means **392** cooperate with each another to provide a pulse correcting means **393** which correct the pulses of CPW, as needed. The corrected CPW pulses are utilized by the BP measuring means **380** for measuring the BP values of the subject.

Furthermore, the control device **258** of the fourth apparatus **308** functions as a BP-measurement terminating means **394** which terminates the current BP measuring operation of the BP measuring means **380**, if the current propagation-velocity value V_{M1} determined by the determining means **384** does not fall within a permission range indicated at one-dot chain line in FIG. **18**. This permission range is experimentally pre-determined for all the values that can be taken by the cuff pressure, and pre-stored in the ROM **264**. However, it is possible to determine the permission range based on the propagation-velocity values V_{M1} determined by the determining means **384** prior to the current value V_{M1}, for example, the estimated value $V_{M1'}$. In either case, the upper and lower limits of each permission range may be determined by a statistical technique such that it is almost impossible for a corresponding value V_{M1} to fall outside the range.

Hereinafter, there will be described the operation of the BP measuring apparatus **308** constructed as described above, by reference to the flow charts of FIGS. **20** and **21**.

Steps SA**201** to SA**207** of FIG. **20** are the same as those SA**201** to SA**207** of FIG. **11**.

At Step SA**308**, a CPU **262** of the control device **258** determines a systolic, a diastolic, and a mean BP value SBP_1, DBP_1, MBP_1 and a pulse-rate value HR in the same manner as that employed at Step SA**208** of FIG. **11**. However, one or more heartbeat-synchronous pulses of the CPW that is utilized by by the BP measuring means **380** may be corrected at Step SB**313** described later.

Step SA**308** is followed by Step SA**309** to judge whether a systolic BP value SBP_1 and a diastolic BP value DBP_1 have been determined at Step SA**308**. If a negative judgment is made at Step SA**309**, the control of the CPU **262** of the control device **258** of the fourth apparatus **308** goes back to Step SA**207**. On the other hand, if a positive judgment is made at Step SA**309**, the control of the CPU **262** goes to Step SA**310** to store a set of BP data which represents the BP and pulse-rate values SBP_1, DBP_1, MBP_1, HR_1 determined at Step SA**308** and the date and time of measurement of those values, in association with ID data identifying a magnetic card **274**, i.e., a living person carrying the card **274**, in a BP-data storing area of a memory device **268**. In addition, at Step SA**310**, the determined BP and pulse-rate values SBP_1, DBP_1, HR_1 are displayed on a SBP, a DBP, and a HR display **232**, **234**, **236**, respectively.

Step SA**310** is followed by Step SA**311** to determine, as a proper propagation velocity V_{PM1} of the subject, an average of the first, second, and third temporary propagation-velocity values V_{M1} which have first, second, and third become not higher than the first or second reference value and have been stored in a second memory area (described later) of a RAM **266** of the control device **258** of the fourth apparatus **308**. Step SA**311** corresponds to the proper-propagation-velocity determining means **387**.

Step SA**311** is followed by Step SA**312** to determine a coefficient A occurring in the expression (7), based on the proper propagation-velocity value V_{PM1} determined at Step SA**311** and the diastolic BP value DBP_1 determined at Step SA**308**, according to the expression (8). Step SA**312** corresponds to the coefficient determining means **388**. Step SA**312** is followed by Step SA**313** to modify the proper propagation velocity V_{PM1} determined at Step SA**311** to a modified, i.e., normalized proper propagation velocity V_{M3} corresponding to the predetermined BP value BP_t and the predetermined pulse rate HR_t, based on the diastolic BP value DBP_1 and the pulse rate HR_1 measured at Step SA**308**, according to the expression (7). Step SA**313** corresponds to the propagation-velocity modifying means **389**.

In addition, at Step SA**313**, the CPU **262** of the control device **258** of the fourth apparatus **308** determines a degree of arterial sclerosis DAS of the person based on the modified propagation velocity V_{M3} according to a predetermined relationship between degree of arterial sclerosis and modified propagation velocity V_{M3}, shown in FIG. **22**, and store data indicative of the determined degree of arterial sclerosis DAS, together with the set of BP data stored at Step SA**310**, in the memory device **268**. The relationship shown in FIG. **22** is experimentally predetermined and is pre-stored in the ROM **264**. As the degree of arterial sclerosis increases, the flexibility or softness of the arteries of the person decreases.

Subsequently, at Step SA**216**, a selector valve **242** is switched to a quick-deflation position thereof so as to start the quick decreasing of the cuff pressure P. Step SA**216** corresponds to the cuff-pressure regulating means **278**. Step SA**216** is followed by Steps SA**221** and SA**222** which are the same as Steps SA**221**, SA**222** of FIG. **11**.

The flow chart of FIG. **21** represents an interrupt subroutine which is implemented when the CPU **262** reads in the R wave of each heartbeat-synchronous pulse of the ECG waveform (i.e., electric signal) detected by the ECG-waveform detecting device **270**, while the main routine represented by the flow chart of FIG. **20** is implemented. At Step SB**301**, the CPU **262** of the control device **258** of the fourth apparatus **308** specifies the time when the R wave of one pulse is detected or read in, and stores the specified time in the RAM **266**. Step SB**301** is followed by Step SB**302** to judge whether the CPU **262** has read in the lower-peak point of a corresponding pulse of the CPW waveform (i.e., CPW signal SM_1) detected through the pressure sensor **240**. If a negative judgment is made at Step SB**302**, Step SB**302** is repeated until a positive judgment is made. Meanwhile, if a positive judgment is made at Step SB**302**, the control of the CPU **262** goes to Step SB**303** to specify the time when the lower-peak point of the corresponding pulse is detected or read in, and stores the specified time in the RAM **266**. Step SB**303** is followed by Step SB**304**.

