

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau



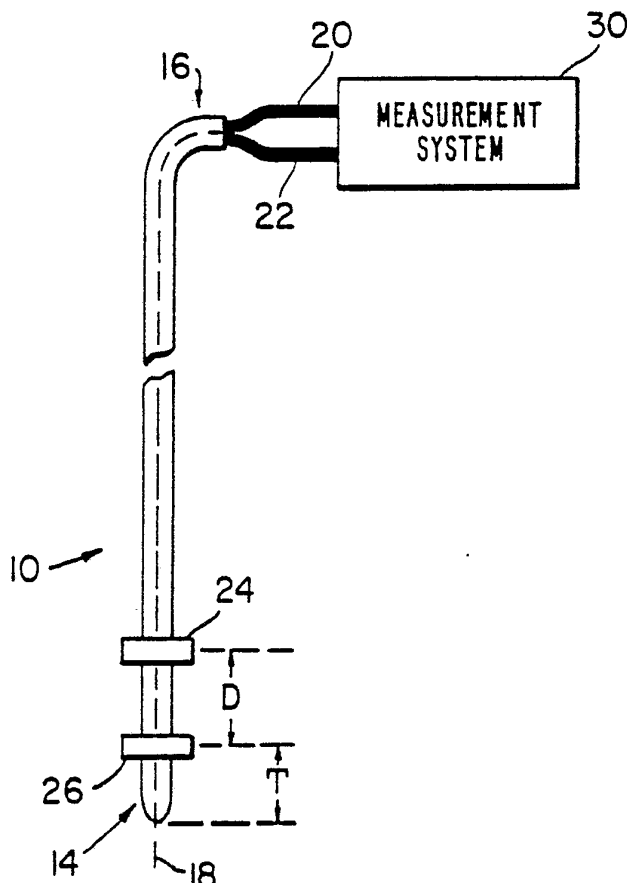
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ³ : A61B 5/00	A1	(11) International Publication Number: WO 82/00581 (43) International Publication Date: 4 March 1982 (04.03.82)
(21) International Application Number: PCT/US80/01056 (22) International Filing Date: 18 August 1980 (18.08.80) (71) Applicant (for all designated States except US): CORDIS CORPORATION [US/US]; 3901 Biscayne Boulevard, Miami, FL 33137 (US). (72) Inventor; and (75) Inventor/Applicant (for US only): STOREY, L. Robert [US/US]; 10921 N.W. 18 Place, Pembroke Pines, FL 33026 (US). (74) Agents: LAPPIN, Mark, G. et al.; Kenway & Jenney, 60 State Street, Boston, MA 02109 (US).		(81) Designated States: DE, DE (European patent), FR (European patent), GB, GB (European patent), JP, NL, NL (European patent), SE, SE (European patent), US. Published With international search report

(54) Title: APPARATUS AND METHOD FOR MEASURING BLOOD VESSEL AND CARDIAC CHARACTERISTICS

(57) Abstract

A sensor (10) includes a catheter (12) with a sensor end (14) and an instrumentation end (16), at least one pair of electrodes (24, 26) with associated leads (20, 22) mounted near the sensor end and spaced apart by a predetermined distance and a conductivity measuring and processing network (30) selectively connected to the leads at the instrumentation end to provide signals representative of blood vessel characteristics, e.g. continuous cardiac output, stroke volume on a beat-to-beat basis.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	KP	Democratic People's Republic of Korea
AU	Australia	LI	Liechtenstein
BR	Brazil	LU	Luxembourg
CF	Central African Republic	MC	Monaco
CG	Congo	MG	Madagascar
CH	Switzerland	MW	Malawi
CM	Cameroon	NL	Netherlands
DE	Germany, Federal Republic of	NO	Norway
DK	Denmark	RO	Romania
FI	Finland	SE	Sweden
FR	France	SN	Senegal
GA	Gabon	SU	Soviet Union
GB	United Kingdom	TD	Chad
HU	Hungary	TG	Togo
JP	Japan	US	United States of America

APPARATUS AND METHOD FOR MEASURING BLOOD VESSEL
AND CARDIAC CHARACTERISTICS

The present invention is in the field of medical instrumentation, and more particularly relates to instrumentation for the in vivo measurement of cardiac
5 characteristics.

