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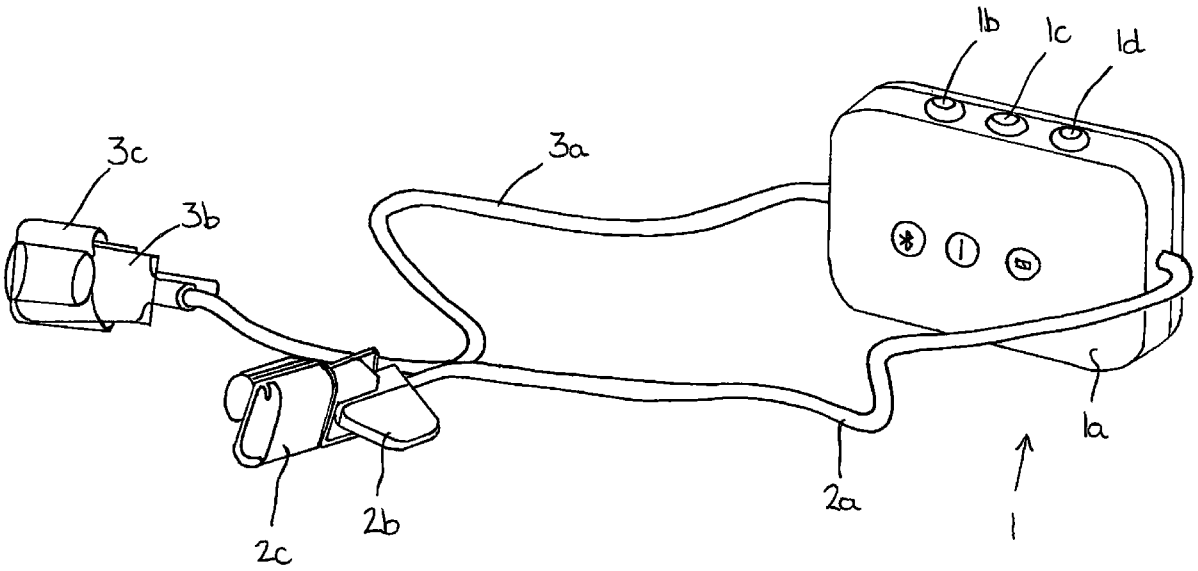

FIGURE 1

(57) Abstract: An apparatus for use in the assessment of peripheral arterial disease (PAD) in a patient, the apparatus comprising: at least one pair of photoplethysmographic (PPG) pulse sensors, one PPG sensor of the at least one pair attachable to a left hand side body extremity and the other of the pair attachable to a corresponding right hand side body extremity; a memory storing normal range values derived from measurements made on individuals without significant PAD; and a processor having at least two inputs and at least one output, the processor configured to operate an algorithm, the algorithm performing the following steps: i. acquire pulse signals from the PPG sensors over a predetermined number of heart beats, wherein the pulse associated with each heart beat has a first pulse foot, a second pulse foot and a first dominant peak; ii. filter the signals to remove unwanted high and low frequency noise; iii. normalise each filtered pulse signal in width over a number of equally spaced time intervals between consecutive pulse feet; iv. normalise each filtered pulse signal in height between lower and upper thresholds from the first pulse foot to the first dominant peak; v. calculate a

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value related to the acquired pulse signals for each equally spaced time interval; vi. for each equally spaced time interval, comparing the value calculated in step v for a patient, with the same value, or a normal range thereof, from the memory and generating an output representing the comparison; vii. calculating a shape distortion index representing the output of step vi.

Device for Use in the Assessment of Peripheral Arterial Disease

Field of the Invention

The present invention relates to a device for use in the assessment of peripheral arterial disease and in particular to a device utilising photoplethysmographic (PPG) peripheral pulse sensors.

Background of the Invention

Peripheral arterial disease (PAD) describes a narrowing of the arteries other than those that supply the heart or the brain. PAD usually occurs in the limbs and most commonly in the lower limbs. The supply of blood to the extremities where PAD occurs can be reduced at rest and more so with ambulation. Individuals experiencing PAD may suffer from pain, cold skin, blue coloured skin and skin ulcers. If untreated, PAD may ultimately lead to infection and gangrene due to the lack of oxygen and nutrients reaching the affected part of the limb. In some cases amputation of the affected part of the limb is necessary.

It is also understood that an individual having PAD has an increased risk of also having coronary artery disease and cerebrovascular disease.

The standard methodology for assessing PAD is by measuring the ankle brachial pressure index (ABPI). This involves measuring the systolic pressure in specific arteries at the ankle and foot and comparing these to the systolic pressure in the brachial artery of the arm after each arterial flow. If the systolic pressure at the ankle is lower than the systolic pressure at the arm then an arterial stenosis restricting the supply of blood from the heart to the ankle is suspected. ABPI is close to 1 in subjects without PAD and the standard cut-off level used to indicate significant PAD is if the ABPI is less than 0.9. A high value of ABPI e.g. >1.5 is considered to be consistent with arterial rigidity as the blood vessels in the leg cannot easily be compressed by applying pressure with the ankle pressure cuff.

The manual measurement of ABPI typically uses a limb cuff applied sequentially to each limb and the blood pressure determined by the return of pulse on cuff-deflation from a supra-

systolic level. An ultrasound device is often used to amplify the sound of the arterial blood flow and communicate when the pulse returns to give a pressure level for each limb to enable an ABPI calculation. ABPI measurement requires skill, can takes 10's of minutes to complete, and has limitations in some patient groups where arterial rigidity is likely to be present. The aforementioned apparatus is not practical for use as a screening tool.

Attempts have been made to develop devices that may allow PAD to be diagnosed more efficiently. EP1671581 describes an apparatus comprising a plurality of photoplethysmographic (PPG) probes each attached to anatomically symmetrical sites of the patients extremities (e.g. to the little toes of both feet or to the index finger of both hands). PPG signals are registered over a period exceeding five pulse beats (for example, 10 seconds). The signals are processed to determine the mean value of the time difference between the signals from the two symmetrical sites. The mean time difference is compared with a threshold value.

It would be desirable to provide an apparatus and method that is capable of providing a PAD indication that is simple to interpret.

It would be desirable to provide an apparatus and method for assessing PAD that is sufficiently simple and quick to do that it may be used to screen large numbers of individuals for PAD.