At Step SB**304**, the CPU **262** determines a time difference TD_{RP} between the time of detection of the R wave of the ECG waveform and the time of detection of the lower-peak point of the CPW waveform, as illustrated in FIG. **17**. Step SB**304** corresponds to the time-difference determining means **382**. Step SB**304** is followed by Step SB**305** to determine a temporary propagation velocity V_{M1} of CPW, based on the time difference TD_{RP} determined at Step SB**304**, according to the expression (2). The determined value V_{M1} is stored in a first memory area of the RAM **66**. Step SB**305** corresponds to the temporary-propagation-velocity determining means **384**.

Subsequently, at Step SB**306**, the CPU **262** judges whether the current propagation-velocity value V_{M1} determined at Step SB**305** falls within a predetermined permission range. This permission range has the upper and lower limits indicated at one-dot chain line in FIG. **18**. If a negative judgment is made at Step SB**306**, the control of the CPU **262** goes to Step SB**307** to switch the selector valve **242** to the quick-deflation position so as to start the quick deflation of the cuff **215**. Thus, the current BP measurement is terminated. Steps SB**306** and SB**307** correspond to the BP-measurement terminating means **394**. Step SB**307** is followed by Step SB**308** to control a printer **226** to print, on a recording sheet **290**, a message that another BP measurement should be tried and output the printed sheet. Then, at Step SB**309**, a magnetic card **274** is ejected through a card insertion slot **228**.

On the other hand, if a positive judgment is made at Step SB**306**, the control of the CPU **262** goes to Step SB**310** to judge whether the amount or rate of change of the current propagation-velocity value V_{M1} determined in the current control cycle from the preceding value V_{M1} determined in the preceding control cycle and stored in the first memory area of the RAM **266** is not greater than 0.1 m/sec or 3%. If a positive judgment is made at Step SB**310**, the control of the CPU **262** goes to Step SB**311** to store temporarily the current propagation-velocity value V_{M1} determined at Step SB**305** in the current control cycle, in the second memory area of the RAM **266**. Step SB**310** corresponds to the stability judging means **386**.

Step SB**311** is followed by Step SB**312** to estimate a next propagation-velocity value $V_{M1'}$ indicated at the white triangle in FIG. **18**, based on the propagation-velocity values V_{M1} stored in the second memory area of the RAM **266**,

according to the expression (9). The estimated next value $V_{M1'}$ is temporarily stored in a third memory area of the RAM **266**. Step SB**312** corresponds to the propagation-velocity estimating means **390**.

On the other hand, if a negative judgment is made at Step SB**310**, the control of the CPU **262** goes to Step SB**313** to determine a difference ΔV_{M1} between the last estimated next propagation-velocity value $V_{M1'}$ (indicated at the white triangle) that has last stored in the third memory area of the RAM **266**, and the current propagation-velocity value V_{M1} (indicated at the black circle) which has been determined at Step SB**305** in the current control cycle, according to the expression (10), as illustrated in FIG. **18**. In addition, the CPU **262** determines a first correction value X_1 based on the determined difference ΔV_{M1} according to the expression (11), or determines a second correction value X_2 based on the determined difference ΔV_{M1} according to the expression (12). The first correction value X_1 is added to the amplitude of the pulse of CPW waveform from which the current value V_{M1} has been derived, or the second correction value X_2 is added to the pressure of the cuff **215** at the time of detection of the pulse of CPW waveform from which the current value V_{M1} has been derived. Thus, the CPW pulse is corrected and the corrected pulse is used by the BP measuring means **380** for carrying out the current BP measurement at Step SB**308**.

As is apparent from the foregoing description, in the fourth embodiment shown in FIGS. **15** to **22**, the ECG-waveform detecting device **270** detects the ECG waveform through the electrodes **318** held in contact with the subject, and the pressure sensor **240** (i.e., pulse-wave sensor) detects the CPW waveform from the subject. The CPU **262** determines, at Step SB**304**, the time difference TD_{RP} between the predetermined periodic point (R wave) of each heartbeat-synchronous pulse of the ECG waveform and the predetermined periodic point (lower-peak or minimum point) of a corresponding heartbeat-synchronous pulse of the CPW waveform and determines, at Step SB**305**, the velocity V_{M1} of propagation of the CPW through the artery of the subject, based on the time difference TD_{RP} determined at Step SB**304**. In addition, at Step SB**310**, the CPU **262** judges whether the change of each of the propagation-velocity values V_{M1} from a corresponding preceding value V_{M1} is smaller than a reference value and, at Step SA**311**, the CPU **262** determines, as a proper propagation-velocity value V_{PM1}, an average of the first, second, and third values V_{M1} for which the first, second, and third positive judgments are made, respectively, at Step SB**310**. Since the proper propagation-velocity value V_{PM1} is determined based on the values V_{M1} that are stable independent of the change of cuff pressure, the accuracy of measurement of pulse-wave propagation velocity is improved.