In many applications, it is desired to have accurate continuous measurement of cardiac output, for example, during stress tests, surgery, or during onset of vasodilator therapy. There have been a number of
10 techniques developed in the prior art for measuring cardiac output, including those referred to in the prior art as dye dilution, thermal dilution and PO₂ respiration (using the Fick method). These dilution techniques require the injection of a fluid in a blood
15 vessel leading to the heart and a time interval for measurement, and thus are based on measurement of blood changes rather than flow, or attempt to compute flow from aortic pressure, or from the impedance plethysmogram. None of these techniques accommodate
20 substantial stroke-to-stroke changes in vascular bed brought on by exercise or various therapeutic interventions, but rather rely on intermittent and time-averaged cardiac output determinations, which are also particularly inaccurate during arrhythmias.

25 Prior art continuous output techniques include use of a magnetic flowmeter (which must be surgically implanted), or imaging (which requires injection of radio-opaque fluid), or doppler technique (non-invasive). However, none of these techniques provide
30 desired accuracy and safety to patient.

It is an object of the present invention to provide a system for continuously measuring the cardiac output.

-2-

Another object is to provide an improved system for measuring stroke volume on a beat-to-beat basis.

SUMMARY OF THE INVENTION

5 Briefly, the present invention is directed to a cardiac sensor including a catheter. The catheter extends along a central axis and has a sensor (distal) end and an instrumentation (proximal) end. The catheter includes at least one pair of electrodes near its sensor
10 end. A pair of conductive leads are mechanically coupled to and extend along the catheter between the sensor and instrumentation ends. Each lead is coupled to one of the electrodes at its end nearest the sensor end of the catheter. The electrodes of each pair of
15 leads are separated by a predetermined distance along the central axis. The proximal end of each lead, i.e. the end nearest the instrumentation end of the catheter, is adapted for electrical coupling to measurement instrumentation. In one form of the invention, the
20 electrodes of each pair of leads are aligned along a reference axis parallel to the central axis, wherein the reference axes of the respective pairs are substantially equidistant from the central axis and uniformly disposed about that central axis.

25 Measurement instrumentation coupled to the instrumentation end of the leads provides continuous measurement of cardiac characteristics such as cardiac output, and also provides measurement of stroke volume on a beat-to-beat basis. In accordance with this inven-
30 tion, the cardiac sensor is adapted for in vivo placement within a chamber of the heart. That chamber is then utilized as part of a conductivity cell. The contraction and expansion of the heart chamber walls causes a change in the total impedance (or conductance)
35 for the region of the chamber between and surrounding the two electrodes. The sensor may also be positioned within a blood vessel.

SUBSTITUTE SHEET



-3-

In one form of the invention, measurement instrumentation coupled to the sensor leads provides a signal representative of this conductivity variation. The instrumentation further provides a signal representative of the peak-to-peak variation of the conductance measured over a stroke (or beat), corresponding to a measure of the stroke volume. The average of the stroke volume values is multiplied by a signal representative of the heart rate to provide a signal representative of the continuous cardiac output. In some forms of the invention, a temperature compensation thermistor may also be positioned on the end of the catheter within the conductivity cells so that changes in patient temperature may also be incorporated in the measurements for better accuracy.

Generally, since the conductivity of the blood depends on the packed cell volume, a factor representative of this packed cell volume may be determined initially, and used for calibration. This factor may be monitored by an additional pair of electrodes coupled to the catheter and upstream of the pair of conductivity electrodes attached to the principle measurement leads, and preferably out of the vessel being measured and in the flow of a lesser vessel. Since a lower packed cell volume increases conductivity and since the blood flow in a small vessel increases in conductivity with increasing pulsatile flow (cells accumulate in the axial stream surrounded by plasma), the readout from the additional pair of electrodes is representative of the packed cell volume. Information from this pair of electrodes is used to periodically update the calibration factor for the conductivity measurements of the conductivity electrodes. Similarly, information is provided to monitor the effect of infusions, infections (increase in white blood cells and other factors related to the packed cell volume). The present invention may also be used in conjunction with instrumentation for

SUBSTITUTE SHEET



-4-

analyzing the waveforms representative of the measured conductivity variation to detect the start of fibrillation and arrhythmias. The system may also be used to profile a vessel by slowly withdrawing the lead while continuously recording the conductivity on a chart recorder. This would provide information relative to the diagnosis of arteriosclerosis, thrombosis, and the like.