Summary of the Invention

According to a first aspect of the invention, there is provided an apparatus for use in the assessment of peripheral arterial disease (PAD) in a patient, the apparatus comprising: at least two photoplethysmographic (PPG) sensors, one PPG sensor of the at least two PPG sensors attachable to a left hand side body extremity and the other of the at least two PPG sensors attachable to a right hand side body extremity; a memory storing normal range values derived from measurements made on individuals without PAD; and a processor having at least two inputs and at least one output, the processor configured to operate an algorithm, the algorithm performing the following steps:

i. for each measurement site acquire pulse signals from the PPG sensors over a predetermined period, wherein each pulse has a first pulse foot, a second pulse foot and a first dominant peak;

ii. filter the signals to remove high frequency noise above a first selected frequency and low frequency noise below a second selected frequency from the filtered signal;

iii. normalise each filtered pulse signal in width over a number of equally spaced time intervals between consecutive pulse feet;

iv. normalise each filtered pulse signal in height between lower and upper thresholds from the first pulse foot to the first dominant peak;

v. calculate a value related to the acquired pulse signals for each equally spaced time interval;

vi. for each equally spaced time interval, comparing the value calculated in step v for a patient, with the same value, or a normal range thereof, from the memory, or from values from one or more of other sensors on the same patient and generating an output representing the comparison;

vii. for each measurement site calculating a shape distortion index representing the output of step vi.

Preferably, the at least two PPG sensors are a pair and are attached to corresponding left hand and right hand side body extremities.

Preferably, the predetermined period is determined by a selected number of heart beats.

Advantageously, the memory is in the form of a database.

Preferably, the selected number of heart beats is at least 10.

Preferably, the number of equally spaced time intervals over which the filtered pulse signals are normalised is at least 20.

The value related to the acquired pulse signal may be one of: the median, the mean, the inter-quartile range, and statistical confidence limits.

The value may be a statistical confidence limit and the confidence limit is defined x% to y% of the acquired pulse signals for each equally spaced time interval.

The x and y values may be selected to provide a confidence range of at least 90%.

Preferably, x is greater than or equal to 2.5 and y is less than or equal to 97.5 to give a 95% confidence limit range.

The value related to the acquired pulse signal may be one of: the pulse waveform shape; the pulse gradient; the pulse rise time; and pulse amplitude or a combination thereof.

The apparatus may further comprise an ECG sensor, the output thereof forming an input to the processor and wherein the algorithm synchronises the ECG output with the acquired pulse signal.

According to another aspect of the invention there is provided a method for generating a shape distortion index indicative of the presence or absence of peripheral arterial disease in a patient, the method comprising:

i. for each measurement site acquire pulse signals from at least two PPG sensors attached to a left hand and right hand side body extremities respectively over a predetermined period, wherein each pulse associated has a first pulse foot, a second pulse foot and a first dominant peak;

ii. filtering the signals to remove high frequency noise above a first selected frequency and low frequency below a second selected frequency noise from the filtered signals;

iii. normalising each filtered pulse signal in width over a number of equally spaced time intervals between consecutive pulse feet;

iv. normalising each filtered pulse signal in height between lower and upper thresholds from the first pulse foot to the first dominant peak;

v. calculating a value related to the acquired pulse signals for each equally spaced time interval;

vi. for each equally spaced time interval, comparing the value calculated in step v for a patient, with the same value, or a normal range thereof, from a memory or from values from one or more of other sensors on the same patient and generating an output representing the comparison;

vii. for each measurement site calculating a shape distortion index representing the output of step vi.

Preferably, the at least two PPG sensors are a pair and are attached to corresponding left hand and right hand side body extremities.

Preferably, the predetermined period is determined by a selected number of heart beats.

Preferably, the predetermined number of heart beats is at least 10.

Preferably, the number of equally spaced time intervals over which the filtered pulse signals are normalised is at least 20.

Advantageously, the value related to the acquired pulse signal is one of: the median, the mean, the inter-quartile range, and statistical confidence limits.

The value may be a statistical confidence limit and the confidence limit is defined x% to y% of the acquired pulse signals for each equally spaced time interval.

Preferably, the x and y values are selected to provide a confidence range of at least 90%.

Preferably, x is greater than or equal to 2.5 and y is less than or equal to 97.5 to give a 95% confidence limit range.

The value related to the acquired pulse signal may be one of: the pulse waveform shape; pulse gradient; pulse amplitude; variability in pulse waveform shape; pulse gradient; pulse amplitude; and a combination thereof.

Advantageously, the output from an ECG sensor attached to the patient forms an input to the processor and wherein the algorithm synchronises the ECG output with the acquired pulse signal(s).

Brief Description of the Drawings

In the Drawings, which illustrate a preferred embodiment of the invention:

Figure 1 is schematic representation of the apparatus of the invention;

Figure 2 is a block diagram illustrating the components of the apparatus illustrated in Figure 1;

Figure 3 is a block diagram illustrating an algorithm operated by the software run by the apparatus illustrated in Figures 1 and 2;

Figure 4a is a graph illustrating PPG and ECG signals; and

Figure 4b is a graph showing normalised pulse width v normalised pulse height at an arm measurement site;

Figure 4c is a graph showing normalised pulse width v normalised pulse height at a leg measurement site; and

Figure 5 is a block diagram illustrating an alternative arrangement of components of an apparatus according to the invention.

Detailed Description of the Preferred Embodiments

Referring first to Figure 1, an apparatus 1 houses electronic circuitry (described with reference to Figure 2 below). The apparatus 1 comprises a housing 1a which is provided with input/output terminals 1b, 1c and 1d. Leads 2a, 3a extend from the housing, with each lead being provided with a connector 2b, 3b to which attaches a PPG sensor 2c, 3c. The PPG sensors 2c, 3c may be disposable. In use, the sensor 2c is attached to a toe of the left foot, whereas the sensor 3c is attached to a toe of the right foot. The toes are a key measurement site because PAD generally manifests itself in the legs. The input output terminals may be connected to or replaced by wireless communication means.

Additionally or alternatively, the apparatus 1 may be configured to communicate with a patient records system so that data obtained by the device may be recorded on a patient's records. Preferably, the apparatus 1 is configured so that any patient records system with which the apparatus is connected may be recognised so that data can be transferred thereto. Communication may be via hard wires or wireless communication.

One of the input/output terminals 1b-1d may be configured as an output and be connected to a display (not shown). Another of the input/output terminals may be configured as an input and receive an input from an ECG sensor.

The block diagram of Figure 2 illustrates how the signals from the PAD sensors 2c, 3c are processed. Referring now to Figure 2 a controller 20 is illustrated in block diagram form. The controller 20 comprises a filter 21. The filter 21provides high pass and low pass filtering. The high pass filtering to remove low frequency variability in the PPG signal, which in the present example

also removes the DC offset in the signal, and the low pass filtering to remove high frequency noise from the PPG signal, for example by removing signals above 20Hz. The signal is predominantly contained typically within the 1 to 5Hz range. Signals from the PPG sensors 2c, 3c are received by the filter 21. The filtered signals output from filter 21 are subjected to an artefact rejection process by an artefact filter 22. The signals output from artefact filter 22 are collected for a pre-defined number of pulses in a memory 23.

In a processor 24 the pulse wave form outputs from 23 are characterised in terms of one or more of the following parameters: For each measurement site the PPG signal timing, amplitude, shape, and their variability over a predetermined period of time, and differences between measurement sites. It should be noted that the pulse features differ according to the measurement site chosen. As can be seen from Figure 2, in addition or in place of PPG sensors 2c, 3c other sensors 2c', 3c', 2c'', 3c'' may be provided, such sensors in use being connected to body extremities such as fingers in the case of sensors 2c', 3c' and ear lobes 2c'', 3c'' or to cover the supra-orbital arteries. However, whilst the pulse features from different measuring sites may differ, the principles of analysis are broadly similar.

