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Cheng

(54) **METHOD AND DEVICE FOR MEASURING PARAMETERS OF CARDIAC FUNCTION**

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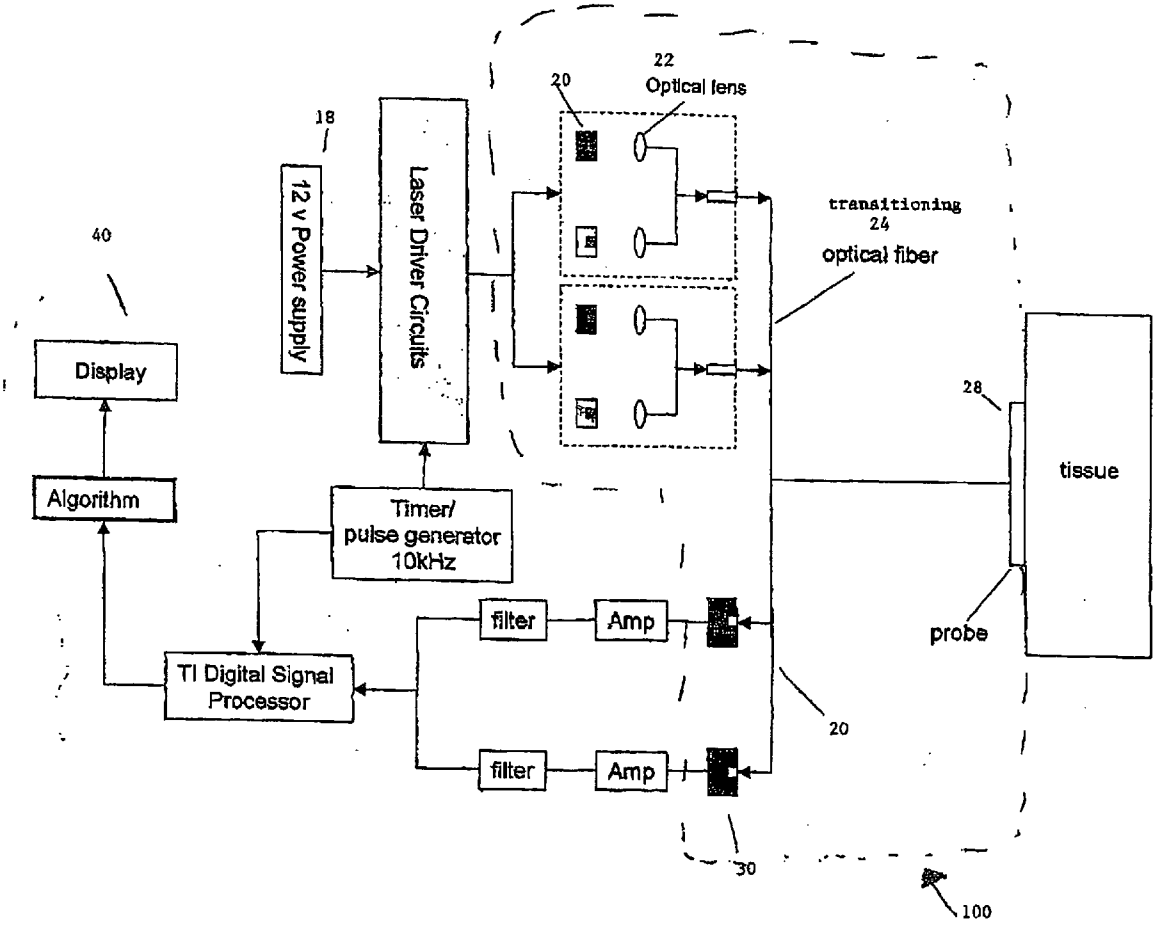
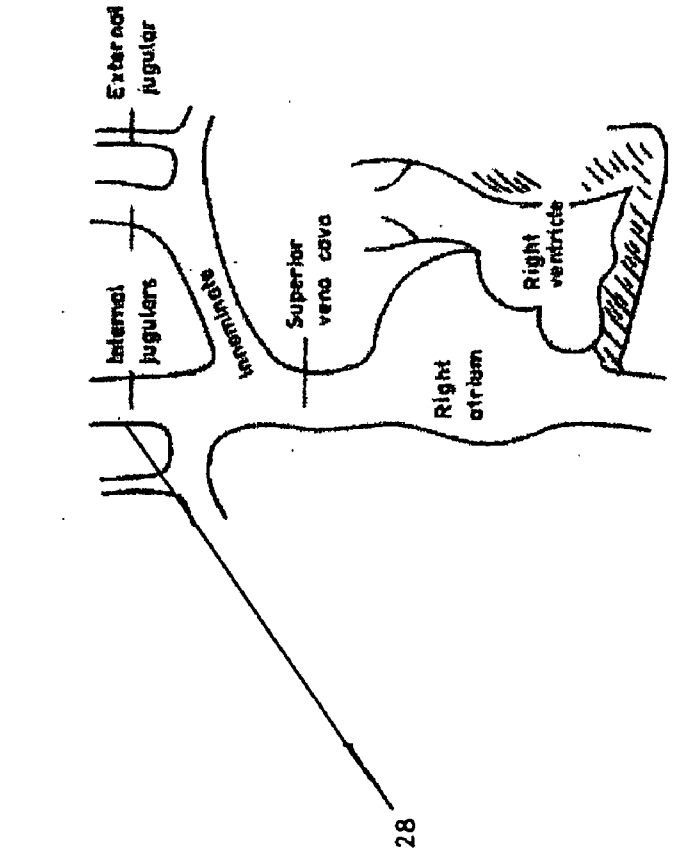
(57) **ABSTRACT**

A device for non-invasively measuring parameters of a cardiac blood vessel in a patient is provided. The device comprises at least one light source that emits light in the 400 nm to 1000 nm wavelength range and at least one photodetector adapted to receive light emitted by the light source, which light is reflected from or transmitted through tissue of the patient, the output of said photodetector correlating with a parameter of the blood vessel. The device also includes a probe which permits delivery of light from the light source to an external tissue site on the patient in the proximity of a cardiac blood vessel and permits the photodetector to receive light originating from the light source which has been reflected from or transmitted through tissue at the patient site.




External jugular
Internal jugulars
Innominate
Superior vena cava
Right atrium
Right ventricle
28