In addition, at Step SB**312**, the CPU **262** estimates, according to the expression (9), a next propagation-velocity value $V_{M1'}$ which will next be determined at Step SB**305**, based on the propagation-velocity values V_{M1} which have been determined at Step SB**305** and for each of which a positive judgment is made at Step SB**310**. Subsequently, at Step SB**313**, the CPU **262** determines the difference ΔV_{M1} between the estimated next value $V_{M1'}$ and the current value V_{M1} determined at Step SB**305** in the current control cycle, according to the expression (10), and additionally determines the first correction value X_1 based on the determined difference ΔV_{M1} according to the expression (11), or determines the second correction value X_2 based on the determined difference ΔV_{M1} according to the expression (12). The first correction value X_1 is added to the amplitude of the pulse of CPW waveform from which the current value V_{M1} has been derived, or the second correction value X_2 is added to the pressure of the cuff **215** at the time of detection of the pulse of CPW waveform from which the current value V_{M1} has been derived. Thus, the CPW pulse is corrected and the corrected pulse is used at Step SB**308** for determining BP values in the current BP measurement. In this way, even in the case where the relationship of correspondence of pulse amplitude and cuff pressure (or blood pressure) breaks for a certain reason during each BP measurement, the pulse-amplitude value or the cuff-pressure value is advantageously corrected. Thus, the accuracy of measurement of BP values is improved.

Moreover, in the fourth apparatus **308**, at Step SB**306**, the CPU **262** judges whether each temporary propagation-velocity value V_{M1} determined at Step SB**305** falls within the predetermined permission range having the upper and lower limits indicated at one-dot chain line in FIG. **18**. This permission range is experimentally pre-determined for all the values that can be taken by the pressure of the cuff **215**. If a negative judgment is made at Step SB**306**, the CPU **262** terminates the current BP measurement being carried out at Step SB**308** of FIG. **20**, by quickly deflating the cuff **215** at Step SB**307** of the interrupt subroutine of FIG. **21**. Thus, if an abnormal event occurs during each BP measurement and the propagation velocity V_{M1} takes an excessively high or low value, the BP measurement is ended. Therefore, inaccurate BP measurements are effectively avoided.

In the fourth embodiment, at Step SA**311**, the CPU **262** determines, as the proper propagation velocity V_{PM1}, the average of the first three values V_{M1} for each of which a positive judgment is made at Step SB**310**. However, the CPU **262** may be modified to determine, as the proper propagation velocity V_{PM1}, the first value V_{M1} for which the first positive judgment is made at Step SB**310**, or a different single value V_{M1} for which a positive judgment is made at Step SB**310**. Alternatively, the CPU **262** may be modified to determine, as the proper propagation velocity V_{PM1}, the average of two, four, or more values V_{M1} for each of which a positive judgment is made at Step SB**310**.

In the fourth embodiment, at Step SB**312**, the CPU **262** estimates the next propagation-velocity value $V_{M1'}$, based on the prior propagation-velocity values V_{M1} stored in the second memory areas of the RAM **266**, according to the expression (9), i.e., determines, as the estimated value $V_{M1'}$, a moving average of the values V_{M1} stored in the second memory area of the RAM **266**. However, the CPU **262** may be modified to estimate the next value $V_{M1'}$ by utilizing a statistical method, i.e., a regression line.

In the fourth apparatus **308**, the electrodes **318** provided on the arm rests **317**, **319** may be replaced by conventional suction-type electrodes adapted to be placed at predetermined positions on a living subject.

Referring next to FIGS. **23** to **27**, there will described a fifth embodiment of the present invention which relates to an automatic BP measuring apparatus **408** which automatically measures a BP value of a living subject and which also functions as an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of the subject.

The BP measuring apparatus **408** as the fifth embodiment has the same hardware construction as the BP measuring apparatus **208** as the third embodiment shown in FIGS. **8** and **9**. The same reference numerals as used in FIGS. **8** and **9** are used to designate the corresponding elements or parts of the fifth apparatus **408**, and the description thereof is omitted from the following description.

However, as shown in FIG. **23**, an electronic control device **258** of the fifth apparatus **408** has different control

functions **482**, **484**, **486**, **488**, **490**, **492**, **494**, **496**, **497** in addition to the same control functions **278**, **280** as those **278**, **280** of the control device **258** of the third apparatus **208** shown in FIG. **10**. The fifth apparatus **408** is controlled according to the control program represented by the flow charts of FIGS. **26** and **27**, in place of the control program represented by the flow chart of FIG. **11**. However, the main routine represented by the flow chart of FIG. **26** has the same steps SA**201** through SA**208**, SA**216**, SA**221**, and SA**222** as those SA**201**–SA**208**, SA**216**, SA**221**, SA**222** of the control program represented by the flow chart of FIG. **11**, and the same steps SA**309**, SA**310** as those SA**309**, SA**310** of the main routine of FIG. **20** employed in the fourth apparatus **308**. The subroutine of FIG. **27** has the same step SB**301** as that SB**301** of the subroutine of FIG. **21** employed in the fourth apparatus **308**. The description of those steps is omitted from the following description.

The following description relates to only the differences of the fifth apparatus **408** from the third apparatus **208** or the fourth apparatus **308**.

In the present embodiment, an inflatable cuff **215**, a pressure sensor **240**, a pulse-wave filter circuit **254**, etc. cooperate with one another to provide one of a pair of heartbeat-synchronous-wave (HSW) sensors, and a cuff pulse wave (CPW) or a CPW signal SM_1 detected or provided by this HSW sensor corresponds to a heartbeat-synchronous wave (HSW) which is produced from an artery of a living subject in synchronism with the heartbeat of the subject.

In addition, in the present embodiment, an electrocardiographic-waveform (ECG-waveform) detecting device **270** and two electrodes **218** cooperate with one another to provide the other of the pair of HSW sensors, and an ECG waveform detected by this HSW sensor corresponds to another HSW.

The ECG-wave detecting device **270** detects the ECG waveform of the subject through the two electrodes **218** respectively held in contact with a right and a left arm **212**, **213** of the subject. An example of the ECG waveform represented by an electric signal supplied from the detecting device **270** is shown in an upper portion of the graph of FIG. **24**. An example of the CPW waveform detected through the pressure sensor **240** is shown in a lower portion of the graph of FIG. **24**.