The output of the characterisation processor 24 forms the input to a processor 25 which computes a value from the collected and characterised pulses output from characterisation processor 24. The computed value could be the average pulse waveform normalised shape.

The controller 20 includes a reference database 26 in which is stored data representing the same computed value or values from processor 25, but averaged from a set of individuals known to be unlikely to have PAD.

In a comparator 27 of the controller 20, the value computed by processor 25 is compared with a corresponding value from the normal range database 26. The output of the comparator 26 forms the input of a processor 28 which calculates the likelihood of PAD in the individual under test. The output of the processor 28 may be output directly to a visual display 29, which may be comprised in the apparatus or to an external display 31, which may be connected to the controller by either a wireless or wired connection 33.

The output signals from the processor 28 may be stored in a database 30, the output signals being transmitted to the database 30 either directly or via the visual display 29.

The controller 20 is powered by power supply 32.

The sensors may include an ECG sensor 4, which also outputs to the filters 21. The function of the ECG sensor will be described in greater detail below.

The algorithm performed by the apparatus illustrated in Figures 1 and 2 and is described in greater detail below with reference to Figure 3.

In step 50 PPG signals and, if an ECG sensor is used, ECG signals are acquired from preferred body sites, such as the toes, fingers and ear lobes. As mentioned above, for the detection of PAD the feet are the most important part of the body to study. However, taking measurements from the fingers and/or more proximal sites such as the ears may add useful information about the patient.

In step 51 the pulse signal is conditioned, that is unwanted high and low frequencies and DC offset are removed.

In step 52 the filtered pulse signals are collected for the predetermined number of pulses/ heat beats (a predetermined time period could be used instead), for example 60 pulses or 90 seconds.

Each of the 60 pulses is then normalised in width and height. Normalising the pulse in width involves dividing the pulse into equally spaced time intervals, preferably one hundred intervals, between consecutive pulse feet (see Figure 4). Normalising each filtered pulse signal in height involves assigning the first pulse foot to 0 and the first dominant peak to 1. The selection of 60 pulses and 100 equally spaced time intervals is just one possible example. Other numbers of pulses and equally spaced time intervals may be used, for example 10 pulses and 20 equally spaced time intervals.

During collection, and preferably after normalisation, each pulse is compared with a set of previous, and preferably normalised, pulses that were within a specified criteria. If the pulse that is being compared with the set of previous pulses is also within the specified criteria then it is added

to the set. If, however, the pulse that is being compared with the set of previous pulses is without the specified criteria then it is rejected.

Typically, the specified criteria relate to noise artefacts which may arise from patient movement, electrical noise for example. The techniques used for rejecting noise are in themselves well known in the art

The process performed in step 52 of the algorithm is to calculate a value related to at least one parameter common to each of the acquired pulses for each equally spaced time interval. Where the number of pulses acquired is sixty and the number of spaced intervals is one hundred, if the value is the median of parameter, then the result is one hundred median values, each being the median of the sixty pulses.

The value need not be the median. Other statistical measures may be used, such as the mean, the inter-quartile range, and confidence limits such as a 95% confidence limit (for example, where 0-2.5% and 97.5% to 100% are ignored).

The parameter may be the PPG waveform shape, the PPG pulse gradient (the rise time, typically from the first pulse foot to the first dominant peak), the PPG pulse amplitude (typically from the first pulse foot to the first dominant peak, and can be normailsed to the level of pulse measurement device amplification). The degree of variability of these measures over a fixed period of time can also be used. A combination of different parameters may be utilised and the values of these different parameters clustered together so that the resulting shape distortion index is developed from a number of different parameters of the PPG pulse signals.

In step 53, the normalised values resulting from the PPG signal gathered from the patient are compared with corresponding normalised values gathered from a group of individuals known to be unlikely to have PAD. In this embodiment, the normalised values are expressed as a normal range of values. This is preferred because the PPG signals of individuals unlikely to be have PAD will be different. However, it is not essential that the comparison is with a normal range, the comparison could be with a statistical measure such as the median of the parameter for all the sampled individuals who are considered unlikely to have PAD.

The output of step 53 is a shape distortion index representing the difference between the PPG analysis of the patient and the same PPG analysis of a group of individuals known not to suffer from PAD. The output is an indication of the likelihood of the patient having PAD which allows that clinician to assess whether further investigation of PAD in the patient is necessary.

The apparatus and method of the invention are particularly effective at providing indications that a patient does not have PAD. That is clinicians can be confident that a result indication that a patient does not have PAD is accurate. The clinician can therefore be confident in advising the patient that no further investigation is required. The apparatus and method provide of the invention therefore provide a useful screening tool for screening large numbers of individuals for PAD.

Figure 4a illustrates the shapes of an ECG QRS wave complex (i.e. ventricular depolarization) and a PPG pulse signal P. Each pulse in the signal P has a first pulse foot A, a first dominant peak B and a second pulse foot C. The R peak of the ECG QRS wave complex and the PPG signal P are aligned by a broken line. The time from the R peak of the ECG QRS wave complex to the first pulse foot is the pulse transit time f (PTTf), the time from the R peak to the first dominant peak B is the pulse transit time p (PTTp), and the time from the first pulse foot to the first dominant peak is the rise time (RT). The afore-mentioned times may be measured with respect to other significant landmarks in the QRS wave complex, such as the foot Q of the wave that precedes the peak R, or the foot S that follows the peak R.

Figure 4b illustrates the output of step 53 for an upper limb site, which in this example is a finger, of the algorithm prior to assigning a shape distortion index value to the difference between the patient values and the corresponding values of the group of individuals known not to have PAD.

Figure 4c illustrates the output of step 53 for a lower limb site, which in this example is a toe, of the algorithm prior to assigning a shape distortion index value to the difference between the patient values and the corresponding values of the group of individuals known not to have PAD.

The shaded areas of the graphs of Figure 4b and Figure 4c represent the difference between a patient and a group known not to have PAD. A shape distortion index may be expressed in a number of ways. The shape distortion index may be numeric from, for example, 0

to 20, with 0 representing no deviation from the normal range of the group considered unlikely to have PAD and above a threshold the shaded area of pulse distortion is consistent with significant PAD, with a higher numeric value generally corresponding to lower values of ABPI and hence indicating PAD.

The invention provides a single value representative of the difference between the pulse parameter or group of pulse parameters measured on a patient and a reference range of that parameter from a group of patients known not to suffer from PAD.

The value of the difference between the parameter measured on a patient and the reference range can be used to classify the patient as having or not having of the peripheral arterial disease.