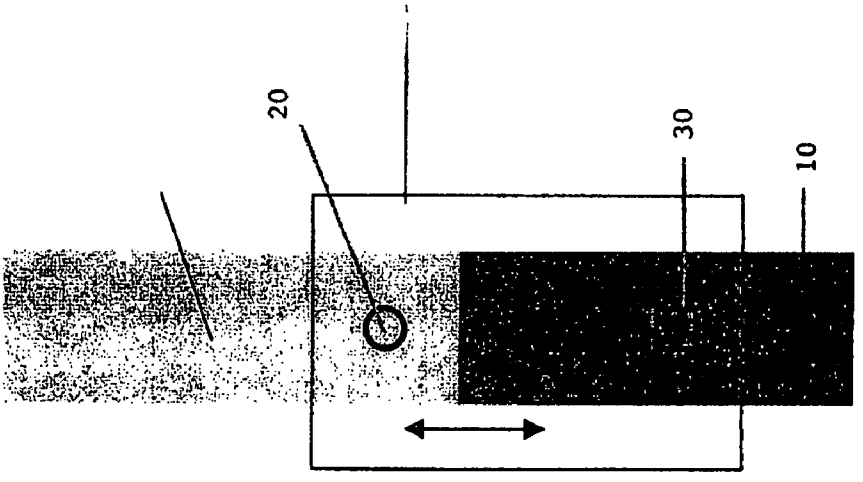

20
30
10

Figure 1

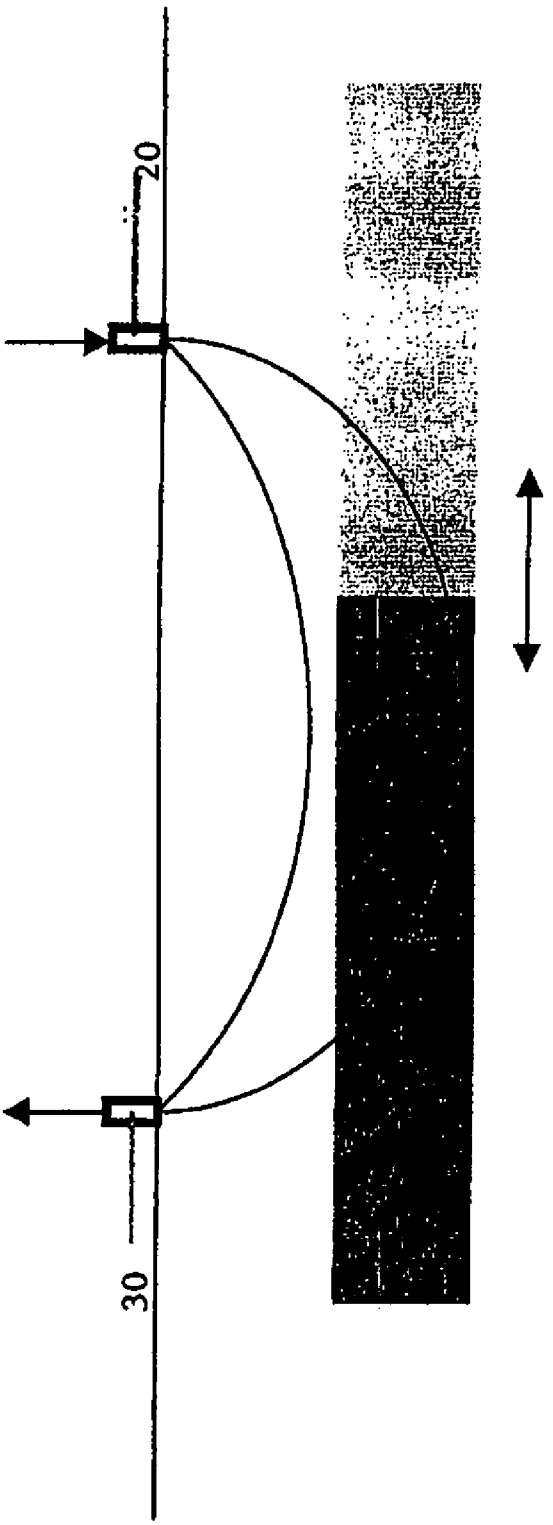


Figure 2

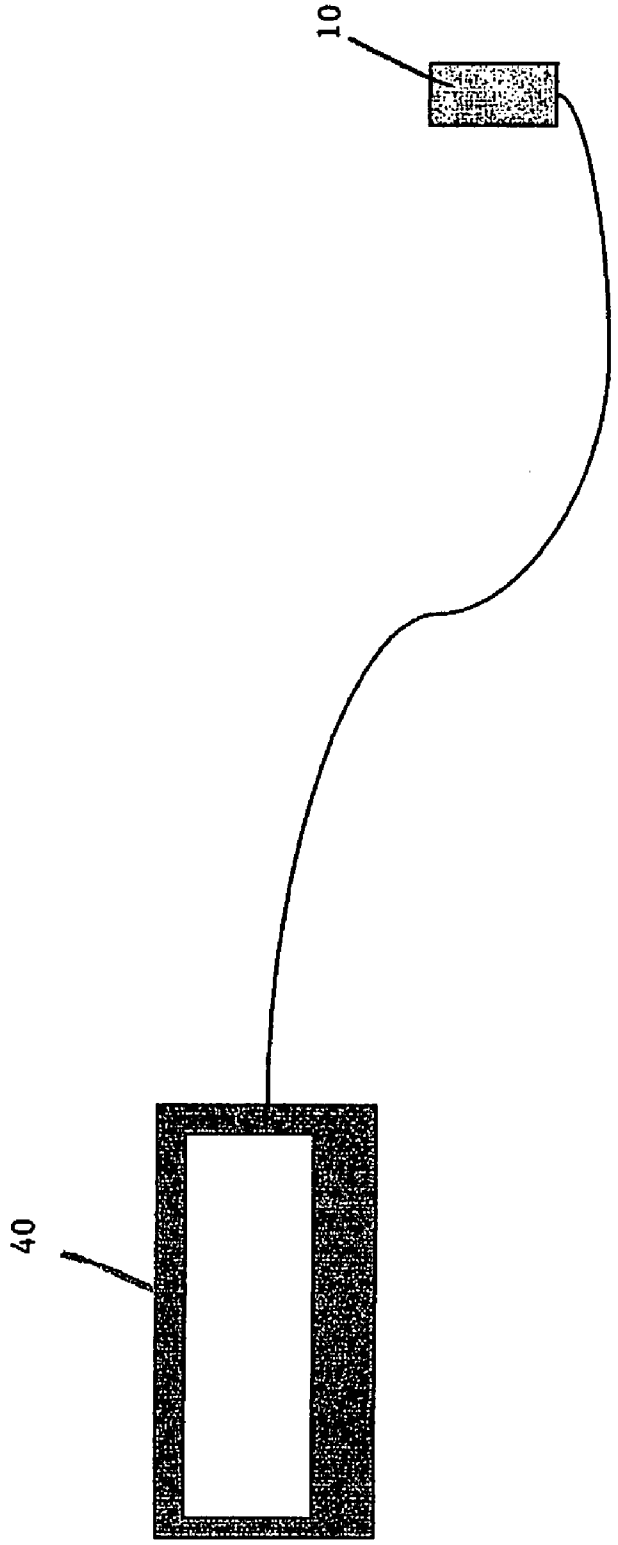
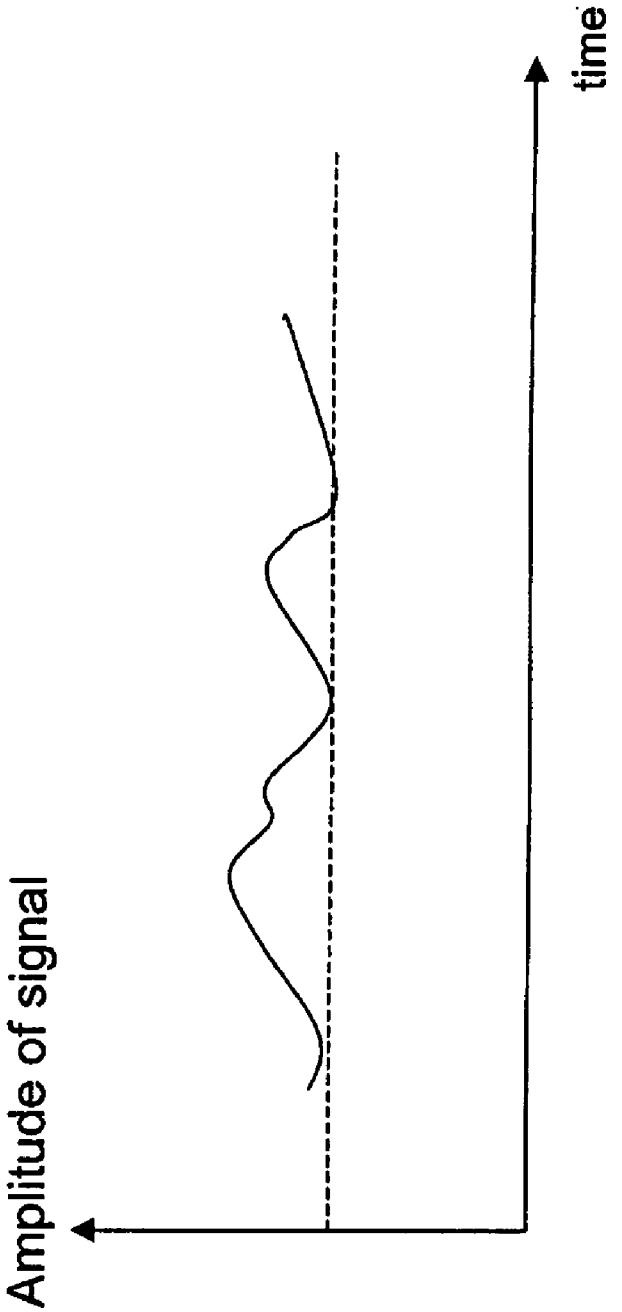


Figure 3

Figure 4



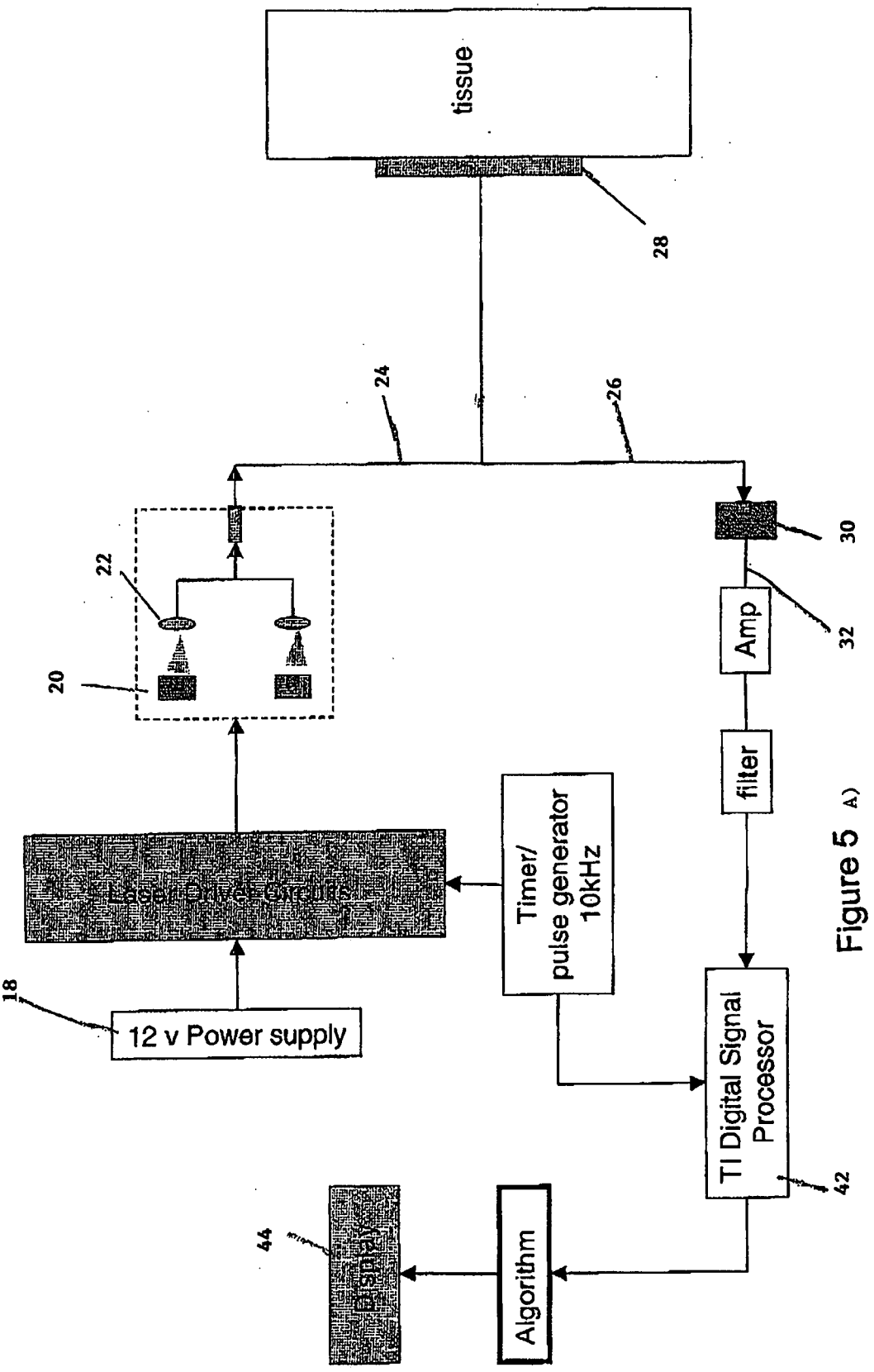

tissue
28
24
26
30
22
Amp
32
20
filter
Timer/
pulse generator
10kHz
Laser Driver Circuits
18
12 v Power supply
TI Digital Signal
Processor
42
Algorithm
44