FIG. **23** illustrates essential control functions of the control device **258** of the fifth apparatus **408**. The control device **258** functions as a cuff-pressure regulating means **278** and a BP measuring means **280** which are the same as the cuff-pressure regulating means **278** and the BP measuring means **280**, respectively, of the third apparatus **208** shown in FIG. **10**.

The control device **258** of the fifth apparatus **408** additionally functions as a time-difference determining means **482** which successively determines a time difference between a predetermined periodic point relating to the ECG waveform of each of heartbeat-synchronous pulses of the electric signal supplied from the ECG-waveform detecting device **270**, and a predetermined periodic point relating to the CPW waveform of a corresponding one of heartbeat-synchronous pulses of the CPW signal SM_1 which is supplied from the pressure sensor **240** when the pressure of the cuff **215** is changed around a diastolic BP value DBP of the subject. In the present embodiment, the determining means **482** determines a time difference, TD_{RP}, between the time of occurrence or detection of an R wave of each pulse of the ECG waveform and the time of occurrence or detection of a reference point, T_S, which is determined, as described later, with respect to a corresponding pulse of the CPW waveform, as shown in FIG. **24**.

The control device **258** of the fifth apparatus **408** functions as a temporary-propagation-velocity determining means **484** which successively determines a temporary propagation velocity V_{M1} (m/sec) of CPW, based on each of the successively determined time-difference values TD_{RP}, according to the same expression as the previously-indicated expression (2): $V_{M1}=L/(TD_{RP}-T_{PEP})$. In the present embodiment, the pre-ejection period T_{PEP} is defined as a time interval (sec) between the R wave of ECG waveform and a reference point T_S of an aortic pulse wave, as illustrated in FIG. **24**. The respective values of length L (m) and pre-ejection period T_{PEP} are experimentally determined in advance.

In addition, the control device **258** of the fifth apparatus **408** functions as a maximum-slope-line determining means **486** which determines, with respect to each pulse of the CPW waveform, a maximum-slope line, L_{Kmax}, (indicated at broken line in FIG. **25**) which passes through a maximum-slope point, K_{max}, where the CPW waveform takes a maximum slope, such that the maximum-slope line L_{Kmax} has the maximum slope. More specifically described, the determining means **486** differentiates the CPW waveform and determines, as the maximum-slope point K_{max}, a point where the differentiated waveform or curve takes a maximum value.

The control device **258** of the fifth apparatus **408** also functions as a base-line determining means **488** which determines, with respect to each pulse of the CPW waveform, a base line, BL, (indicated at one-dot chain line in FIG. **25**) which passes through respective minimum points on both sides of a maximum point of each pulse of CPW. In the present embodiment, one of the two minimum points (i.e., left one in FIG. **25**) detected before the maximum point is defined as the minimum point of the current pulse, and the other minimum point (i.e., right one) detected after the maximum point is defined as the minimum point of the next pulse of CPW. One pulse of CPW corresponds to one beat of the heart of the subject.

Further, the control device **258** of the fifth apparatus **408** also functions as a reference-point determining means **490** which determines, as the reference point T_S, a point of intersection of the maximum-slope line L_{Kmax} and the base line BL.

Moreover, the control device **258** of the fifth apparatus **408** functions as a stability judging means **492**, a proper-propagation-velocity determining means **494**, a propagation-velocity modifying means **497**, and a coefficient determining means **496** which are the same as those **386**, **387**, **389**, **388** of the fourth apparatus **308** shown in FIG. **16**, and the description thereof is omitted.

Hereinafter, there will be described the operation of the BP measuring apparatus **408** constructed as described above, by reference to the flow charts of FIGS. **26** and **27**.

Steps SA**201** to SA**208** of FIG. **26** are the same as those SA**201** to SA**208** of FIG. **11**.

Steps SA**309** and SA**310** of FIG. **26** are the same as those SA**309**, SA**310** of FIG. **20**.

Step SA**310** is followed by Step SA**411** to determine, as a proper propagation velocity V_{PM1} of the subject, an average of the first, second, and third temporary propagation-velocity values V_{M1} which have first, second, and third become not higher than a first or a second reference value and have been stored in a second memory area of a RAM **266** of the control device **258** of the fifth apparatus **408**. Step SA**411** corresponds to the proper-propagation-velocity determining means **494**.

Step SA411 is followed by Step SA412 to determine a coefficient A occurring in the expression (7), based on the proper propagation velocity V_{PM1} determined at Step SA411 and a diastolic BP value DBP_1 determined at Step SA208, according to the expression (8). Step SA412 corresponds to the coefficient determining means 496. Step SA412 is followed by Step SA413 to modify the proper propagation velocity V_{PM1} determined at Step SA411 to a modified, i.e., normalized proper propagation velocity V_{M3} corresponding to a predetermined BP value BP_t and a predetermined pulse rate HR_t, based on the diastolic BP value DBP_1 and a pulse rate HR_1 measured at Step SA208, according to the expression (7). Step SA413 corresponds to the propagation-velocity modifying means 497.

Step SA413 is followed by Steps SA216, SA221, and SA222 which are the same as Steps SA216, SA221, SA222 of FIG. 11.