In yet other forms of the invention, a plurality of pairs of leads (such as n , where n is an integer) may be coupled to the catheter, where each pair has an associated pair of conductivity electrodes separated by a predetermined distance, D , along the central axis of the catheter, with the electrodes of each pair being aligned along a reference axis which is parallel to the central axis. In this form of the invention, the reference axes for the various pairs of leads may be uniformly disposed about the central axis. With this configuration, similar measurements to those described above may be made, where each measurement is representative of a $1/n$ angular volume segment of the conductivity cell. The information from the n pairs of leads may then be readily processed to provide a three-dimensional mapping of the region within the vessel, i.e. the conductivity cell. This latter form of the invention is particularly useful in identifying certain cardiac characteristics, such as valve disorders, septal defects, and the like. The invention in this form may also be used for a number of other functions, such as providing EKG signals, temporary cardiac pacing, and detecting region wall movement to identify dead tissue.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects of this invention, the various features thereof, as well as the invention itself, may be more fully understood from the following description, when read together with the accompanying drawings in which:

SUBSTITUTE SHEET



-5-

Fig. 1 shows a catheter and measuring system in accordance with the present invention;

Fig. 2 shows in block diagram form, an exemplary form of the measuring system of Fig. 1;

5 Fig. 3 shows in schematic form, an exemplary form of the measuring system of Fig. 2;

Figs. 4 and 5 show alternative forms for the catheter of Fig. 1; and

Fig. 6 shows in block diagram form another
10 embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 shows an exemplary cardiac sensor 10 in accordance with the present invention. Sensor 10 includes a catheter 12 which has a sensor end 14 and 15 instrumentation end 16, and which extends along a central axis 18. By way of example, the catheter 12 may generally have the form of a DUCOR catheter, manufactured by Cordis Corporation, Miami, Florida. A pair of electrically conductive leads 20 and 22 are mechanically 20 coupled to catheter 12 (e.g. through a lumen) and extend along the central axis 18. In the illustrated embodiment of Fig. 1, the leads 20 and 22 are positioned within the outer wall of catheter 12 and thus are not shown in that figure. At the ends of leads 20 and 22 25 which are closest to the sensor end 14, each lead is terminated by a respective one of conductivity probes 24 and 26. In the present embodiment each of electrodes 24 and 26 is a smooth annular ring of thin wall stainless steel tubing having an outer diameter matching the outer 30 diameter of catheter 12. In fabrication, leads 20 and 22 are brought out to the exterior of, and looped around catheter 12. Then catheter 12 is heated in boiling water and stretched so that the electrodes can be

SUBSTITUTE SHEET



-6-

slipped into the desired position. The respective electrodes and associated leads are then cemented together using a silver-loaded (conductive) epoxy. Finally the catheter is exposed to dry heat, returning the diameter of the catheter to its original size.

The probes 24 and 26 are separated by a predetermined distance D along axis 18. In the preferred form of the invention, the distance D is selected to be in the range 4-8 centimeters, depending for example on the size heart in which the distal end is to be inserted. Other separations may also be used. As shown, the electrode 26 is spaced by a distance T from the distal end of catheter 10. This spacing ensures that the electrode 26 is spaced from the end wall of the conductivity cell (minimizing the possibility that signals in leads 20 and 22 may themselves provide undesirable cardiac stimulation.

The ends of leads 20 and 22 which are opposite the ends coupled to electrodes 24 and 26 are adapted for electrically coupling to measurement instrumentation, which is represented by a measurement system 30 in Fig. 1.

In general, the measurement network 30 provides circuitry for continuously measuring cardiac characteristics of the heart, or beat-to-beat stroke characteristics of a patient's heart. The network 30 may continuously monitor the electrical conductivity between the probes of each of the pairs, or alternatively may periodically monitor that conductivity on a multiplexed basis.

Generally, this network 30 includes a circuit 30a for generating a first signal representative of the time varying electrical conductivity between the probes of at least one of the pairs of probes, and also a cir-

SUBSTITUTE SHEET



-7-

cuit (not shown) for generating a second signal representative of the heart rate of the heart in which the sensor end of the catheter is inserted. The heart rate signal is determined by generating a signal having 5 pulses corresponding to peaks, or maxima, of the first (or conductivity) signal. An associated computer 52 processes the conductivity variation signal by generating an SV signal representative of the peak-to-peak value of that conductivity variation signal over a 10 stroke of the heart. This SV signal is representative of the stroke volume of the heart for that stroke, or beat, and is displayed on display 54. The average of a succession of the SV signals is multiplied by the heart rate signal to provide a CO signal. In the preferred 15 form, the computer 52 includes a microprocessor which is adapted to perform these various functions in a conventional fashion.