Figure 5 A)

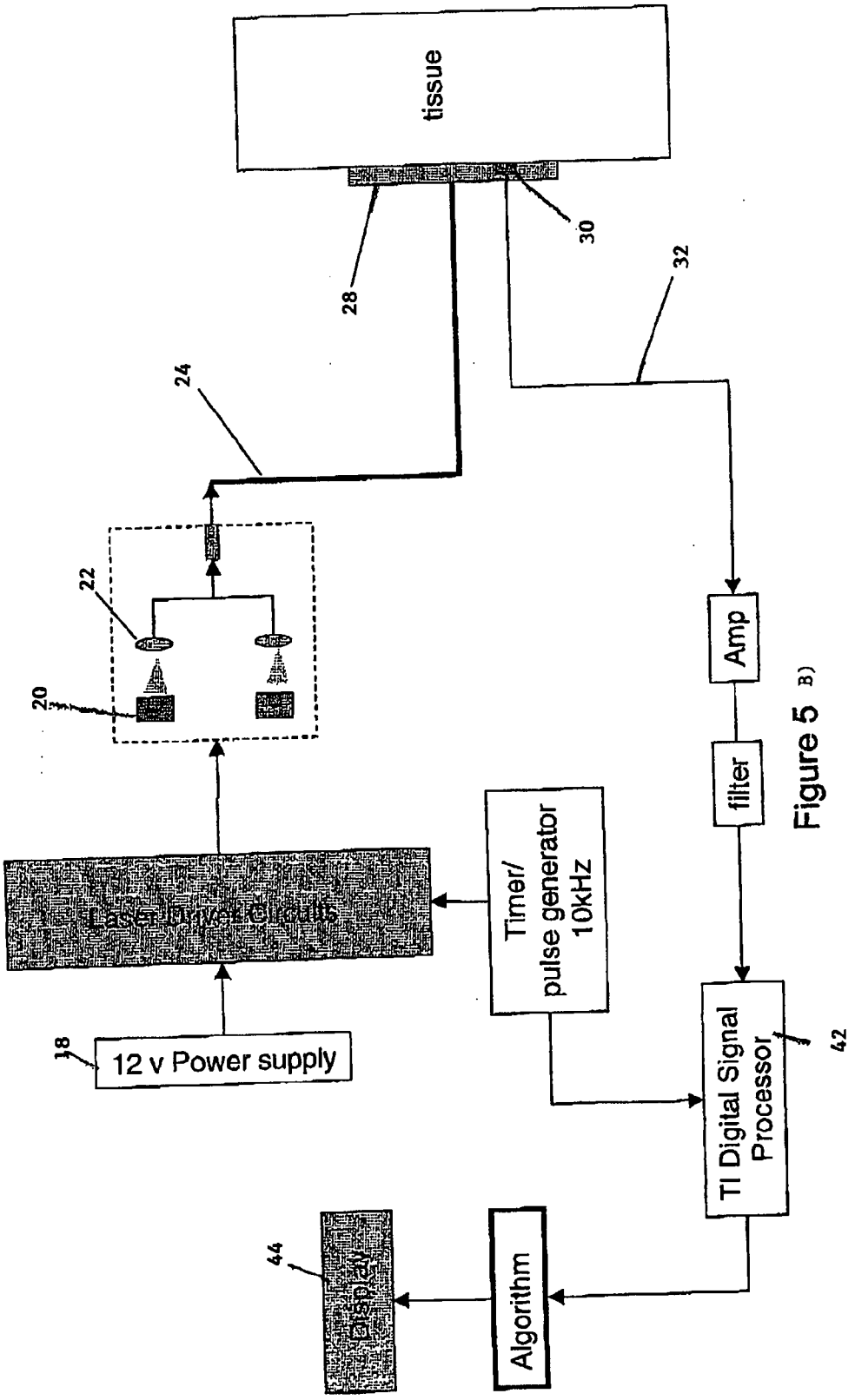

tissue
30
28
32
24
22
20
Amp
filter
Timer/
pulse generator
10kHz
Laser Driver Circuits
12 v Power supply
18
TI Digital Signal
Processor
42
Algorithm
44
Display

Figure 5 B)