Figure 5 illustrates an alternative arrangement of components to that shown in Figure 2. In this example the left and right foot toe sensors 2c, 3c connect to a toe module 60, which includes a power source 61, an on/off button 62 and an indicator light in the form of an LED 63. The toe module 60 further comprises a micro-processor 64 which performs the high/low pass and artefact filtering of elements 21 to 23 of the apparatus illustrated in Figure 2. The toe module 60 further includes a wireless (Bluetooth) communications module 65, which provides for communication between the toe module 60 and the main controller 70.

The main controller 70 includes a micro-processor 72 and a finger processor 73. The finger processor 73 is powered by a power source 74 and may be switched on and off by button 75. A light in the form of an LED 76 indicates whether the finger processor 73 is powered or not. The power sources 74 also powers the micro-processor 72 and other components with hard wired connections thereto.

The finger processor 73 receives signals from left and right finger PPG sensors 2c', 3c', the processor 73 performing the high/low pass and artefact filtering operations of elements 21 to 23 in Figure 2. The finger processor 73 may also receive an input from an ECG pad 4 via an analogue to digital converter 77.

The micro-processor 72 performs the operations carried out by elements 24 to 28 in the Figure 2 example. The micro-processor 72 may output to a data store 78 and to a wireless

(Bluetooth) communications device 79, which allows data to be transmitted to an external display, such as a tablet computer 80, to an external electronic patient record for example held on an external drive such as a USB memory dongle 81 and to a separate display module 82, which includes a wireless (Bluetooth) communications device 83, a DC (batteries) power supply 84, a switch 85 in the form of buttons or a touch screen for turning the display module on and off, and an indicator light in the form of an LED 86. The display module 82 further includes a display driver 87 connected to the output of the wireless communication device 83 and a 320x240 pixel display 88 on which the output from the micro-controller 72 is displayed.

Claims

1. An apparatus for use in the assessment of peripheral arterial disease (PAD) in a patient, the apparatus comprising: at least two photoplethysmographic (PPG) sensors, one PPG sensor of the at least two PPG sensors attachable to a left hand side body extremity and the other of the at least two PPG sensors attachable to a right hand side body extremity; a memory storing normal range values derived from measurements made on individuals without PAD; and a processor having at least two inputs and at least one output, the processor configured to operate an algorithm, the algorithm performing the following steps:

i. acquire pulse signals from the PPG sensors over a selected number of heart beats or time period, wherein the pulse associated with each heart beat has a first pulse foot, a second pulse foot and a first dominant peak;

ii. filter the signals to remove high frequency noise above a first selected frequency and low frequency below a second selected frequency noise from the filtered signals;

iii. normalise each filtered pulse signal in width over a number of equally spaced time intervals between consecutive pulse feet;

iv. normalise each filtered pulse signal in height between lower and upper thresholds from the first pulse foot to the first dominant peak;

v. calculate a value related to the acquired pulse signals for each equally spaced time interval;

vi. for each equally spaced time interval, comparing the value calculated in step v for a patient, with the same value, or a normal range thereof, from the memory and generating an output representing the comparison;

vii. calculating a shape distortion index representing the output of step vi.

2. An apparatus according to Claim 1, wherein the algorithm includes the additional step of comparing a current normalised filtered pulse signal with previous normalised filtered pulse signals that fell within a specified criteria and rejecting the current normalised filtered pulse signal if it falls without the specified criteria.

3. An apparatus according to Claim 1 or 2, wherein the memory is in the form of a database.

4. An apparatus according to any preceding claim, wherein the selected number of heart beats is at least 10.

5. An apparatus according to any preceding claim, wherein the number of equally spaced time intervals over which the filtered pulse signals are normalised is at least 20.

6. An apparatus according to any preceding claim, wherein the value related to the acquired pulse signal is one of: the median, the mean, the inter-quartile range, and statistical confidence limits.

7. An apparatus according to Claim 6, wherein the value is a statistical confidence limit and the confidence limit is defined x% to y% of the acquired pulse signals for each equally spaced time interval.

8. An apparatus according to Claim 7, wherein the x and y values are selected to provide a confidence range of at least 90%.

9. An apparatus according to Claim 8, wherein x is greater than or equal to 2.5 and y is less than or equal to 97.5 to give a 95% confidence limit range.

10. An apparatus according to any preceding claim, wherein the value related to the acquired pulse signal is one of: the pulse waveform shape; the pulse gradient; the pulse rise time; and pulse amplitude or a combination thereof.

11. An apparatus according to any preceding claim, further comprising an ECG sensor, the output thereof forming an input to the processor and wherein the algorithm synchronises the ECG output with the acquired pulse signal.

12. A method for generating a shape distortion index indicative of the presence or absence of peripheral arterial disease in a patient, the method comprising:

i. acquiring pulse signals from at least one pair of PPG sensors attached to a corresponding left hand and right hand side body extremities respectively over a predetermined number of heart beats, wherein the pulse associated with each heart beat has a first pulse foot, a second pulse foot and a first dominant peak;

ii. filtering the signals to remove high frequency noise above a first selected frequency and low frequency below a second selected frequency noise from the filtered signals;

iii. normalising each filtered pulse signal in width over a number of equally spaced time intervals between consecutive pulse feet;

iv. normalising each filtered pulse signal in height between lower and upper thresholds from the first pulse foot to the first dominant peak;

v. calculating a value related to the acquired pulse signals for each equally spaced time interval;

vi. for each equally space time interval, comparing the value calculated in step v for a patient, with the same value, or a normal range thereof, from a memory and generating an output representing the comparison;

vii. calculating a shape index representing the output of step vi.

13. A method according to Claim 12, wherein the algorithm includes the additional step of comparing a current normalised filtered pulse signal with previous normalised filtered pulse signals that fell within a specified criteria and rejecting the current normalised filtered pulse signal if it falls without the specified criteria.

14. A method according to Claim 12 or 13, wherein the predetermined number of heart beats is at least 10.

15. A method according to any of Claims 12 or 14, wherein the number of equally spaced time intervals over which the filtered pulse signals are normalised is at least 20.

16. A method according to any of Claims 12 to 15, wherein the value related to the acquired pulse signal is one of: the median, the mean, the inter-quartile range, and statistical confidence limits.

17. A method according to Claim 16, wherein the value is a statistical confidence limit and the confidence limit is defined x% to y% of the acquired pulse signals for each equally spaced time interval.

18. An apparatus according to Claim 17, wherein the x and y values are selected to provide a confidence range of at least 90%.

19. A method according to Claim 17, wherein x is greater than or equal to 2.5 and y is less than or equal to 97.5 to give a 95% confidence limit range.

20. A method according to any of Claims 12 to 19, wherein the value related to the acquired pulse signal is one of: the pulse waveform shape; pulse gradient; pulse amplitude; variability in pulse waveform shape; pulse gradient; pulse amplitude; and a combination thereof.

21. A method according to any of Claims 12 to 20, the output from an ECG sensor attached to the patient forms an input to the processor and wherein the algorithm synchronises the ECG output with the acquired pulse signal(s).

20. An apparatus for use in the assessment of peripheral arterial disease (PAD) in a patient substantially as shown in, and as described with reference to, the drawings.