The measurement system 30, for the present embodiment includes a two probe, time-varying 20 impedance/conductivity measuring circuit 30a shown in block diagram form in Fig. 2. This circuit includes a positive bridge 32 coupled to the leads 20 and 22. Bridge 32 is also coupled by way of pulse transformers 34 to an oscillator 38 and by way of pulse transformer 2542 to rectifier/mixer 44 and amplifier 48. With this configuration, the system 30, in effect, alternately applies a pulse to the two probe electrodes 24 and 26 of the conductivity cell (i.e. the region surrounding electrodes 24 and 26), and then reads the resultant 30 change in current through that cell, providing a voltage signal at the output terminal 49 of amplifier 48 which is representative of the time-varying conduct conductivity of that cell. By way of example, Fig. 3 shows a schematic diagram for an exemplary form of the circuit 3530a of Fig. 2, where oscillator 38 is a 25 kHz oscillator.

SUBSTITUTE SHEET



-8-

In measurement systems particularly suited for cardiac monitoring, system 30 may also include a circuit for generating a signal representative of the trigger signals for the heart, where that signal includes a pulse each time the heart is to beat. In this form, the trigger signal as well as the signal from amplifier 48 may be displayed for visual analysis on a chart record 56 (or a CRT display). Arrhythmias may readily be detected by identifying trigger signal pulses for which there is no corresponding variation in the conductivity signal from leads 20 and 22.

With this illustrated two probe impedance/conductivity form of measurement system 30, the entire field in the conductivity cell is monitored by the electrodes, rather than just the field between two sensor electrodes, as in the case where a pair of excitation electrodes might be used to generate drive a.c. current between two points in the cell and the two sensor electrodes positioned between those excitation electrodes might be used to detect voltage which is representative of conductivity changes between those sensor electrodes. As a direct result of the two probe form for system 30, one of the electrodes may be positioned near the valve in the heart with the result that the conductivity variation signal reflects detailed operation of the valve, permitting detection of valve disorders from visual analysis of the conductivity variation waveform.

Fig. 4 shows the distal end of an alternative embodiment for the cardiac sensor of Fig. 1 which is particularly adapted for four pairs of electrically conductive leads and associated conductivity electrodes. In Fig. 4, elements corresponding to similar elements in Fig. 1 are identified by the same reference designations. The catheter in Fig. 4 shows the portion of catheter 12 near the sensor end 24.

SUBSTITUTE SHEET



-9-

The sensor of Fig. 4 includes four pairs of electrically conductive leads, where the leads of the first pair are coupled to conductivity electrodes 24a and 26a, respectively, the leads of the second pair are coupled to electrodes 24b and 26b, respectively, the leads of the third pair coupled to electrodes 24c and 26c, respectively, and the leads of the fourth pair are coupled to electrodes 24d (not shown) and 26d (not shown), respectively. The electrodes for each of the 10 pairs of leads are positioned along an associated reference axis which is parallel to the central axis 18. In Fig. 4, electrodes 24a and 26a are shown to be positioned along reference axis 18a, and electrodes 24c and 26c are shown positioned along reference axis 18c.

15 In order to provide this configuration, the end of catheter 12 is constructed of an expandable mesh material and associated inflatable balloon portions associated with portions of the catheter 12 underlying the conductivity electrodes. With this configuration, 20 the catheter 12 may be inserted into a patient's heart, for example, with the balloons deflated, so that the catheter has a relatively small radial dimension. When the sensor end of the catheter is in place, the balloons underlying the conductivity electrodes may be inflated 25 in a conventional manner so that a desired radial separation of the electrodes 24a-d and electrodes 26a-d may be attained.

Fig. 5 shows an alternative embodiment of the configuration of Fig. 4 for a non-mesh catheter. In 30 Fig. 5, elements having corresponding parts to those shown in Fig. 4 are identified by identical reference designations. In this configuration, the end of catheter 12 underlying the conductivity electrodes has longitudinal slits in its outer surface, with underlying 35 inflatable balloons 32 and 34 (shown inflated in Fig. 5). When the catheter is in place, the balloons provide

SUBSTITUTE SHEET.



-10-

expansion of the region supporting the electrodes 24a-d and 26a-d to provide a similar electrode geometry as that shown in the embodiment of Fig. 4.

In yet other embodiments, the number of pairs of conductive leads may differ, for example, there may be two pairs of leads or there may be in general n pairs, where n is an integer. The electrodes for each pair are separated by a predetermined distance D . The conductivity electrodes for these n pairs are uniformly distributed about the central axis 18 with each of the conductivity electrodes being substantially equidistant from the central axis.