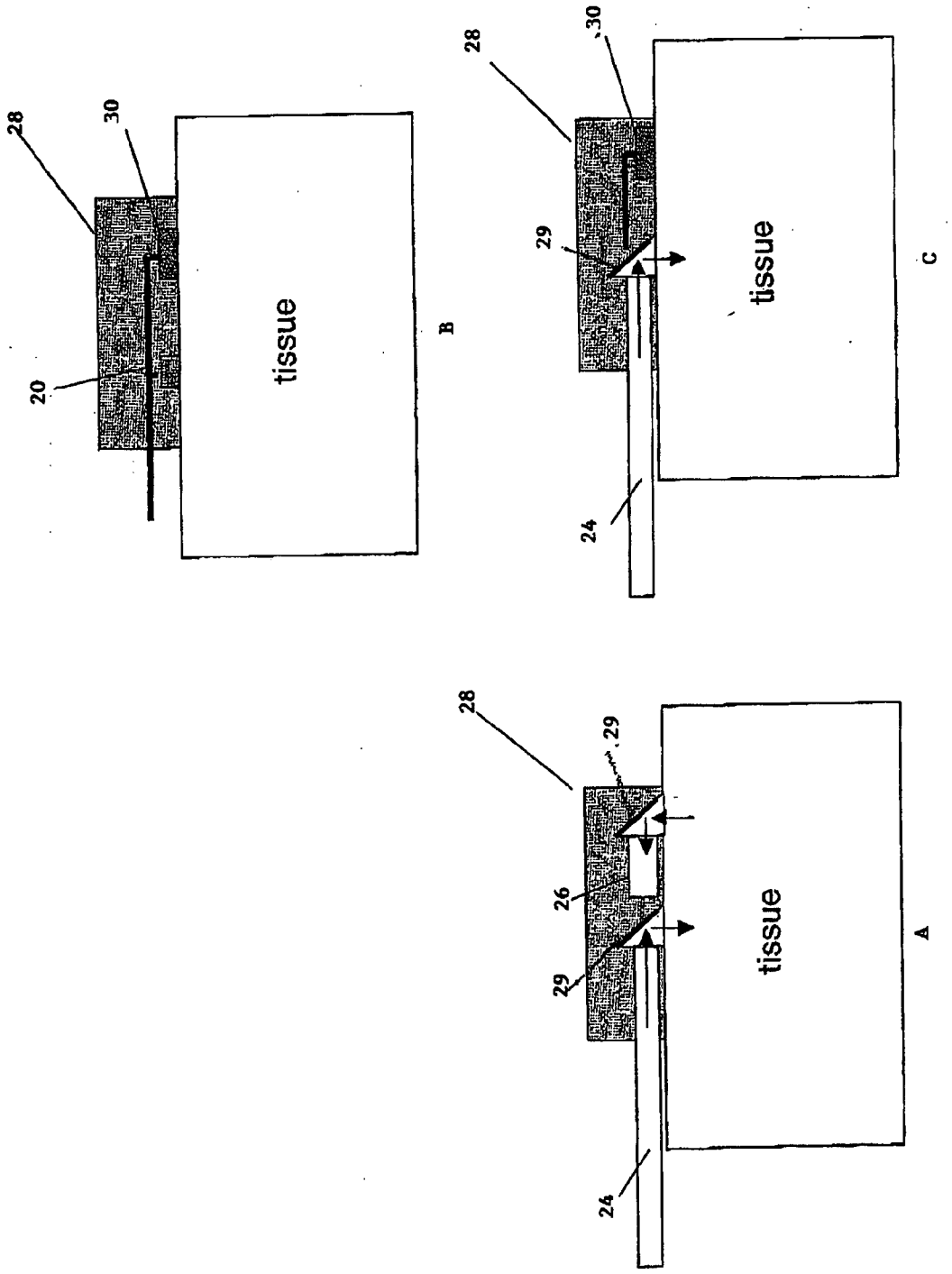


Figure 6

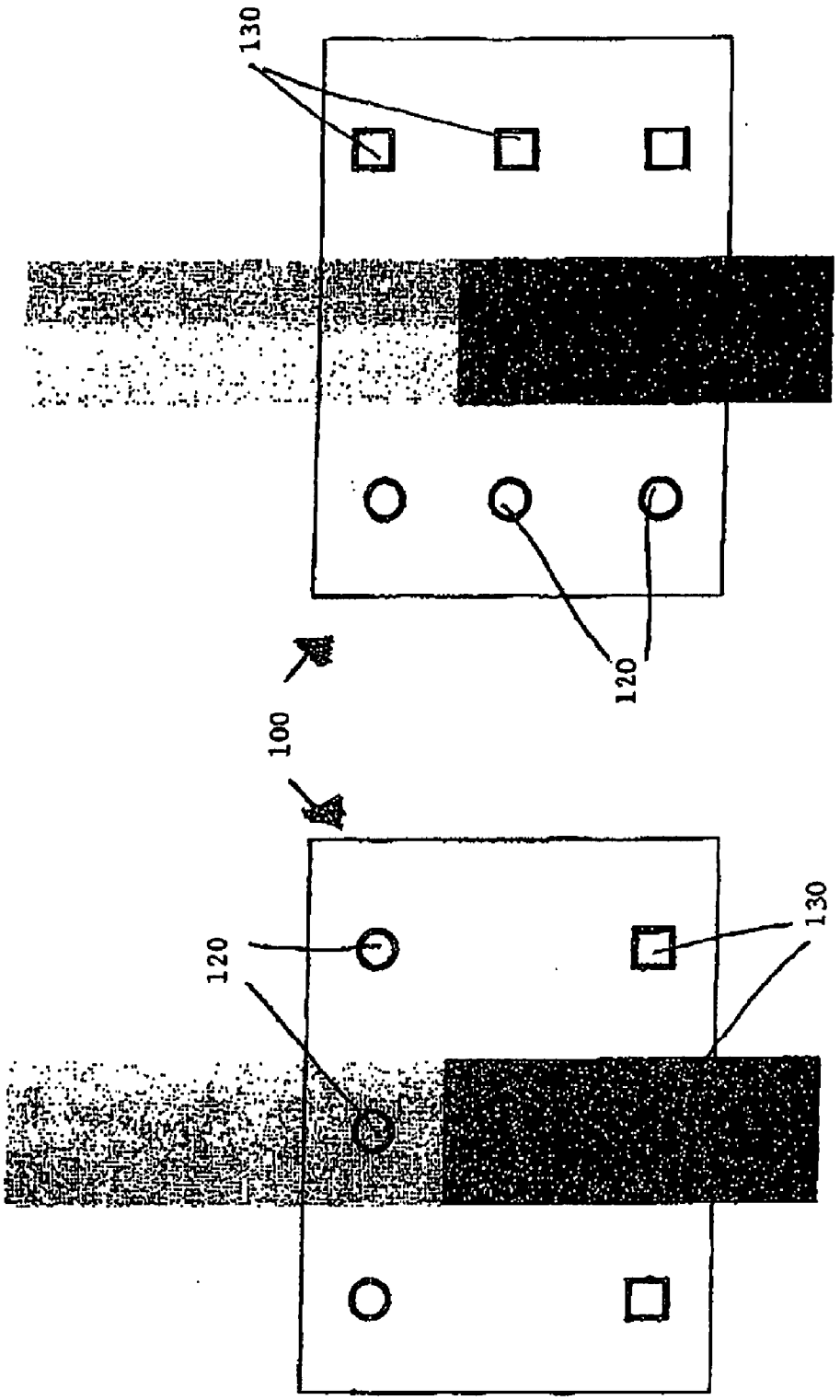


Figure 7

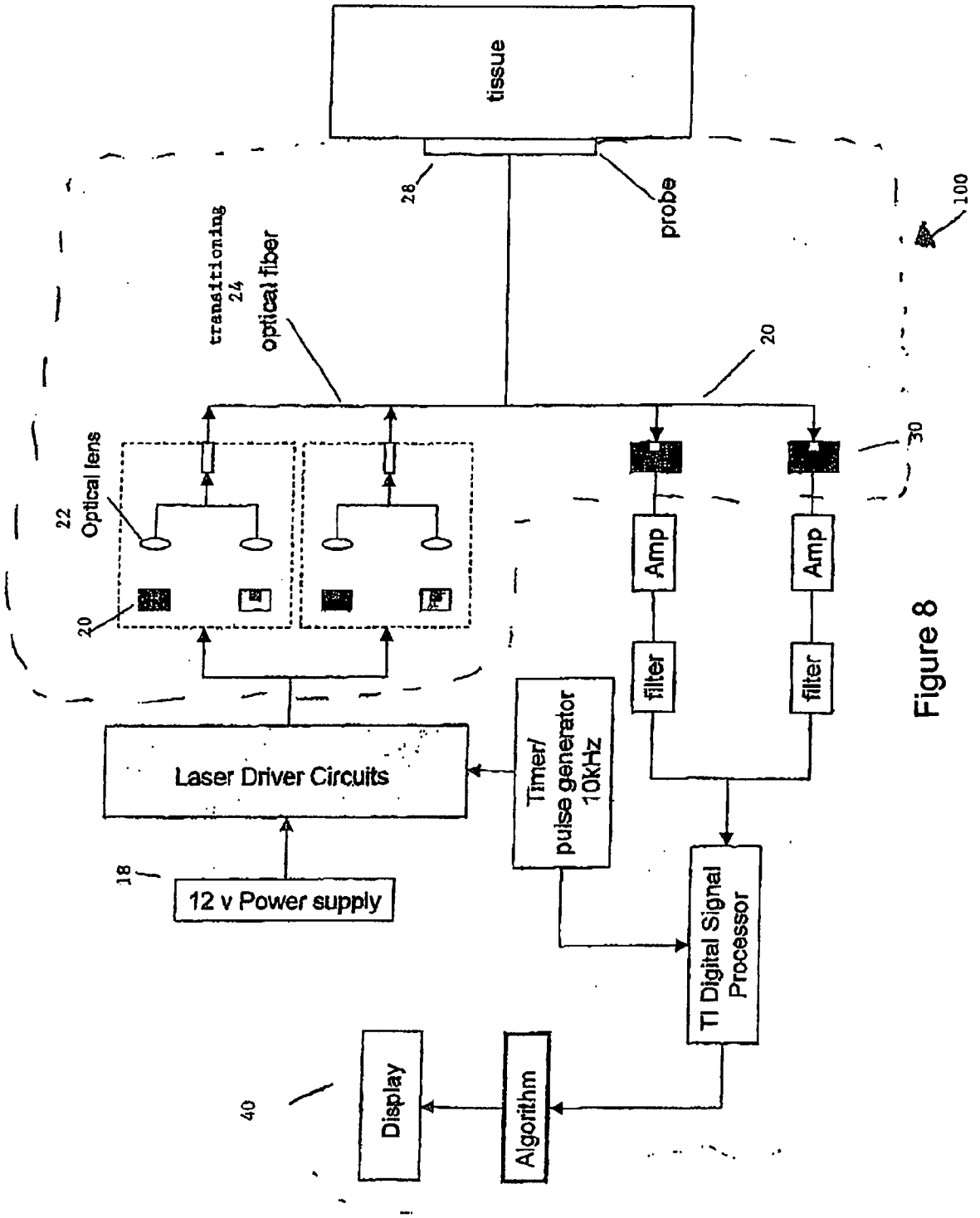
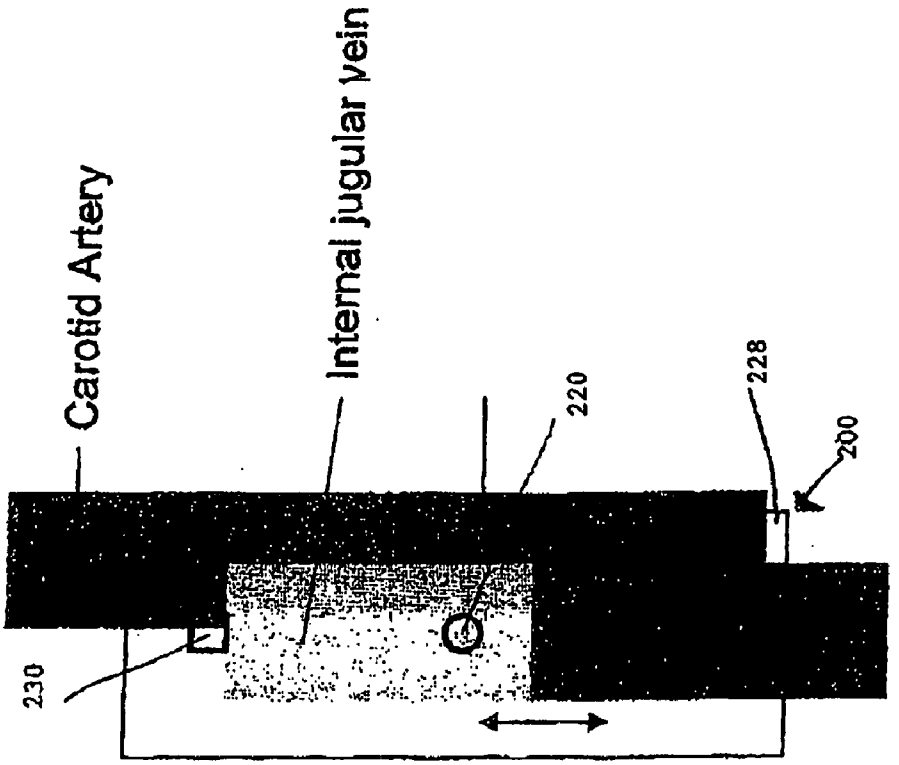
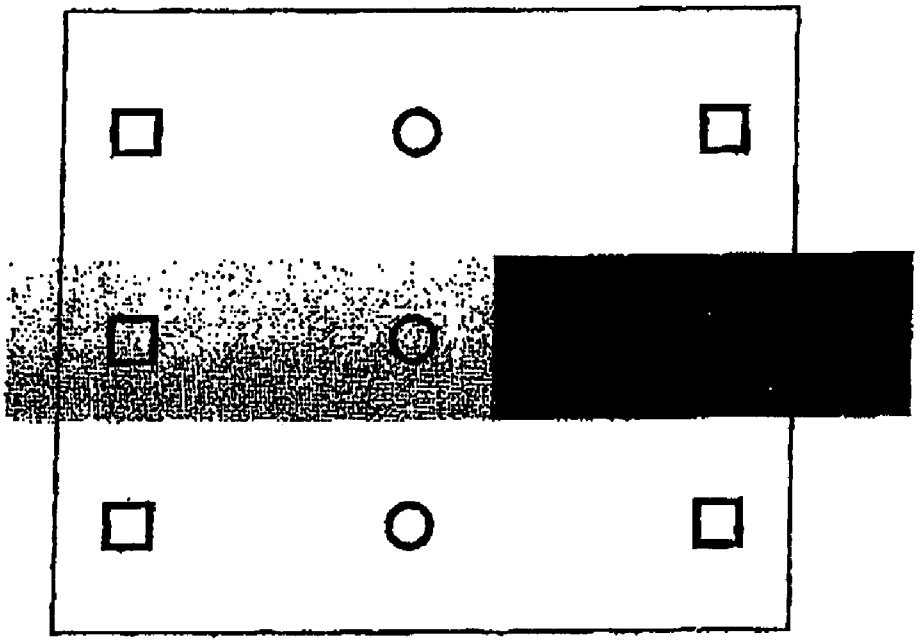

tissue
28
probe
100
transitioning
24
optical fiber
20
Optical lens
22
20
30
Amp
Amp
filter
filter
Laser Driver Circuits
Timer/
pulse generator
10kHz
18
12 v Power supply
TI Digital Signal
Processor
40
Display
Algorithm