The flow chart of FIG. 27 represents an interrupt subroutine which is implemented when the CPU 262 reads in the R wave of each heartbeat-synchronous pulse of the ECG waveform (i.e., electric signal) detected by the ECG-waveform detecting device 270, while the main routine represented by the flow chart of FIG. 26 is implemented. Step SB301 of FIG. 27 is the same as Step SB301 of FIG. 21. That is, at Step SB402, the CPU 262 of the control device 258 of the fifth apparatus 408 specifies the time when the R wave of one pulse is detected or read in, and stores the specified time in the RAM 266. Step SB301 is followed by Step SB402 to judge whether the CPU 262 has read in one heartbeat-synchronous pulse of the CPW waveform (i.e., CPW signal SM_1) detected through the pressure sensor 240. If a negative judgment is made at Step SB402, Step SB402 is repeated until a positive judgment is made. Meanwhile, if a positive judgment is made at Step SB402, the control of the CPU 262 goes to Step SB403 to determine a maximum-slope point K_{max} of the pulse of CPW where the differentiated waveform or curve derived from the original CPW waveform shown in FIG. 25 takes a maximum value, i.e, where the CPW waveform takes a maximum slope. In addition, at Step SB403, the CPU 262 determines a maximum-slope line L_{Kmax} which passes through the maximum-slope point K_{max} and has the maximum slope. Step SB403 corresponds to the maximum-line determining means 486.

Step S403 is followed by Step S404 to determine a base line BL which passes through the two minimum points before and after the maximum point of the CPW pulse. Step SB404 corresponds to the base-line determining means 488. Step SB404 is followed by Step SB405 to determine, as the reference point T_S relating to the CPW pulse, a point of intersection of the maximum-slope line L_{Kmax} and the base line BL, as shown in FIG. 25. Step SB405 corresponds to the reference-point determining means 490.

Step SB405 is followed by Step SB406 to specify the time when the reference point T_S of the CPW pulse is detected or read in, and stores the specified time in the RAM 266. Step SB406 is followed by Step SB407.

At Step SB407, the CPU 262 determines a time difference TD_{RP} between the time of detection of the R wave of the ECG pulse and the time of occurrence of the reference point T_S of the corresponding CPW pulse, as illustrated in FIG. 24. Step SB407 corresponds to the time-difference determining means 482. Step SB407 is followed by Step SB408 to determine a temporary propagation velocity V_{M1} of CPW, based on the time difference TD_{RP} determined at Step SB407, according to the expression (2). The determined temporary value V_{M1} is stored in a first memory area of the RAM 66. Step SB408 corresponds to the temporary-propagation-velocity determining means 484.

Subsequently, at Step SB409, the CPU 262 judges whether the amount or rate of change of the current temporary propagation-velocity value V_{M1} determined at Step SB408 in the current control cycle, from the preceding value V_{M1} determined at Step SB408 in the preceding control cycle and stored in the first memory area of the RAM 266, is not greater than 0.1 m/sec or 3%. If a negative judgment is made at Step SB409, the current control cycle in accordance with this subroutine is ended. On the other hand, if a positive judgment is made at Step SB409, the control of the CPU 262 goes to Step SB410 to store temporarily the current propagation-velocity value V_{M1} determined at Step SB408 in the current control cycle, in the second memory area of the RAM 266. Step SB409 corresponds to the stability judging means 492.

As is apparent from the foregoing description, in the fifth embodiment shown in FIGS. 23 to 27, the CPU 256 determines, at Step SB403, the maximum-slope line L_{Kmax} which passes through the maximum-slope point K_{max} and has the maximum slope and, at Step S404, determines the base line BL which passes through the two minimum points before and after the maximum point of each CPW pulse. In addition, at Step SB405, the CPU 262 determines, as the reference point T_S relating to each CPW pulse, a point of intersection of the maximum-slope line L_{Kmax} and the base line BL. This reference point T_S is free from the influences of a reflected wave as a secondary component of the CPW waveform, as shown in FIG. 25. Therefore, the reference point T_S does not substantially change or move on even a CPW waveform obtained from a living subject who suffers a serious arterial sclerosis. Accordingly, the present apparatus 408 measures, with high accuracy, the propagation velocity of a pulse wave which is propagated through an artery of a living subject.

Referring next to FIGS. 28 to 30, there will described a sixth embodiment of the present invention which relates to an automatic BP measuring apparatus 508 which automatically measures a BP value of a living subject and which also functions as an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of the subject.

The BP measuring apparatus 508 as the sixth embodiment has the same hardware construction as the BP measuring apparatus 208 as the third embodiment shown in FIGS. 8 and 9. The same reference numerals as used in FIGS. 8 and 9 are used to designate the corresponding elements or parts of the sixth apparatus 508, and the description thereof is omitted from the following description.

However, as shown in FIG. 28, an electronic control device 258 of the sixth apparatus 508 has different control functions 598, 599 in addition to the same control functions 278, 280 as those 278, 280 of the control device 258 of the third apparatus 208 shown in FIG. 10 and the same control functions 482, 484, 486, 492, 494, 496, 497 as those 482, 484, 486, 492, 494, 496, 497 of the control device 258 of the fifth apparatus 408 shown in FIG. 23.

The sixth apparatus 508 is controlled according to the control program represented by the flow chart of FIG. 26 employed in the fifth apparatus 408 and the flow chart of FIG. 30. The subroutine of FIG. 30 is different from the subroutine of FIG. 27 employed in the fifth apparatus 408 only in that the former has Steps SC504 and SC505 in place of Steps SB404 and SB405 of the latter.

The following description relates to only the differences of the sixth apparatus 508 from the fifth apparatus 408.