21. A method for generating a shape distortion index indicative of the presence or absence of significant peripheral arterial disease in a patient substantially as shown in, and as described with reference to, the drawings.

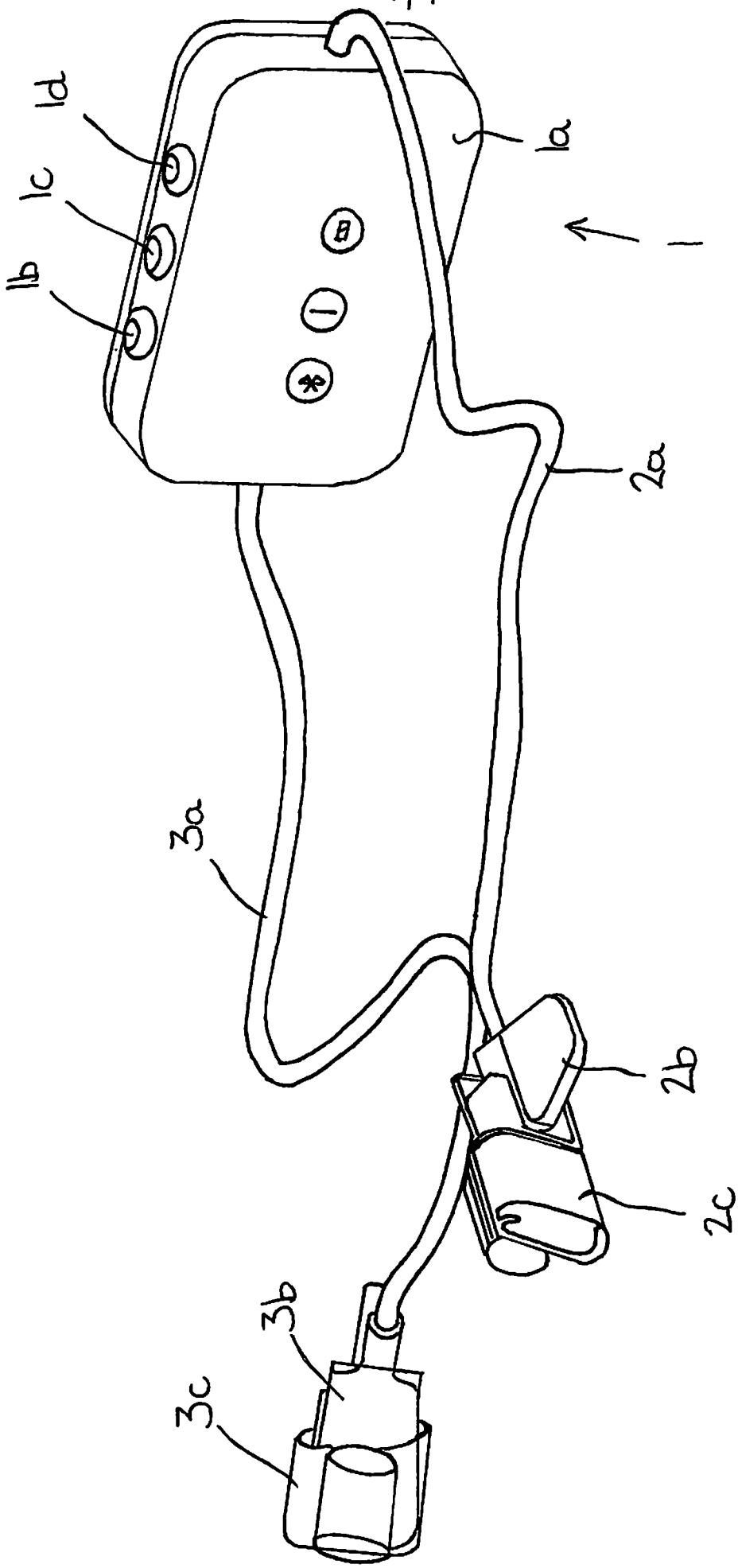

FIGURE 1

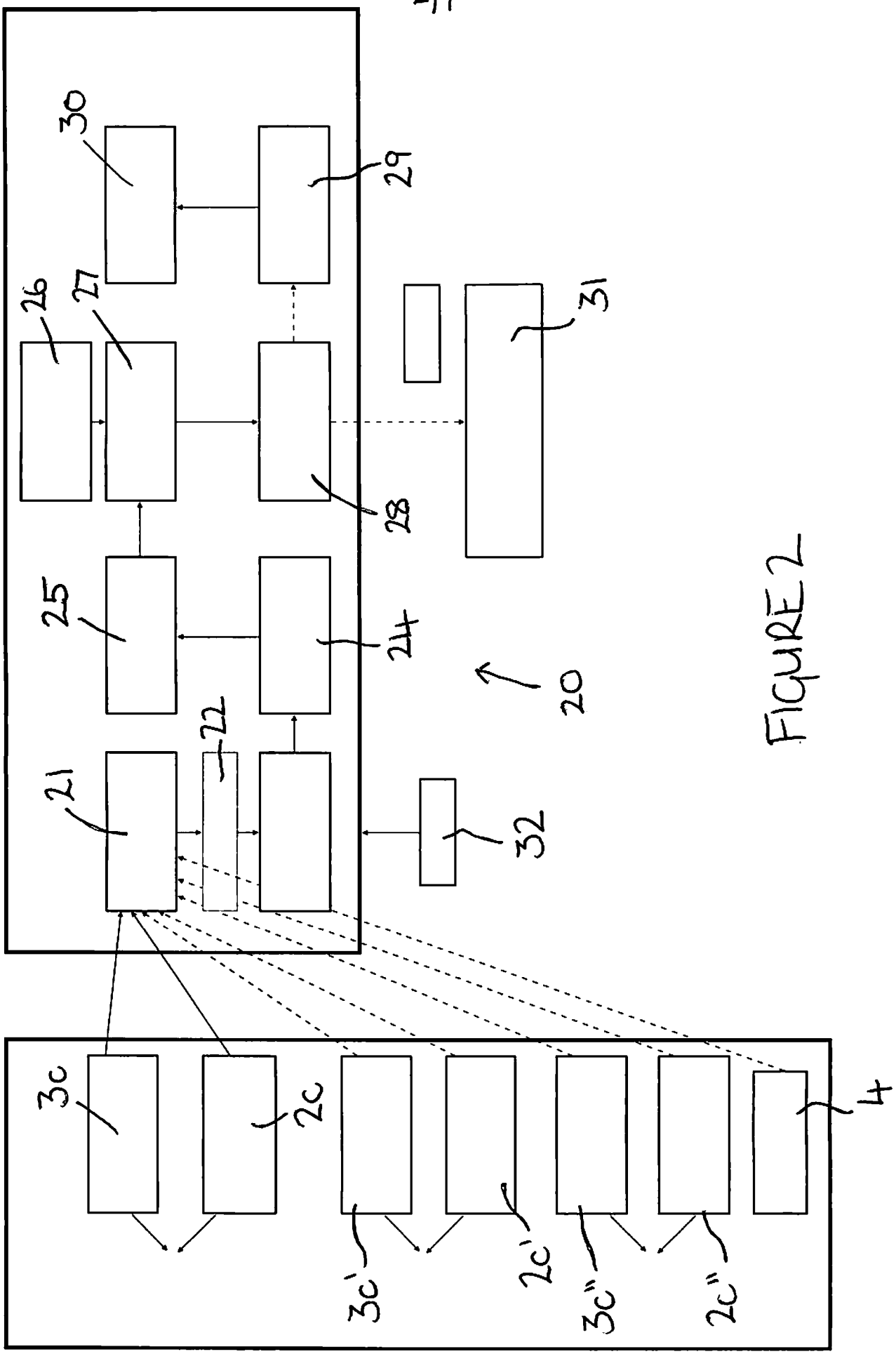

FIGURE 2

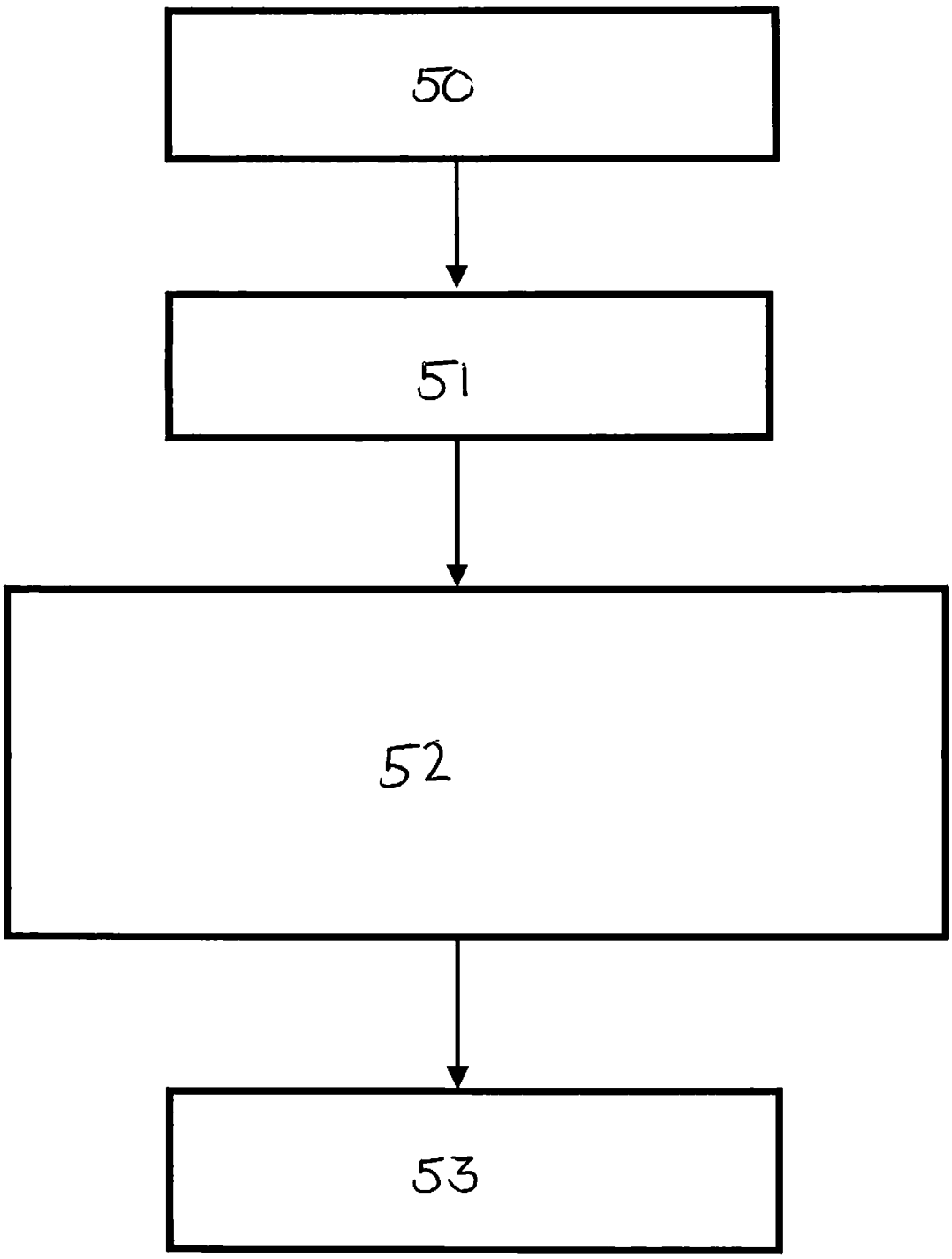

FIGURE 3

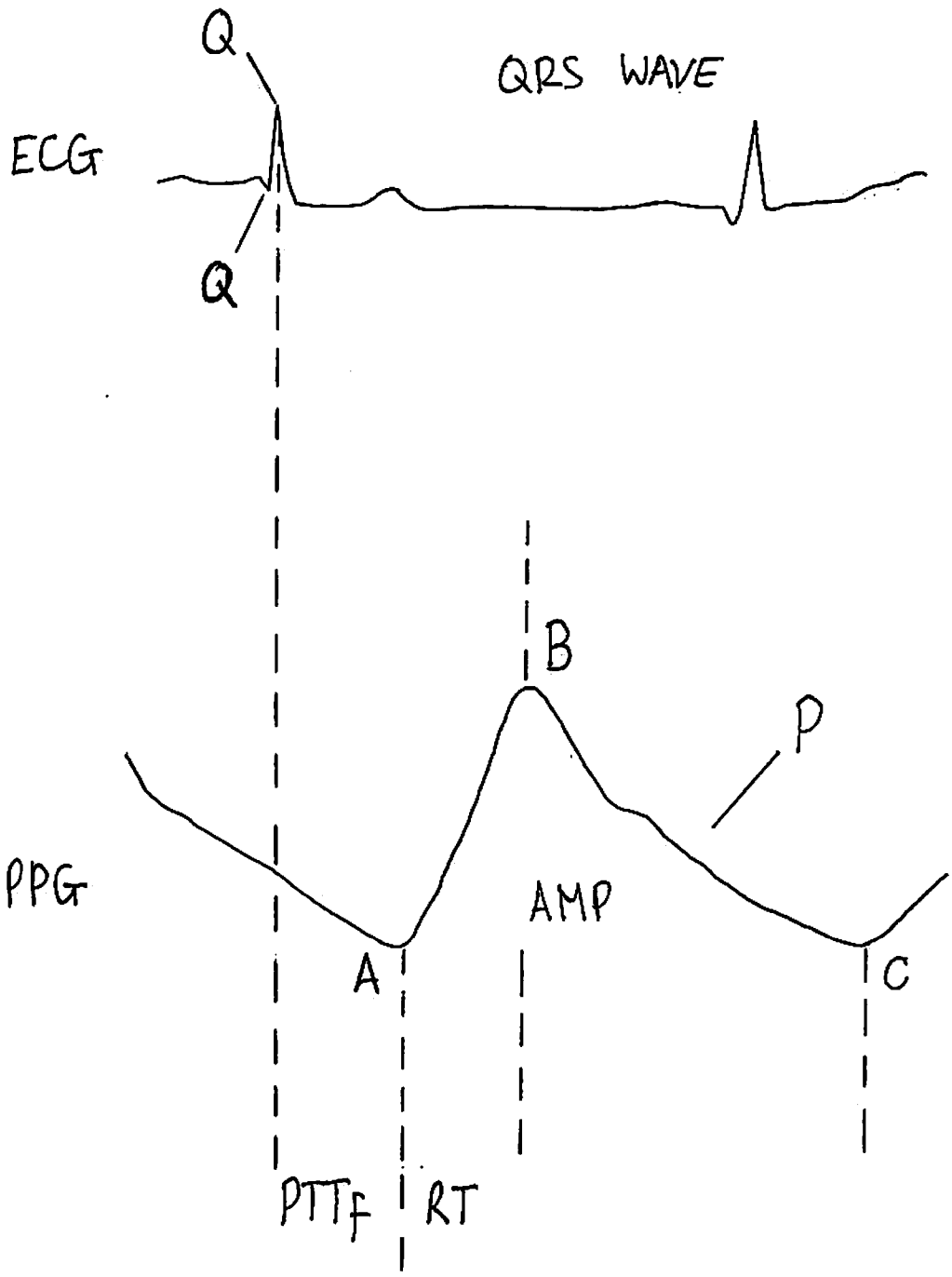

FIGURE 4a

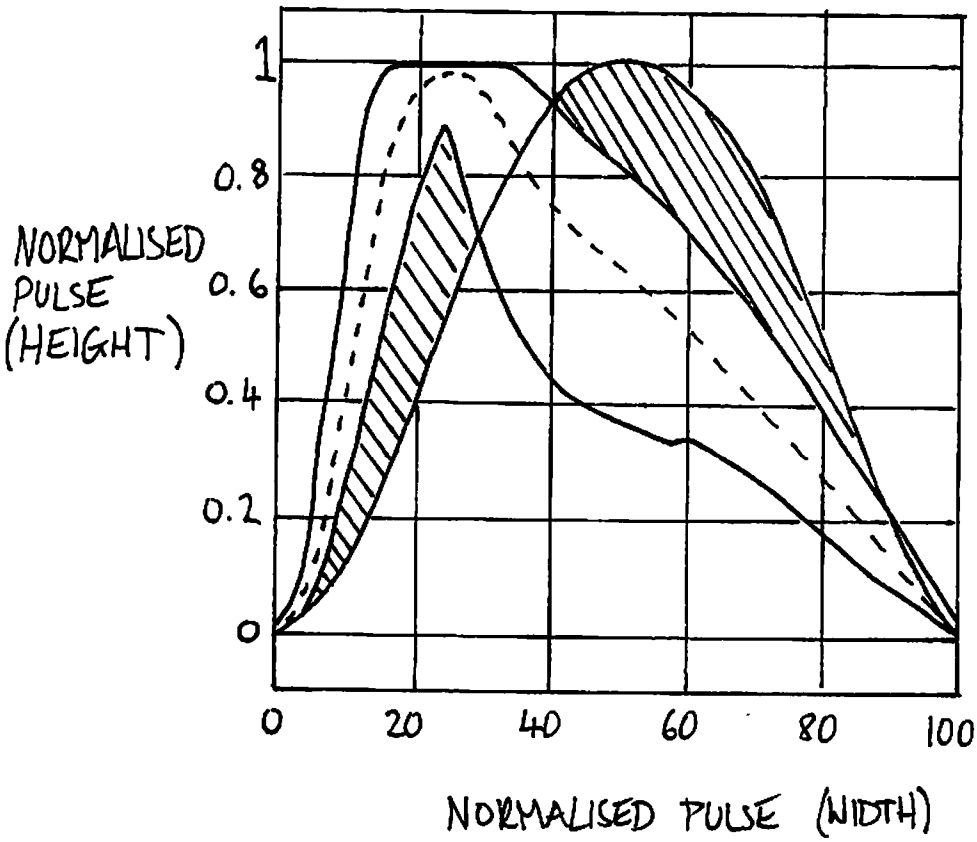
NORMALISED PULSE (HEIGHT)