Figure 8

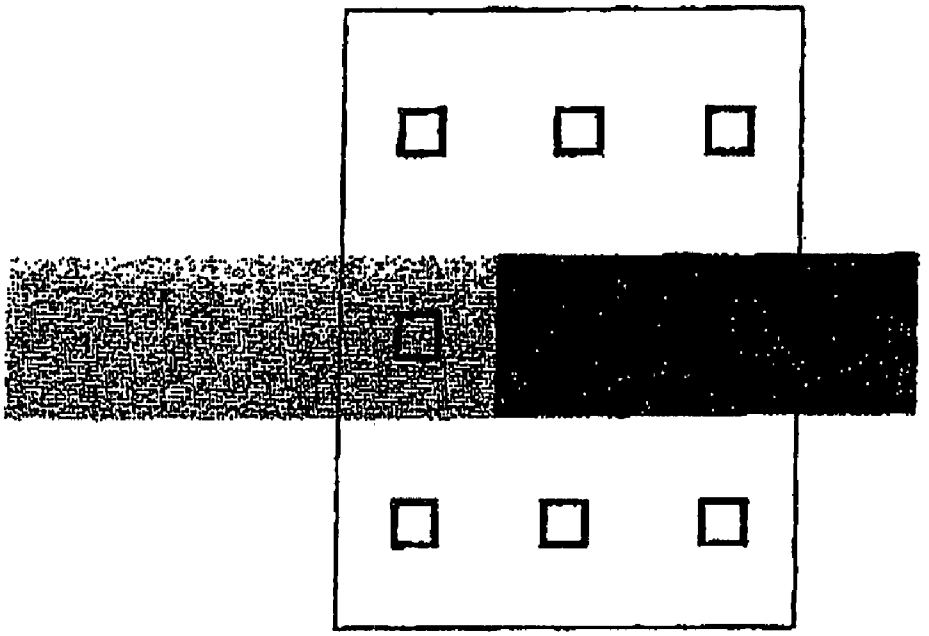


A)

Figure 9



C)



B)

Figure 9

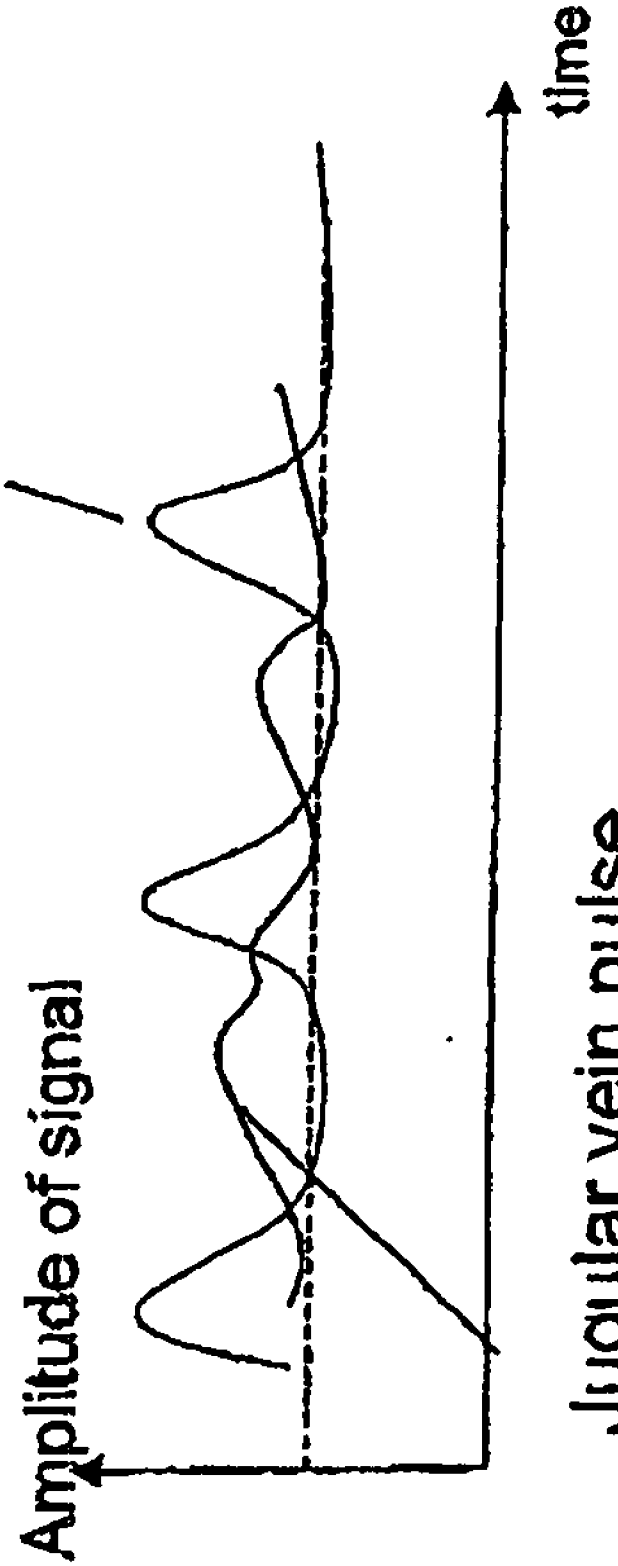
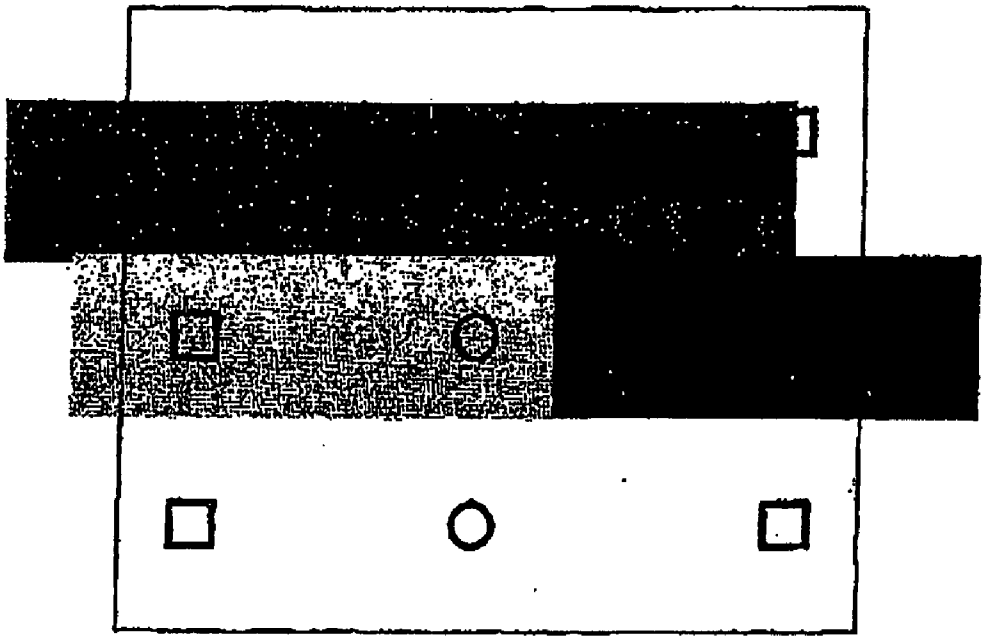