The catheters of Figs. 4 and 5 as well as those more generally having n pairs of electrodes, may be used in a system 60 having the form shown in Fig. 6. System 60 includes n measurement circuits (denoted 30_1-30_n), each of which is similar to circuit 30a and is coupled to a pair of leads from an n -pair catheter similar to that shown in Fig. 2. The circuits 30_1-30_n are coupled by way of a multiplexer 62 to a computer 64 having an associated display 66. Generally, circuits 30_1-30_n provide waveform signals representative of the conductivity of an angular segment of the region interior to a conductivity cell, such as a heart chamber or blood vessel. These signals are multiplexed conventionally and passed to computer 64, which in turn may provide drive signals to display (on display 66) a conductivity profile of a transverse slice of the cell.

In yet other embodiments, the catheter 10 may include additional electrodes along each of the respective reference axes. The conductivity between various pairs of these electrodes may be read out in a multiplexed fashion to provide a plurality of data points representative of a three-dimensional mapping of the conductivity within the vessel. These data points

SUBSTITUTE SHEET



-11-

may be displayed using conventional CRT graphics display techniques. By way of example, one such display would provide an on-line three dimensional perspective display of the interior region of the beating heart.

5 The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention
10 being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

SUBSTITUTE SHEET



-12-

CLAIMS

1. A sensor comprising:

- A. a catheter extending along a central axis and having a sensor end and an instrumentation end,
- 5 B. at least one pair of electrodes and associated electrically conductive leads, said electrodes being positioned at the lead ends nearest said sensor end of said catheter and on the exterior surface of said catheter, and said
- 10 leads being mechanically coupled to and extending along said catheter between said sensor and instrumentation ends, each lead including means for electrically coupling said lead to measurement instrumentation at its end
- 15 nearest said instrumentation end of said catheter, wherein the electrodes of each of said pair of leads are separated by a predetermined distance along said central axis, and wherein the electrode closest to said sensor
- 20 end is spaced from said sensor end by a predetermined distance along said central axis.

2. A sensor according to claim 1 including n pairs of said leads wherein the probes for each pair are aligned along a reference axis parallel to said central axis, and wherein the reference axes of said n pairs are substantially equidistant from said central axis, and uniformly disposed about said central axis.

3. A sensor according to claim 2 further including one or more additional electrodes associated with each of said pairs, said additional electrodes being substantially aligned with the reference axis of their associated pair and being spaced apart along said reference

SUBSTITUTE SHEET



-13-

axis by predetermined distances between each other and from the electrodes of said pair.

4. A sensor according to claim 2 where n is an integer in the range 2-10.

5 5. A sensor according to claim 3 where n is an integer in the range of 2-10.

6. A sensor according to claim 1 or 2 or 3 wherein said sensor end of said catheter is adapted for in vivo insertion into a blood vessel and further comprising:

10 conductivity measuring means associated with at least one of said pairs of electrodes and including circuit means coupled to said one pair of electrodes for alternately exciting said electrodes and generating a response signal therefrom, said response signal being
15 representative of the electrical conductivity between said one pair of electrodes.

7. A sensor according to claim 6 wherein said circuit means further includes means for generating a waveform representative of the electrical conductivity between
20 said one pair of electrodes.

8. A sensor according to claims 1 or 2 or 3 wherein said sensor end of said catheter is adapted for in vivo insertion into a heart chamber, further comprising:

means for generating a waveform signal representative of
25 the electrical conductivity between the electrodes of one or more of said pairs.

9. A sensor according to claim 8 further comprising:

means for generating a SV signal representative of the peak-to-peak variation of said waveform signal over a

-14-

stroke of said heart, said variation corresponding to the stroke volume of said heart for said stroke.

10. A sensor according to claim 9 further including means responsive to said SV signal and a rate signal
5 representative of the rate of said heart to generate a CO signal representative of the cardiac output of said heart, said CO signal having the product of the average of said SV signals and said rate signal.