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
NORMALISED PULSE (WIDTH)

FIGURE 4b

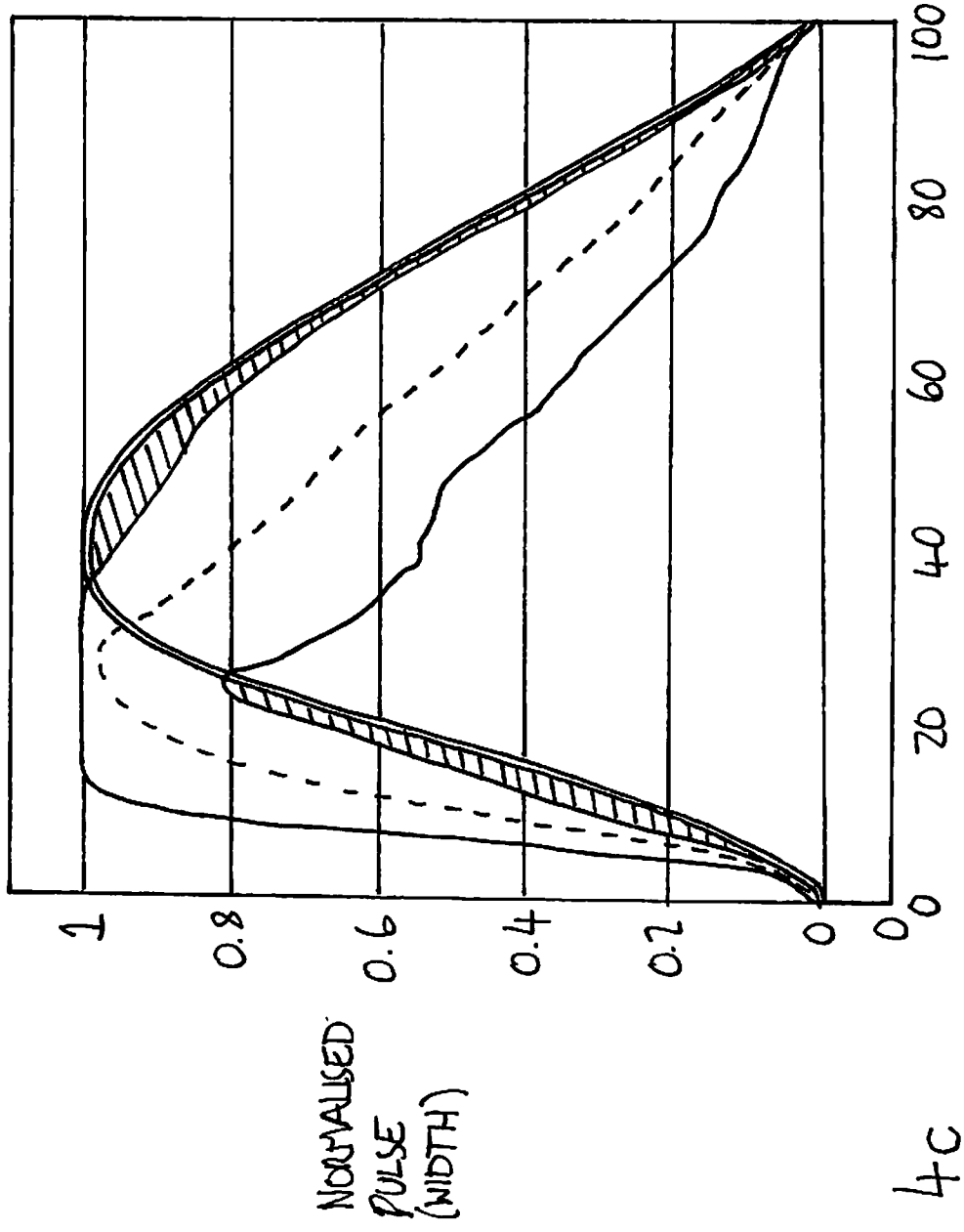
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
NORMALISED PULSE (WIDTH)
NORMALISED PULSE (WIDTH)