FIG. **28** illustrates essential control functions of the control device **258** of the sixth apparatus **508**. The control device **258** functions as a maximum-point-line determining means **598** which determines, with respect to each pulse of the CPW waveform, a maximum-point line, L_{Mmax}, (indicated at two-dot chain line in FIG. **29**) which passes through a maximum point, M_{max}, where the waveform of the CPW pulse takes a maximum amplitude, such that the maximum-point line L_{Mmax} is parallel to a base line BL which passes through respective minimum points on both sides of the maximum point M_{max} of the CPW pulse. In the present embodiment, the amplitude of each point on the CPW waveform is defined as the distance of each point from the base line BL.

The control device **258** of the sixth apparatus **508** also functions as a reference-point determining means **599** which determines a reference point, T_S, based on a point of intersection, X_2, of the CPW waveform and a straight line which passes through a point of intersection, X_1, of the maximum-point line L_{Mmax} and a maximum-slope line L_{Kmax} (indicated at broken line in FIG. **29**) determined by a maximum-slope-line determining means **486** and which is perpendicular to the maximum-point line L_{Mmax}. More specifically described, a point having an amplitude equal to one fifth of the amplitude of the point X_2 is determined as the reference point T_S, as shown in FIG. **29**.

Next, there will be described the operation of the BP measuring apparatus **508** constructed as described above. The present apparatus **508** is operated according to the main routine represented by the flow chart of FIG. **26** and the subroutine represented by the flow chart of FIG. **30**. Since, however, the subroutine FIG. **30** is different from that of FIG. **27** only in that the former has Steps SC**504** and SC**505** in place of Steps SB**404** and SB**405** of FIG. **27**, the following description relates only to Steps SC**504** and SC**505**.

At Step SC**504**, the CPU **262** of the control device **258** of the sixth apparatus **508** determines, with respect to each pulse of the CPW waveform, a maximum-point line L_{Mmax} which passes through a maximum point M_{max} where the waveform of the CPW pulse takes a maximum amplitude, such that the maximum-point line L_{Mmax} is parallel to a base line BL which passes through respective minimum points on both sides of the maximum point M_{max} of the CPW pulse. Step SC**504** corresponds to the maximum-point-line determining means **598**.

Step SC**504** is followed by Step SC**505** to determine a reference point T_S based on a point of intersection X_2 of the CPW waveform and a straight line which passes through a point of intersection X_1 of the maximum-point line L_{Mmax} and a maximum-slope line L_{Kmax} determined at Step SB**403** and which is perpendicular to the maximum-point line L_{Mmax}. For example, a point having an amplitude equal to one fifth of the amplitude of the point X_2 is determined as the reference point T_S. Step SC**505** corresponds to the reference-point determining means **599**.

As is apparent from the foregoing description, in the sixth embodiment shown in FIGS. **28** through **30**, the CPU **262** determines, at Step SB**403**, the maximum-slope line L_{Kmax} which passes through the maximum-slope point K_{max} of the CPW waveform and has the maximum slope and, at Step SC**504**, determines the maximum-point line L_{Mmax} which passes through the maximum point M_{max} of the CPW waveform and extends parallel to the base line BL which passes through the two minimum points on both sides of the maximum point M_{max}. In addition, the CPU **262** determines, at Step SC**505**, the reference point T_S based on the point of intersection X_2 of the CPW waveform and the straight line which passes through the point of intersection X_1 of the maximum-point line L_{Mmax} and the maximum-slope line L_{Kmax} determined at Step SB**403** and which is perpendicular to the maximum-point line L_{Mmax}, for example, determines a point having an amplitude equal to one fifth of the amplitude of the point X_2, as the reference point T_S. This reference point T_S is free from the influences of a reflected wave as a component of the CPW waveform, as shown in FIG. **29**. Therefore, the reference point T_S does not change or move on even a CPW waveform obtained from a living subject suffering a serious arterial sclerosis. Accordingly, the present apparatus **508** measures, with high accuracy, the propagation velocity of a pulse wave which is propagated through an artery of a living subject.

In the present embodiment, a point having an amplitude equal to one fifth of the amplitude of the point X_2, is determined as the reference point T_S. However, it is possible to determine, as the reference point T_S, a point having an amplitude equal to one third or one tenth of the amplitude of the point X_2, or otherwise to determine the point X_2 itself as the reference point T_S.

Referring next to FIGS. **31** and **32**, there will described a seventh embodiment of the present invention which relates to an automatic BP measuring apparatus **608** which automatically measures a BP value of a living subject and which also functions as an apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of the subject.

The BP measuring apparatus **608** as the seventh embodiment has the same hardware construction as the BP measuring apparatus **208** as the third embodiment shown in FIGS. **8** and **9**. The same reference numerals as used in FIGS. **8** and **9** are used to designate the corresponding elements or parts of the seventh apparatus **608**, and the description thereof is omitted from the following description.

However, as shown in FIG. **31**, an electronic control device **258** of the seventh apparatus **608** has a different control function **676** in addition to the same control functions **278**, **280** as those **278**, **280** of the control device **258** of the third apparatus **208** shown in FIG. **10** and the same control functions **482**, **484**, **492**, **494**, **496**, **497** as those **482**, **484**, **492**, **494**, **496**, **497** of the control device **258** of the fifth apparatus **408** as shown in FIG. **23**.

The seventh apparatus **608** is controlled according to the control program represented by the flow chart of FIG. **26** employed in the fifth apparatus **408** and the flow chart of FIG. **32**. The subroutine of FIG. **32** is different from the subroutine of FIG. **27** employed in the fifth apparatus **408** only in that the former has Step SD**603** in place of Steps SB**403**, SB**404**, and SB**405** of the latter.

The following description relates to only the differences of the seventh apparatus **608** from the fifth apparatus **408**.