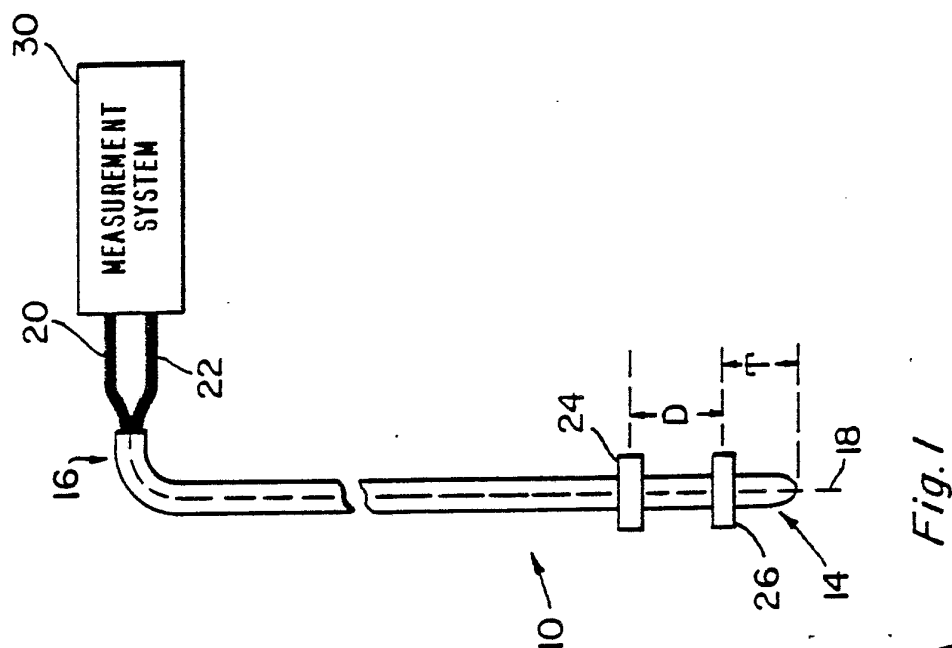
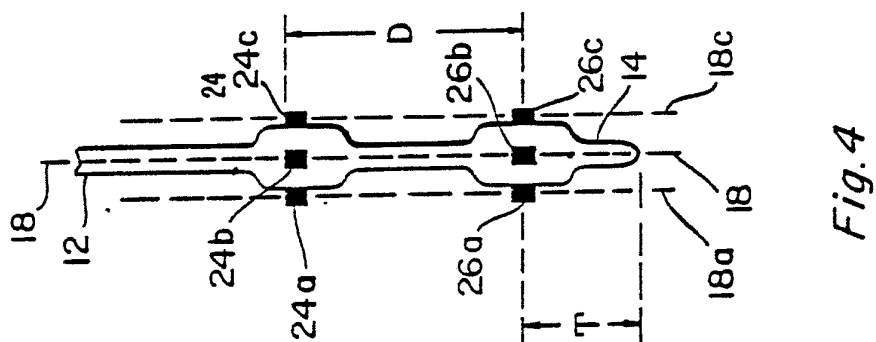
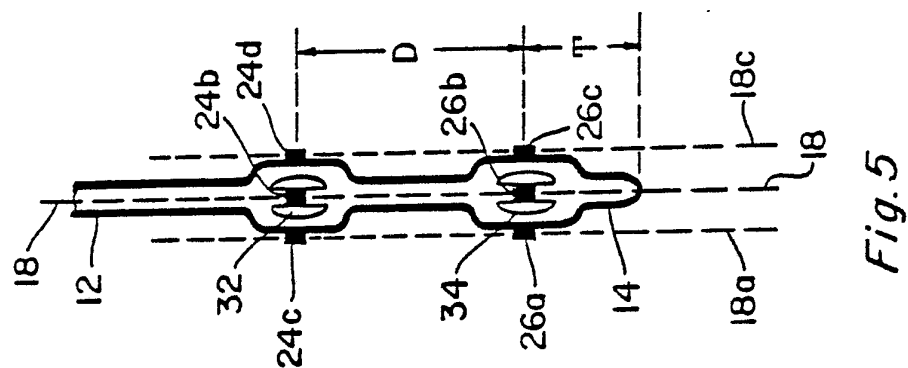
11. A sensor according to claims 2 or 3 or 4 or 5
10 wherein the diameter of the exterior surface of said catheter underlying said electrodes is selectively adjustable at least between the diameter of said catheter near said sensor end and twice the distance between said central axes and one of said reference
15 axes.