FIGURE 4c

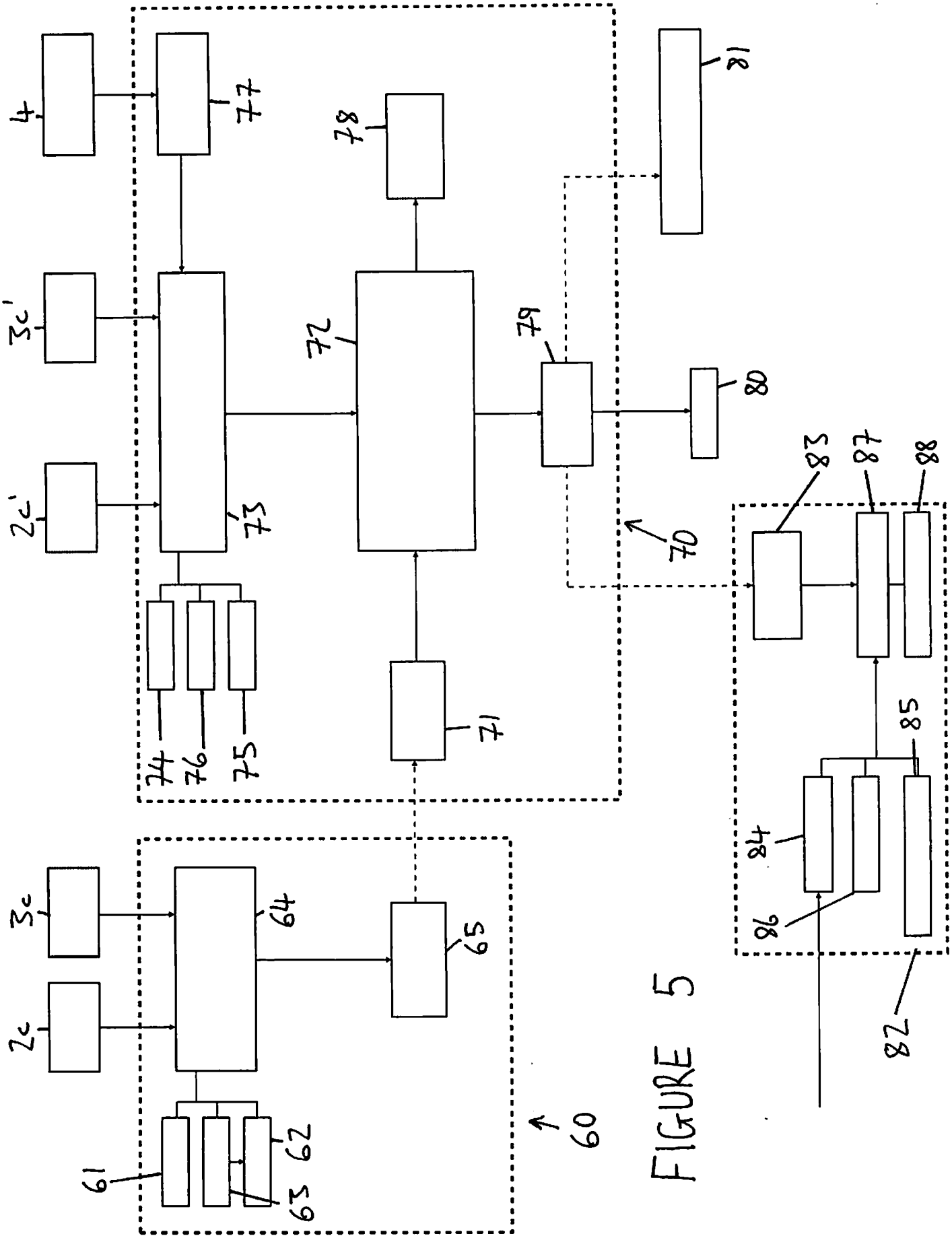
4
77
78
81
3c'
72
79
80
2c'
73'
70
83
87
88
74
76
75
71
85
84
86
82
3c
64
65
2c
61
62
63
60

FIGURE 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2017/051131

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JOHN ALLEN ET AL: "Photoplethysmography detection of lower limb peripheral arterial occlusive disease: a comparison of pulse timing, amplitude and shape characteristics; Photoplethysmography detection of arterial disease", PHYSIOLOGICAL MEASUREMENT, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 26, no. 5, 1 October 2005 (2005-10-01), pages 811-821, XP020092231, ISSN: 0967-3334, DOI: 10.1088/0967-3334/26/5/018 abstract * section 2.2. "Multi-site PPG pulse measurement system" * * section 2.4.1. "Pulse wave characterization" * * section 2.4.2. "Normative ranges of -/--	1-23

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 August 2017	28/08/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Knüpling, Moritz

1

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	multi-site pulse characteristics" * figure 1	
A	JOHN ALLEN: "TOPICAL REVIEW; Photoplethysmography and its application in clinical physiological measurement", PHYSIOLOGICAL MEASUREMENT, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 28, no. 3, 1 March 2007 (2007-03-01), pages R1-R39, XP020120750, ISSN: 0967-3334, DOI: 10.1088/0967-3334/28/3/R01 * passage bridging pages R4 and R5; figure 2, caption *	1-23
A	US 2012/197140 A1 (OKUDA NORIAKI [JP]) 2 August 2012 (2012-08-02) paragraph [0014]	1,2,12, 13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2017/051131

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012197140 A1	02-08-2012	JP 5252088 B2	31-07-2013
		JP WO2011048729 A1	07-03-2013
		US 2012197140 A1	02-08-2012
		WO 2011048729 A1	28-04-2011