Carotid artery pulse
time
Amplitude of signal
Jugular vein pulse

Figure 10

Figure 11



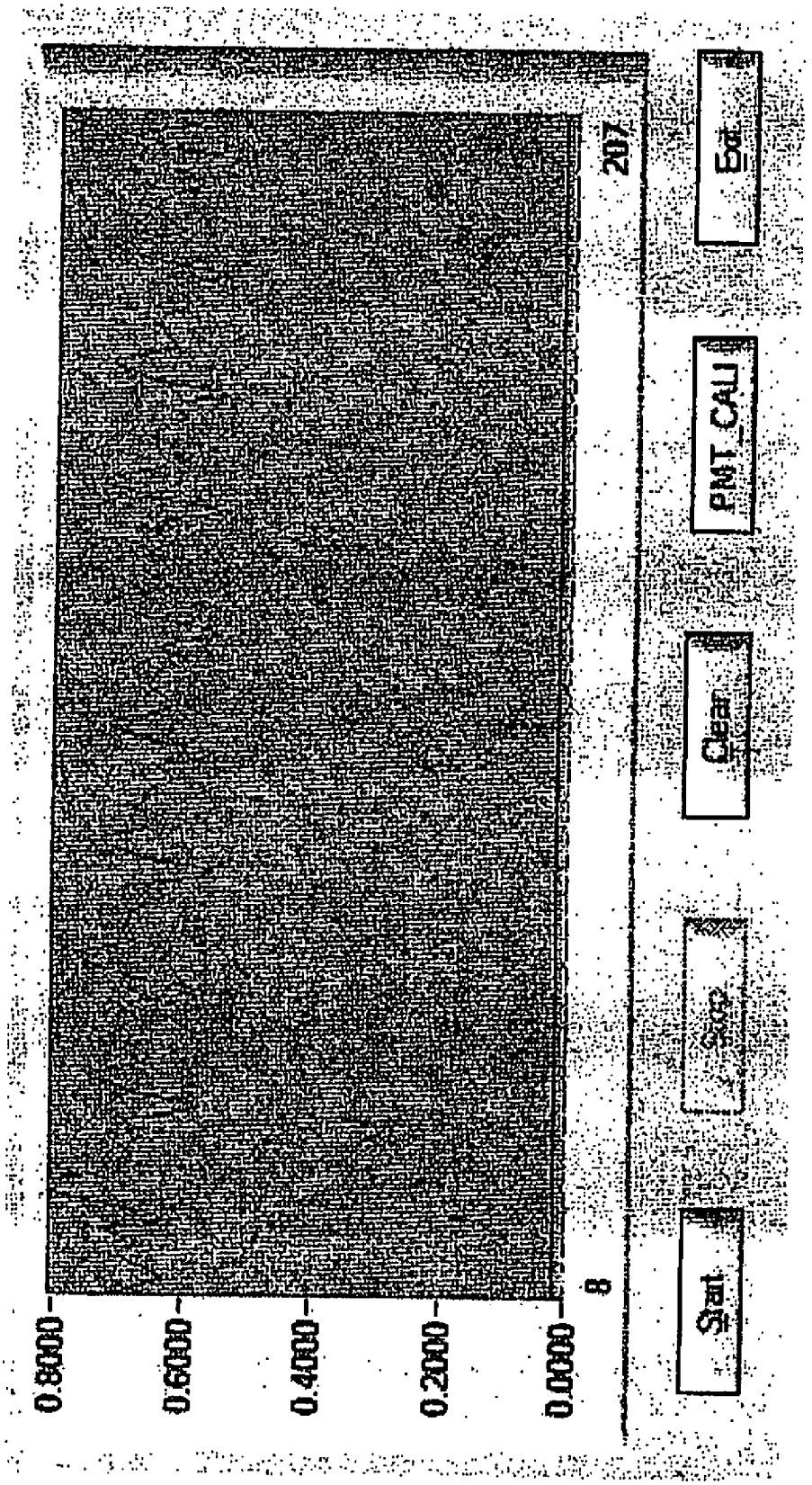

0.8000
0.6000
0.4000
0.2000
0.0000
8
207
Start
Clear
PMT_CALI
Exit

Figure 12

METHOD AND DEVICE FOR MEASURING PARAMETERS OF CARDIAC FUNCTION

FIELD OF THE INVENTION

[0001] The present invention is related to techniques for monitoring vital functions of the human body, including cardiac functions such as cardiac output and central venous blood oxygenation. It relates, in particular, to an optical method and device for the non-invasive and continuous monitoring of cardiac parameters such as blood flow, blood volume and blood oxygen saturation.

BACKGROUND OF THE INVENTION

[0002] The evaluation of jugular venous pulse has been an integral part of cardiovascular examination and has important clinical diagnostic values [1-2]. Jugular venous pulse is produced by the changes in blood flow and pressure in central veins caused by right atrial and ventricular filling and contraction. The two main objectives of the bedside examination of jugular vein pulse include the estimation of central venous pressure and the inspection of the waveform. Because of its more direct route to the right atrium, the right internal jugular vein is superior for the purpose. Based upon these measurements, physicians can access hemodynamic events in the right atrium and thus diagnose heart diseases and abnormalities. For example, the most common cause of elevated jugular venous pressure is an increase in right ventricular pressure such as occurs in patients with pulmonary stenosis, pulmonary hypertension, or right ventricular failure secondary to right ventricular infarction. The venous pressure also is elevated when obstruction to right ventricular inflow occurs, such as with tricuspid stenosis or right atrial myxoma, or when constructive pericardial disease impedes right ventricular inflow. It may also result from vena caval obstruction and, at times, an increase blood volume. Patients with obstructive pulmonary disease may have an elevated venous pressure only during expiration.

[0003] The conventional technique for measuring venous pulse and waveform has been described in the literature [3]. The patient is examined at the optimum degree of trunk elevation for visualization of venous pulsations. The venous pressure is measured by a ruler as the vertical distance from the top of the oscillating venous column, to the level of the sternal angle plus vertical distance to the right atrium Due to the fact that the venous pulse is in generally very small, and due to complications with patients, this method is challenging for physicians to use and provides approximate values only.

[0004] Cardiac output is defined as the volume of blood circulated per minute. It is equal to the heart rate multiplied by the stroke volume (the amount ejected by the heart with each contraction). Cardiac output is of central importance in the monitoring of cardiovascular health [4]. Accurate clinical assessment of circulatory status is particularly desirable in critically ill patients in the ICU and patients undergoing cardiac, thoracic, or vascular interventions, and has proven valuable in long term follow-up of outpatient therapies. As a patient's hemodynamic status may change rapidly, continuous monitoring of cardiac output will provide information that allows rapid adjustment of therapy. Measurements of cardiac output and blood pressure can also be used to calculate peripheral resistance.

[0005] Jansen (J. R. C. Jansen, "Novel methods of invasive/non-invasive cardiac output monitoring", Abstracts of the 7th annual meeting of the European Society for Intravenous Anesthesia, Lisbon 2004) describes eight desirable characteristics for cardiac output monitoring techniques; accuracy, reproducibility or precision, fast response time, operator independency, ease of use, continuous use, cost effectiveness, and no increased mortality and morbidity.

[0006] Pulmonary artery catheter (PAC) thermodilution method is generally accepted as the clinical standard for monitoring cardiac output, to which all other methods are compared as discussed by Conway and Lund-Johansen [6]. As this technology is highly invasive, complicated, and expensive, many new methods have been developed in an attempt to replace it, but none have so far gained acceptance. A recent review of the various techniques for measuring cardiac output is given in Linton and Gilon [5]. This article lists both non/minimally invasive and invasive methods and compares the advantages and disadvantages of each. A brief description of some of these techniques follows.

[0007] Indicator dilution techniques There are several indicator dilution techniques including transpulmonary thermodilution (also known as PiCCO technology, Pulsion Medical Technologies of Munich, Germany), transpulmonary lithium dilution method (LiDCO Group plc of London, UK), PAC based thermo-dilution and other methods (Vigilance, Baxter; Opti-Q, Abbott; and TruCCOMS, AorTech). Application of such techniques assumes three major conditions, namely, complete mixing of blood and indicator, no loss of indicator between place of injection and place of detection, and constant blood flow. The errors associated with indicator dilution techniques are primarily related to the violation of these conditions, as discussed by Lund-Johansen [7-8].

[0008] Fick principle. The direct oxygen Fick approach is currently the standard reference technique for cardiac output measurement as discussed by Keinanen et al [9-10]. It is generally considered the most accurate method currently available. The NICO (Novametrix) system is a non-invasive device that applies Fick's principle and relies solely on airway gas measurement as described by Botero et al [11]. This method shows a lack of agreement between thermodilution and CO_2-rebreathing cardiac output as described in Nielsson et al [12], due to unknown ventilation/perfusion inequality in patients.

[0009] Bio-Impedance and conduction techniques. The bio-impedance method was developed as a simple, low-cost method that gives information about the cardiovascular system and/or (de)-hydration status of the body in a non-invasive way. Over the years, a diversity of thoracic impedance measurement systems have also been developed. These systems determine CO on a beat-to-beat time basis. Studies have been reported with mostly poor results, but in some exceptional cases, there was good correlation with a reference method. Many of these studies refer to the poor physical principles of the thoracic impedance method as described in Patterson "Fundamentals of impedance cardiography", IEEE Engineering in Medicine and Biology 1989; 35 to explain the discrepancies.

[0010] Echo-Doppler ultrasound. This technique uses ultrasound and the Doppler Effect to measure cardiac output. The blood velocity through the aorta causes a 'Doppler shift' in the frequency of the returning ultrasound waves. Echo-Doppler probes positioned inside the esophagus with their echo window on the thoracic aorta may be used for measuring aortic flow velocity, as discussed by Schinidlin et al [13]. Aortic cross sectional area is assumed in devices such as the

CardioQ, made by Deltex Medical PLC, Chichester, UK, or measured simultaneously as, for example, in the HemoSonic device made by Arrow International. With these minimally invasive techniques what is measured is aortic blood flow, not cardiac output. A fixed relationship between aortic blood flow and cardiac output is assumed. Echo-Doppler ultrasound requires an above average level of skill on the part of the operator of the ultrasound machine to get accurate reliable results.

[0011] Arterial pulse contour analysis. The estimation of cardiac output based on pulse contour analysis is an indirect method, since cardiac output is not measured directly but is computed from a pressure pulsation on the basis of a criterion or model [14-17]. Three pulse contour methods are currently available; PiCCO (Pulsion), PulseCO (LiDCO) and Modelflow (TNO/BMI). All three of these pulse contour methods use an invasively measured arterial blood pressure and they need to be calibrated. PiCCO is calibrated by transpulmonary thermodilution, LIDCO by transpulmonary lithium dilution and Modelflow by the mean of 3 or 4 conventional thermodilution measurements equally spread over the ventilatory cycle.

[0012] Near infrared spectroscopy has been used to non-invasively measure various physiological properties in animal and human subjects. The basic principle underlying near infrared spectroscopy is that a physiological medium such as tissues includes a variety of light-absorbing (chromophores) and light-scattering substances which can interact with transmitted low energy near infrared photons. For example, deoxygenated and oxygenated hemoglobins in human blood are the most dominant chromophores in the spectrum range of 400 nm to 1000 nm. Therefore, diff-use optical spectroscopy has been applied to non-invasively measure oxygen levels in the physiological medium in terms of tissue hemoglobin oxygen saturation. Technical background for diffuse optical spectroscopy has been discussed in, e.g., Neuman, M. R., Pulse Oximetry: Physical Principles, Technical Realization and Present Limitations,@ Adv. Exp. Med. Biol., vol. 220, p. 135-144, 1987 and Severinghaus, J. W., History and Recent Developments in Pulse Oximetry,@ Scan. J. Clin. and Lab. Investigations, vol. 53, p. 105-111, 1993.

[0013] Because of the highly scattering nature of tissue to the visible and near infrared light (400 nm-1000 nm), it is difficult to apply diffuse optical spectroscopy non-invasively to select blood vessels within a tissue to calculate blood oxygenation. Thus, diff-use optical spectroscopy has only been used to measure the combined or average oxygenation of blood from arteries, veins, and capillaries within a tissue medium. However, in many clinical applications, it is desirable to know the blood oxygenation of particular blood vessels. To do so, various invasive methods have been developed which involve the use of catheters that must be inserted into a targeted blood vessel to make the measurement.