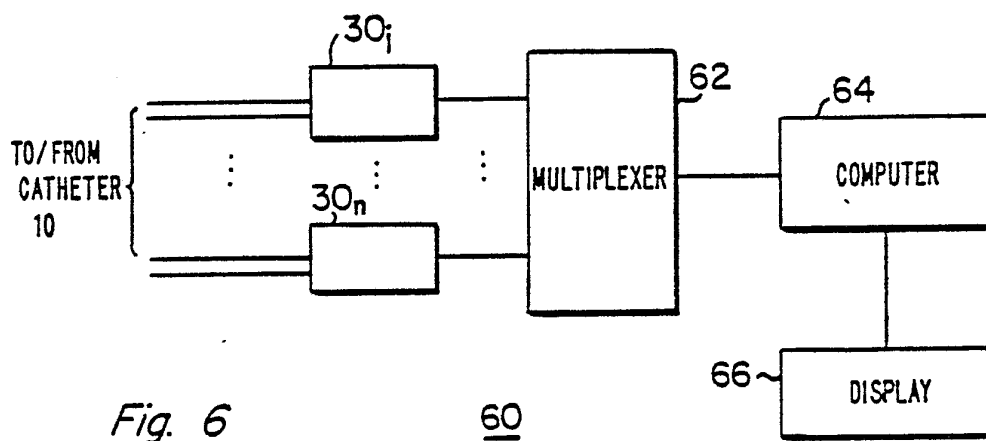
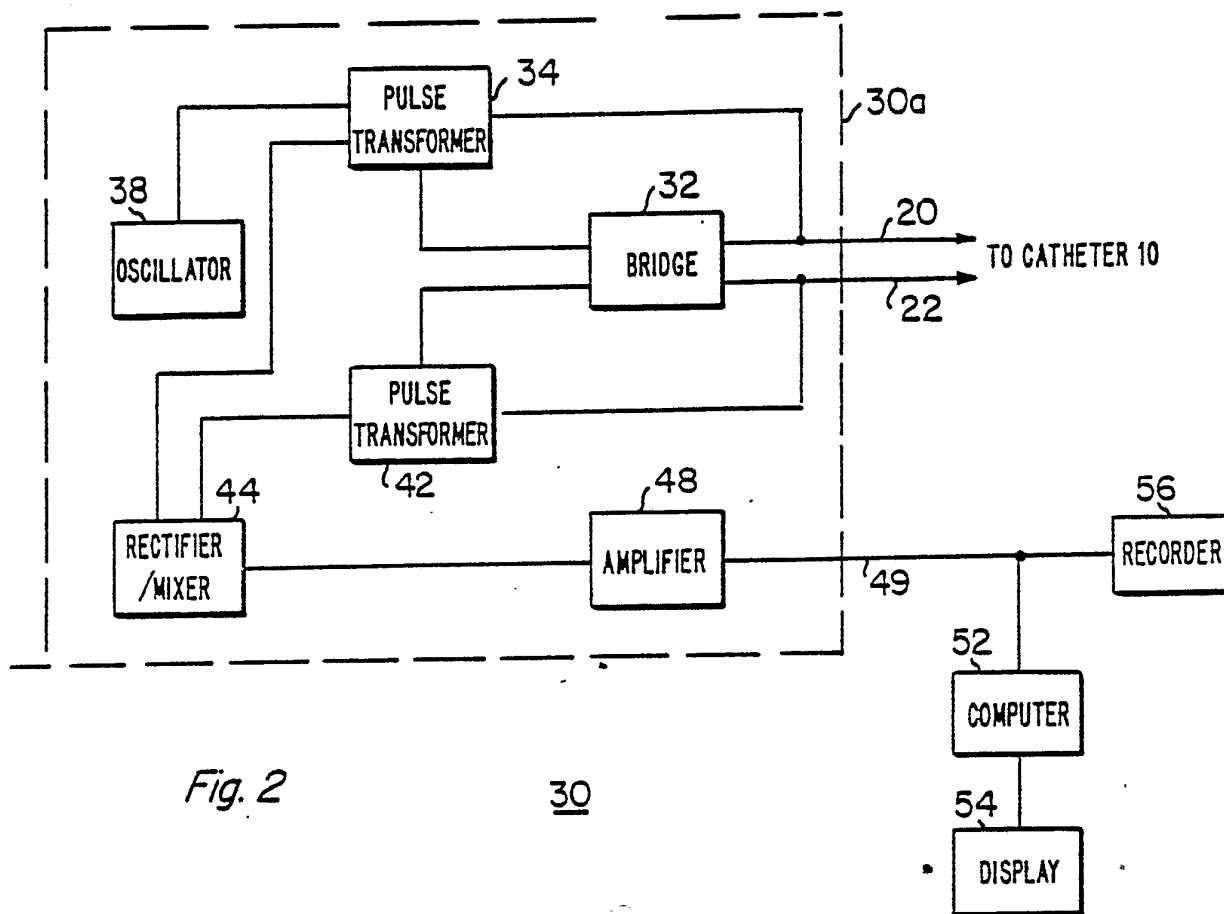
12. A sensor according to claim 11 wherein said exterior surface of said catheter underlying and between said electrodes is an expandable mesh material, and wherein said mesh material overlies a selectively
20 inflatable member.