FIG. **31** illustrates essential control functions of the control device **258** of the seventh apparatus **608**. The control device **258** functions a reference-point determining means **676** which determines, with respect to each pulse of the CPW waveform, a maximum-slope point K_{max} (shown in FIG. **25**) where the CPW waveform takes a maximum slope. For example, the determining means **676** differentiates the CPW waveform and determines, as the maximum-slope point K_{max}, a point where the differentiated waveform or curve takes a maximum value. In addition, the determining means **676** determines the maximum-slope point K_{max} as a reference point, T_S.

Next, there will be described the operation of the BP measuring apparatus **608** constructed as described above.

The present apparatus **608** is operated according to the main routine represented by the flow chart of FIG. **26** and the subroutine represented by the flow chart of FIG. **32**. Since, however, the subroutine FIG. **32** is different from that of FIG. **27** only in that the former has Step SD**603** in place of Steps SB**403**, SB**404**, and SB**405** of FIG. **27**, the following description relates only to Step SD**603**.

At Step SD**603**, a CPU **262** of the control device **258** of the seventh apparatus **608** determines, with respect to each pulse of the CPW waveform, a maximum-slope point K_{max} of the CPW pulse where the differentiated waveform or curve derived from the original CPW waveform shown in FIG. **25** takes a maximum value, i.e, where the CPW waveform takes a maximum slope. In addition, the CPU **262** determines the maximum-slope point K_{max} as the reference point T_S. The time of occurrence of this reference point T_S is specified at Step SB**406**, and this time is used to determine a time difference TD_{RP} at, Step SB**407**. Step SD**603** corresponds to the reference-point determining means **676**.

As is apparent from the foregoing description, in the seventh embodiment shown in FIGS. **31** and **32**, the CPU **262** determines, at Step SD**603**, the maximum-slope point K_{max} of each pulse of the CPW waveform and determines this point K_{max} as the reference point T_S. The reference point T_S is free from the influences of a reflected wave as a component of the CPW waveform, as shown in FIG. **25**. Therefore, the reference point T_S does not change or move on even a CPW waveform obtained from a living subject having a serious arterial sclerosis. Accordingly, the present apparatus **608** measures, with high accuracy, the propagation velocity of a pulse wave which is propagated through an artery of a living subject.

While in each of the fifth to seventh embodiments the propagation velocity V_{M1}, V_{PM1}, V_{M3} is determined based on the time difference TD_{RP} between each pulse of the ECG waveform and a corresponding pulse of the PPW or CPW waveform, it is possible to determine a propagation velocity based on a time difference of a heartbeat-synchronous pulse of a first pulse wave detected by a first pulse-wave sensor and a corresponding heartbeat-synchronous pulse of a second pulse wave detected by a second pulse-wave sensor. In the latter case, the two pulse-wave sensors are worn on different portions of the subject, and a reference point T_S is determined with respect to each of the first and second pulse waves. The two pulse-wave sensors correspond to the pair of heartbeat-synchronous-wave sensors, and the two pulse waves correspond to the two heartbeat-synchronous waves, respectively.

It is to be understood that the present invention may be embodied with various changes, improvements, and modifications that may occur to those skilled in the art without departing from the scope and spirit of the invention defined in the appended claims.

What is claimed is:

1. An apparatus for measuring a propagation velocity of a pulse wave which is propagated through an artery of a living subject, the apparatus comprising:

an electrocardiographic-waveform detecting device which detects an electrocardiographic waveform from the subject, the detected electrocardiographic waveform comprising a plurality of first heartbeat-synchronous pulses;

a pulse-wave sensor which is adapted to be worn on the subject and which detects the pulse wave from the subject, the detected pulse wave comprising a plurality of second heartbeat-synchronous pulses;

time-difference determining means for determining a time difference between a first periodic point relating to one of the first heartbeat-synchronous pulses of the detected electrocardiographic waveform and a second periodic point relating to a corresponding one of the second heartbeat-synchronous pulses of the detected pulse wave; and

propagation-velocity determining means for determining the propagation velocity, V_M, of the pulse wave based on the determined time difference, TD_{RP}, according to a following expression:

$$V_M=L/(TD_{RP}-T_{PEP})$$

where

L is a length of the artery of the subject from a left ventricle of the subject via an aorta of the subject to a position where the pulse-wave sensor is worn on the subject, and

T_{PEP} is a pre-ejection period between a Q wave of said one first heartbeat-synchronous pulse of the electrocardiographic waveform and a minimum point of said corresponding one of the second heartbeat-synchronous pulses of the pulse wave.

2. An apparatus according to claim **1**, wherein said pulse-wave sensor comprises a pressure sensor which is adapted to be pressed against a portion of the artery of the subject via a skin of the subject and which detects, as the pulse wave, a heartbeat-synchronous pressure oscillation which is transmitted thereto from the portion of the artery via the skin.

3. An apparatus according to claim **1**, wherein said pulse-wave sensor comprises:

an inflatable cuff which is adapted to be wound around a body portion of the subject; and

a pressure sensor which detects, as the pulse wave, a heartbeat-synchronous pressure oscillation which is produced in said cuff.

4. An apparatus according to claim **1**, wherein said pulse-wave sensor comprises a photoelectric sensor including a light source which emits a light toward a body portion of the subject, and a light detecting element which detects the light transmitted through, or reflected from, the body portion.

5. An apparatus according to claim **1**, further comprising:

a blood-pressure measuring device which measures a blood pressure value of the subject; and

propagation-velocity modifying means for modifying the determined propagation-velocity value to a modified propagation-velocity value corresponding to a predetermined blood pressure value, based on the measured blood pressure value, according to a predetermined relationship between modified propagation velocity, and determined propagation velocity and measured blood pressure.