[0014] None of the above-mentioned techniques of measuring cardiac output combines all of the eight "Jansen" criteria mentioned above and, thus, none can displace the conventional thermodilution technique as described by Jansen et al [18]. Although highly invasive, complicated and expensive, the conventional thermodilution method remains the method of choice for measuring cardiac output. Given the foregoing, it would be highly desirable to develop a non-invasive method for real-time monitoring of cardiac output in a clinical setting which is accurate, reliable, cost effective and easy to use.

SUMMARY OF THE INVENTION

[0015] The present invention provides a device and method by which cardiac output can be continuously monitored in a non-invasive manner by the optical measure of venous blood flow and blood content including oxygenation.

[0016] In one aspect of the invention, a device for measuring the at least one parameter of a cardiac blood vessel in a patient is provided. The device comprises:

[0017] at least one light source that emits light in the 400 nm to 1000 nm wavelength range;

[0018] at least one photodetector adapted to receive light emitted by the light source, wherein said light is reflected from or transmitted through tissue of the patient, the output of said photodetector correlating with a parameter of the blood vessel; and

[0019] a probe which permits delivery of light from the light source to an external tissue site on the patient in the proximity of a cardiac blood vessel and permits the photodetector to receive light originating from the light source which has been reflected from or transmitted through said patient site.

[0020] In another aspect of the invention, a method of generating a waveform of a cardiac blood vessel in a patient is provided. The method comprises the steps of:

[0021] directing a beam of light having a wavelength in the range of 400 nm to 1000 nm at an external tissue site in the proximity of the cardiac blood vessel of the patient;

[0022] detecting light reflected from the tissue or transmitted through the tissue; and

translating the detected light into an output signal against time to generate a waveform for the selected blood vessel.

[0023] In another aspect of the present invention, there is provided a method of measuring blood content of a chromophore in a patient. The method comprises the steps of:

[0024] directing light having at least first and second selected wavelengths at an external tissue site on the patient that is in the proximity of a cardiac blood vessel, wherein said selected wavelengths are based on the absorption characteristics of the chromophore;

[0025] detecting light reflected from the tissue or transmitted through the tissue at the selected wavelengths; and

[0026] translating the detected light into an output signal against time to generate a waveform for each selected wavelength in order to determine the blood content of said chromophore.

[0027] The waveform is the time varying component of optical signal associated with cardiac activities, which can be also translated into dynamic information of such as blood flow, blood volume and blood content within the vessel or physical displacement of blood vessel.

[0028] These and other aspects of the present invention will become apparent by reference to the detailed description that follows, and the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] FIG. **1** illustrates a top view of a device for monitoring cardiac output in accordance with an aspect of the invention and placement of the device relative to cardiac vessels;

[0030] FIG. **2** illustrates a side view of a device as in FIG. **1**;

[0031] FIG. **3** illustrates a system incorporating the device of FIG. **1**;

[0032] FIG. **4** illustrates a signal or waveform produced using a device as in FIG. **1**;

[0033] FIG. **5**(A and B) is a block diagram of a system incorporating a device as in FIG. **1**;

[0034] FIG. **6** illustrates probes (A, B and C) for use in the device;

[0035] FIG. **7** illustrates a top view of embodiments of the invention (A, B) comprising multiple light sources and photodetectors;

[0036] FIG. **8** is a block diagram of a system incorporating a device as in FIG. **7**;

[0037] FIG. **9** illustrates a top view of embodiments of the invention (A, B, C) comprising multiple photodetectors per light source;

[0038] FIG. **10** illustrates a dual signal (waveform) generated by an embodiment as in FIG. **9**;

[0039] FIG. **11** illustrates a top view of a cardiac monitoring device according to an embodiment of the invention comprising multiple sensor patches; and

[0040] FIG. **12** illustrates a waveform obtained using a device in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0041] A device **10** for measuring a parameter of cardiac function in a patient is provided as shown in FIG. **1**, comprising a light source **20** that emits light in the 400 nm to 1000 nm wavelength range, e.g. visible and infra-red light, a photodetector **30** adapted to receive transmitted and reflected light (as shown in FIG. **2**) and a patch probe **28** for placement on a patient at an external site in the vicinity of a cardiac blood vessel (as shown in FIG. **1**) which functions as the interface of the device between light source **20**/photodetector **30** and a selected external patient site. Thus, the probe **28** permits delivery of light emitted by the light source **20** to the selected patient site and transfer of light reflected from or transmitted through the patient site to the photodetector **30**. To generate a visual signal, the device **10** may additionally comprise a signal-producing means **40** (FIG. **3**) which communicates with the photodetector **30** to translate light received by the photodetector **30** into a recordable visual signal or waveform of the cardiac vessel, or central venous pulse, and time course plot of the cardiac parameter (FIG. **4**).

[0042] The light source **20** may be any suitable light source such as a laser diode (e.g. RLT7605G, 760 nm, 5 mW, sm, 9.0 mmh, or RLT8510MG, 850 nm, 100 mW, sm, 5.6 mm), a light emitting diode (LED) or a broadband light source emitting a selected wavelength in the range of 400 nm to 1000 nm. In an embodiment of the invention, the light source **20** emits light having a wavelength in the range of 780 nm and 850 nm. The light source **20** is powered by an appropriate power supply **18** such as a 12V DC power supply. Light from the light source **20** is directed to at least one external tissue site on the patient that is within close proximity to a cardiac blood vessel, such as the internal jugular vein, the external jugular vein and the carotid artery, while the internal jugular vein is preferred. The neck, for example, represents a suitable site for monitoring a cardiac parameter.

[0043] As shown in FIG. **5**A/**5**B, in one embodiment, light from the light source **20** may be directed or focussed by an optical lens **22** into a transmitting means **24**, such as transmitting optical fiber bundles, for transmission to the selected patient site. Receiving means **26**, such as optical fiber bundles **26**, may also be used to receive light that is reflected/transmitted from the patient site and convey this light to photodetector **30** (FIG. **5**A). As one of skill in the art will appreciate, each fibre optic bundle will incorporate fibres manufactured of material appropriate for the transmission of the wavelength of the light emitted from the light source **20**. For example, if the light source **20** emits in the visible wavelength range, both multiple mode plastic and glass optical fibres may be used. The number and diameter of the fibers in the fiber optic bundle is optimized empirically to provide the highest signal to noise ratio in a given application. In this embodiment, the transmitting and receiving optical fiber bundles **24**, **26** are set in the patch probe **28**, at distinct spaced sites or may be combined together at a single site. Optical mirrors **29** may be utilized to direct or reflect light from the transmitting fiber bundle **24** into the tissue at the selected patient site, and to direct reflected or transmitted light from the patient site into the receiving fiber bundle **26** (FIG. **6**A).

[0044] In an alternative embodiment, the light source **20** and photodetector **30** may be set directly in the patch probe **28** obviating the need for optical fibers as shown in FIG. **6**B. In yet another embodiment, a combination of the foregoing embodiments may be utilized in which the light source **20** is set directly in the probe **28** to deliver light to the patient site, while the reflected/transmitted light is received by optical fibers **26** for delivery to the photodetector **30**. A converse embodiment may also be used in which the probe **28** comprises transmitting optical fibers **24** to deliver light from the light source, and a photodetector **30** set directly in the probe **28** (FIG. **6**C).

[0045] The light source **20** or transmitting optical fibers **24** may be set in the same patch probe **28** as the photodetector **30** or receiving optical fibers **26**, or in a separate patch probe **28** for placement at a distinct site on the patient that is within a suitable distance from the photodetector **30** or receiving optical fibers **26** to permit detection of reflected/transmitted light. The distance between the component delivering light to the patient site (light source or transmitting optical fibers) and the component receiving light from the patient site (photodetector or receiving optical fibers) may vary depending on the nature of each of the components, while a typical distance is generally between 2 and 4 cm, for example, 3 cm.

[0046] The patch probe **28** may be made out of any material suitable to support the electronic/optical components it houses, e.g. light source, photodetector, optical fibers or mirrors, and which is compatible for placement on the skin. An example of one such suitable material is medical rubber. The patch **28** may be held in position manually, may be held in position by adhesives (one side of the patch may be coated with a material that is adhesive to skin such as a hydro gel adhesive) or may be adapted to be held in place with straps at either end thereof that can be tied. Opposing ends of the band may also include an adhesive material such as Velcro to facilitate their attachment and hold the device in place.

[0047] The photodetector **30** translates received reflected/transmitted light into a recordable output such as current or voltage. An example of a suitable photodetector **30** for use in the present device is a silicon photo diode (e.g. Hamamatsu S8553). Condensor lenses may be incorporated, if required, to refocus the reflected or transmitted beam of light. The device **10** may be connected to a signal producing means **40** to provide a visual output. The signal producing means **40** may comprise a microprocessor (e.g. digital signal processor, Texas Instruments) or digital acquisition board **42** to digitize

the signal from the photodetector **30**, and a display unit **44**, such as a monitor, which is connected to the microprocessor **42** (FIG. **5**), to display the signal as a waveform. For convenience, the monitor may be portable, and battery operated. The absorbance values collected at regular user-determined intervals, for example, 10 data points/mm, are stored as a spreadsheet associated with a cardiac parameter or cardiac output. The display unit **44** functions in real-time to display the selected blood vessel waveform against time which can be used as described below to calculate the cardiac parameter or cardiac output.

[0048] A sample display of the signal or waveform obtained using the present device is shown in FIG. **4**. As can be seen, there is a time course variation in the signal detected by the photodetector **30** that results from a selected blood vessel pulse, changes in the blood volume and content (such as oxygen saturation) inside the blood vessel. The blood volume and content in the selected blood vessel affects the absorption of light, thereby resulting in a signal with varying amplitude. For example, as the jugular vein pulse increases and decreases the blood volume in the jugular vein, the amplitude of the detected optical signal will decrease and increase. The time course plot of the amplitude of the recorded light reflects the waveform of the jugular vein pulse.

[0049] In another embodiment of the present invention, a device **100**, useful to measure blood content, such as the blood oxygen saturation of central venous blood, is provided. As the jugular vein, especially the right internal jugular vein, is directly connected to the superior vena cava as shown in FIG. **1**, the jugular vein waveform is representative of the parameters of central venous blood.