6. An apparatus according to claim **1**, further comprising a blood-pressure measuring device which includes an inflatable cuff adapted to be wound around a body portion of the subject, said pulse-wave sensor which detects the pulse wave transmitted from the artery of the subject to said cuff when a pressure in the cuff is changed, and means for determining a blood pressure value of the subject based on the detected pulse wave, wherein said time-difference determining means comprises means for successively determining the time difference between the first periodic point on the detected electrocardiographic waveform and the second periodic point on the detected pulse wave, and said propagation-velocity determining means comprises

temporary-propagation-velocity determining means for successively determining the temporary propagation velocity of the pulse wave based on each of the successively determined time-difference values; judging means for judging whether the change of each of the successively determined temporary propagation-velocity values, with respect to the change of the cuff pressure, is smaller than a reference value; and proper-propagation-velocity determining means for determining a proper propagation-velocity value from at least one temporary propagation-velocity value for which a positive judgment is made by said judging means.

7. An apparatus according to claim 1, further comprising:

a blood-pressure measuring device which includes an inflatable cuff adapted to be wound around a body portion of the subject, said pulse-wave sensor which detects a plurality of heartbeat-synchronous pulses of the pulse wave transmitted from the artery of the subject to said cuff when a pressure in the cuff is changed, and means for determining a blood pressure value of the subject based on variation of respective amplitudes of the detected heartbeat-synchronous pulses of the pulse wave, wherein said time-difference determining means successively determines the time difference between the first periodic point on each of heartbeat-synchronous pulses of the detected electrocardiographic waveform and the second periodic point on a corresponding one of the detected heartbeat-synchronous pulses of the pulse wave and said propagation-velocity determining means successively determines the propagation velocity of the pulse wave based on each of the successively determined time-difference values;

judging means for judging whether the change of each of the successively determined propagation-velocity values, with respect to the change of the cuff pressure, is smaller than a reference value; and

correcting means for correcting at least one first pulse of the heartbeat-synchronous pulses of the pulse wave which is deviated from at least one second pulse for which a positive judgment is made by said judging means, based on the deviation of the first pulse from the second pulse, so that said blood-pressure measuring device measures the blood pressure value of the subject based on the variation of the respective amplitudes of the heartbeat-synchronous pulses including the corrected first pulse.

8. An apparatus according to claim 1, further comprising:

a blood-pressure measuring device which includes an inflatable cuff adapted to be wound around a body portion of the subject, said pulse-wave sensor which detects the pulse wave transmitted from the artery of the subject to said cuff when a pressure in the cuff is changed, and means for determining a blood pressure value of the subject based on the detected pulse wave; and

terminating means for terminating a blood pressure measurement of said blood-pressure measuring device when the determined propagation-velocity value does not fall within a permission range.

9. An apparatus according to claim 1, further comprising second-periodic-point determining means for determining said second periodic point based on a curve obtained by differentiating said detected pulse wave.

10. An apparatus according to claim 9, wherein said second-periodic-point determining means comprises means for determining said second periodic point based on a maximum-slope point where said detected pulse wave takes a maximum slope.

11. An apparatus according to claim 9, wherein said second-periodic-point determining means comprises means for determining, as said second periodic point, a maximum-slope point where said detected pulse wave takes a maximum slope.

12. An apparatus according to claim 1, further comprising:

an inflatable cuff which is adapted to be wound around a body portion of the subject;

a pressure sensor which detects a heartbeat-synchronous pressure oscillation which is produced in the cuff while a pressure in the cuff is changed, the detected heartbeat-synchronous pressure oscillation comprising a plurality of third heartbeat-synchronous pulses;

first blood pressure determining means for determining an actual blood pressure of the subject based on a variation of respective amplitudes of the third heartbeat-synchronous pulses of the detected heartbeat-synchronous pressure oscillation;

relationship determining means for determining a relationship between blood pressure and pulse wave magnitude based on at least one actual blood pressure value determined by the first blood pressure determining means and at least one magnitude of one of the second heartbeat-synchronous pulses of the pulse wave detected by the pulse-wave sensor; and

second blood pressure determining means for successively determining, according to the relationship determined by the relationship determining means, a blood pressure value of the subject based on a magnitude of each of the second heartbeat-synchronous pulses of the pulse wave which are detected after the relationship is determined.

13. An apparatus according to claim 12, wherein the pulse-wave sensor comprises a pressure pulse-wave sensor which is adapted to be pressed against a portion of the artery of the subject via a skin of the subject and which detects, as the pulse wave, a heartbeat-synchronous pressure pulse wave which is transmitted thereto from the portion of the artery via the skin, the detected heartbeat-synchronous pressure pulse wave comprising a plurality of second heartbeat-synchronous pulses, and wherein the relationship determining means comprises means for determining, as the relationship between blood pressure, MBP, and pressure-pulse-wave magnitude, P_M, a linear function: $MBP=A \cdot P_M+B$, where A and B are a first and a second constant, respectively, based on at least one actual blood pressure determined by the first blood pressure determining means and at least one magnitude of one of the second heartbeat-synchronous pulses of the pressure pulse wave detected by the pressure pulse-wave sensor.

14. An apparatus according to claim 13, wherein the second blood pressure determining means comprises means for successively determining, according to the linear function, a systolic and diastolic blood pressure value of the subject based on a maximum and a minimum magnitude of each of the second heartbeat-synchronous pulses of the pressure pulse wave which are detected by the pressure pulse-wave sensor after the linear function is determined.

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