[0050] For this utility, the device **100**, as shown in FIG. **7**, comprises at least two light sources **120**, each emitting light of a different wavelength within the range of 400 nm to 1000 nm. The device also comprises a photodetector **130** for each light source **120** to receive the transmitted or reflected light at each wavelength. As set out above, each light transmitting component (e.g. light source **120** or transmitting optical fibers) and light receiving component (e.g. photodetector **130** or receiving optical fibers) is set in a patch **128**, and may be arranged as shown in FIG. **7**A or **7**B; however, as one of skill in the art will appreciate, alternative arrangements of the light transmitting components and light receiving components exist which will not affect the function of the device **100**. For example, the device **100** may comprise multiple patches **128**, each of which includes a light transmitting component and a light receiving component. Alternatively, the device **100** may comprise a single patch **128** including multiple light transmitting components and light receiving components. In another alternative, the device **100** may comprise a first patch **128** with one or more light tranmitting components and light receiving components, and a second patch with one or more light transmitting components and corresponding light receiving components. As set out above, regardless of the number of patches and arrangements thereof, the device will also include the circuitry necessary to power the device, and other electronic and/or optical components necessary for its function as previously described.

[0051] The time course variation in the detected signal associated with a cardiac vessel pulse at different wavelengths may be used to calculate the blood content, such as blood oxygen saturation, and other parameters associated with the cardiac vessel pulse. There are various ways to calculate blood oxygen saturation as a function of variations in the detected signal caused by cardiac vessel pulse at multiple light wavelengths, e.g. at 780 nm and 850 nm. As one of skill in the art will appreciate, the selected wavelengths for use in blood content determination will vary with the blood entity being determined. This function can be determined through experiment or derived through photon diffusion equations, photon transportation equations or Modified Beer Lambert's Law.

Modified Beer Lambert's Law

[0052] The detected signal can be expressed as:

$$I_{\lambda_1} = I_{0,\lambda_1} e^{-B[\varepsilon_{Hb,\lambda_1}\cdot(C_{Hb}+\Delta C_{Hb})+\varepsilon_{HbO,\lambda_1}\cdot(C_{HbO}+\Delta C_{HbO})]L+A} \quad (1)$$

where:

[0053] I_{80_1} is the signal detected by the photodetector at wavelength λ_1,,

[0054] I_{0,λ_1} is the signal from the light source at wavelength, λ_1,,

[0055] C_{Hb}, C_{HbO} are the concentrations of deoxygenated and oxygenated hemoglobin of steady tissue medium blood;

[0056] ΔC_{Hb}, ΔC_{HbO} are the changes in the concentrations of deoxygenated and oxygenated hemoglobin caused by the jugular vein pulse;

[0057] ϵ_{Hb,λ_1}, ϵ_{HbO,λ_1} are the absorption properties of deoxygenated and oxygenated hemoglobin at wavelength λ_1 for the purposes of calculating blood oxygen saturation. Blood saturation of other chromophores can also be calculated by substituting into the equation the appropriate extinction coefficients (ϵ) for the selected chromophore including, for example, water, cytochromes such as cytochrome oxides, and cholesterol; and

[0058] A, B are constants determined by boundary conditions.

[0059] The relative change in signal from the signal emitted from the light source to the signal detected by the photodetector which is caused by the jugular vein pulse is represented for a first wavelength by:

$$\Delta I_{\lambda_1} = e^{-B[\varepsilon_{Hb,\lambda_1}\cdot(\Delta C_{Hb})+\varepsilon_{HbO,\lambda_1}\cdot(\Delta C_{HbO})]L}; \quad (2)$$

or as

$$OD_{\lambda_1} = \ln(\Delta I_{\lambda_1}) = -B(\varepsilon_{Hb,\lambda_1}\cdot\Delta C_{Hb} + \varepsilon_{HbO,\lambda_1}\cdot\Delta C_{HbO}). \quad (3)$$

[0060] Similarly, the change in signal between emitted and detected for a second light wavelength is represented by:

$$OD_{\lambda_2}=\ln(\Delta I_{\lambda_2})=-B(\epsilon_{Hb,\lambda_2}\cdot\Delta C_{Hb}+\epsilon_{HbO,\lambda_2}\cdot\Delta C_{HbO}) \quad (4)$$

[0061] Blood oxygenation derived from jugular vein pulse is then determined using the following equation:

$$S_{jv}O_2 = \frac{\Delta C_{HbO}}{\Delta C_{Hb} + \Delta C_{HbO}} \quad (5)$$

-continued

$$= \frac{\varepsilon_{Hb,\lambda_1} \cdot OD_{\lambda_2} - \varepsilon_{Hb,\lambda_2} \cdot OD_{\lambda_2}}{(\varepsilon_{Hb,\lambda_1} - \varepsilon_{HbO,\lambda_2}) \cdot OD_{\lambda_2} - (\varepsilon_{Hb,\lambda_2} - \varepsilon_{HbO,\lambda_2}) \cdot OD_{\lambda_1}}$$

[0062] In use, the patch **28** of device **10** comprising light source (s) **20** and photodetector (s) **30** is generally placed on the neck of the patient at a site near a selected blood vessel, for example, the internal jugular vein. It is desirable for the patient to be lying down at about a 30 degree incline. The patient maintains regular breathing during the process of measuring the pulse of the blood vessel. Light from the light source **20** is either reflected off of, or transmitted through, the target site on the patient's neck, and detected by the photodetector **30**. The photodetector **30** translates the detected light into an output signal that may be digitized for expression as amplitude against time to result in a waveform of the selected blood vessel pulse. The amplitude of signals obtained using different wavelengths is used according to Lambert's law as above to determine blood oxygenation.

[0063] In another embodiment, illustrated in FIG. **9**(A-C), a device **200** is provided comprising 1 or more light sources **220**, each emitting selected wavelengths of light in the 400 nm to 1000 nm range. Each light source **220** is coupled with at least two photodetectors **230** each adapted to receive light emitted at a given frequency. As discussed above, the circuitry required for the function of the device **200** is included in the device such as power supply **18**, as well as the necessary electronic/optical components.

[0064] The device **200** is useful to simultaneously measure multiple cardiac blood vessel pulses, such as jugular venous pulse as well as carotid arterial pulse, thereby generating a dual waveform as illustrated in FIG. **10**, and thus, has utility to simultaneously measure arterial blood oxygenation, S_aO_2, in addition to central venous oxygenation, $S_{jv}O_2$, as described above. As one of skill in the art will appreciate, in the case of multiple light sources **220**, each light source is turned on in sequence, and the amplitude of light emitted from the light source(s) is modulated at a selected frequency, such as 10 kHz. Light emitted by a single light source **220** can be sequentially modulated at two alternating frequencies. The output from the photodetectors is filtered at a frequency selected to correlate with a given frequency emitted from a light source.

[0065] In another embodiment, cardiac output may be measured or monitored. As the jugular vein pulse represents central venous blood and correlates well with mixed venous blood, the trend of cardiac output can be calculated through Fick's Law as follows:

$$COI = \frac{OCR}{S_aO_2 - S_vO_2} \tag{6}$$

[0066] where COI is the cardiac output index which is the cardiac output (CO) per unit body surface;

[0067] OCR is the oxygen consumption rate which is oxygen consumption (OC) per unit body surface;

[0068] S_aO_2 is the arterial blood oxygen saturation; and

[0069] $S_{jv}O_2$ is the venous blood oxygen saturation.

Or:

$$CO = \frac{OC}{S_aO_2 - S_{jv}O_2} \tag{7}$$

[0070] As the oxygen consumption or oxygen consumption rate are constant during many clinical procedures, the trend of cardiac output index or cardiac output can be reliably monitored.

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We claim:

1. A device for non-invasively measuring at least one parameter of a cardiac blood vessel in a patient comprising:

at least one light source that emits light in the 400 nm to 1000 nm wavelength range;

at least one photodetector adapted to receive light emitted by the light source, wherein said light is reflected from or transmitted through tissue of the patient, the output of said photodetector correlating with a parameter of the blood vessel; and

a probe which permits delivery of light from the light source to an external tissue site on the patient in the proximity of a cardiac blood vessel and permits transfer of light from said light source which is reflected from or transmitted through said patient site.

2. A device as defined in claim **1**, additionally comprising a signal-producing means in communication with the photodetector, said signal-producing means being capable of translating the light received from the photodetector into a recordable signal to generate a wave form of the blood vessel.

3. A device as defined in claim **1**, adapted to emit and receive light of at least two different wavelengths in the 400 nm to 1000 nm wavelength range.

4. A device as defined in claim **1**, comprising at least two photodetectors, each of said photodetectors adapted to receive light at a distinct wavelength, **5**. A method for measuring the waveform of a cardiac blood vessel in a patient comprising the steps of:

directing a beam of light having a wavelength in the range of 400 nm to 1000 nm at an external tissue site on the patient that is in the proximity of the blood vessel;

detecting light reflected from the tissue site or transmitted through the tissue site; and

translating the detected light into an output signal against time to generate a waveform for the selected blood vessel.

6. A method as defined in claim **5**, comprising directing more than one beam of light at the same or different tissue site on a patient, each beam having a different wavelength in the range of 400 nm to 1000 nm.

7. A method as defined in claim **6**, wherein the light of each wavelength is detected to generate a waveform for two different blood vessels.

8. A method for measuring the blood content of a chromophore in a patient comprising:

directing light having at least first and second selected wavelengths at an external tissue site on the patient that is in the proximity of a cardiac blood vessel, wherein said selected wavelengths are based on the absorption characteristics of the chromophore;

detecting light reflected from the tissue or transmitted through the tissue at the selected wavelengths; and

translating the detected light into an output signal against time to generate a waveform for each selected wavelength in order to determine the blood content of said chromophore.

9. A device as defined in claim **1**, wherein the parameter is selected from the group consisting of blood vessel pulse, blood vessel volume, blood vessel oxygenation, blood vessel flow and blood vessel content.

10. A device as defined in claim **1**, wherein the device produces a waveform of the blood vessel.

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