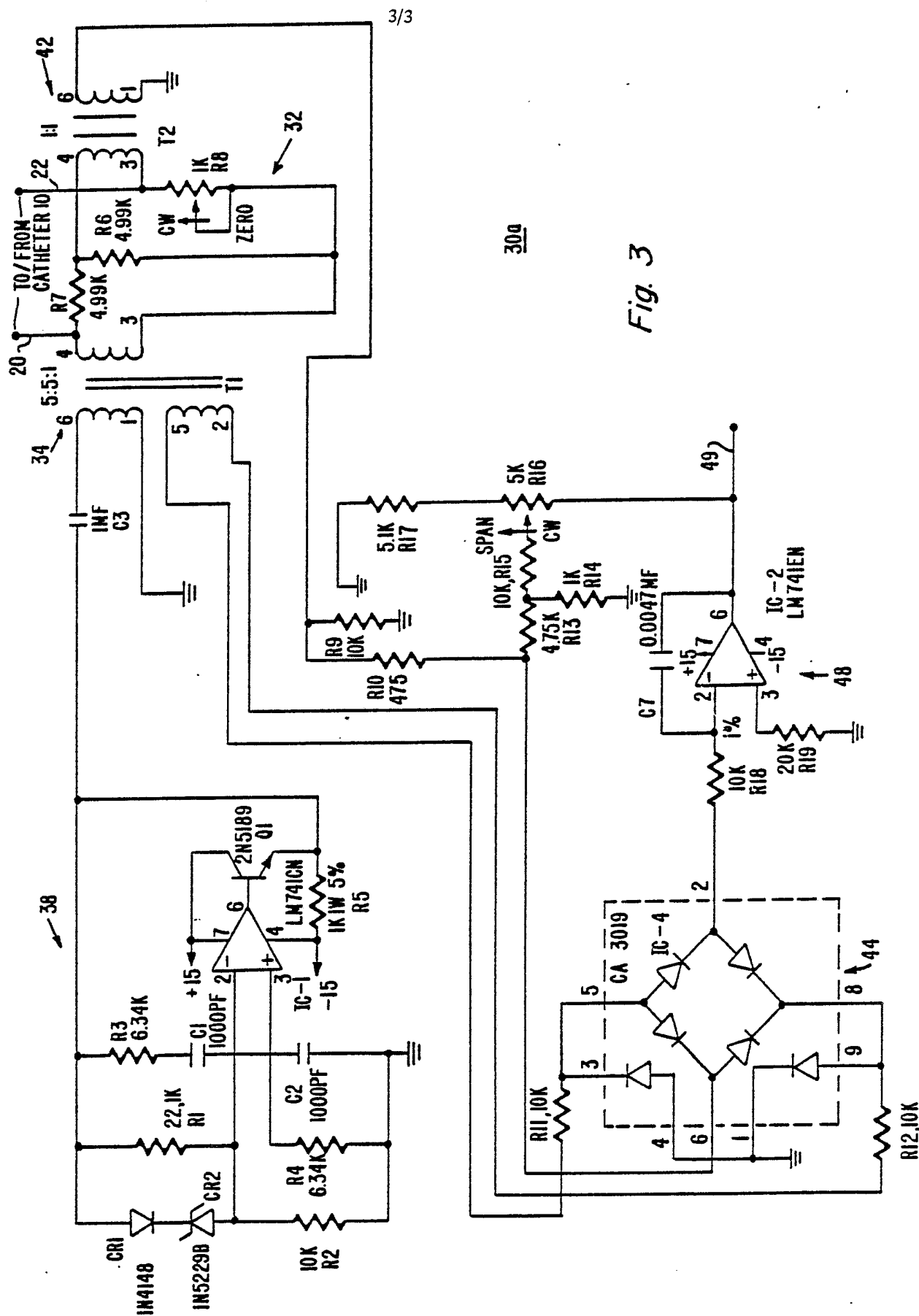
13. A sensor according to claim 12 wherein said exterior surface of said catheter between said electrodes is slit in the direction of said central axis, and wherein that exterior surface of said catheter
25 underlying and between said electrodes overlies a selectively inflatable member.

SUBSTITUTE SHEET









SUBSTITUTE SHEET
BAD ORIGINAL



INTERNATIONAL SEARCH REPORT

International Application No PCT/US80/01056

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC CL. 3 A61B5/00		
US CL. 128/692		
II. FIELDS SEARCHED		
Minimum Documentation Searched *		
Classification System	Classification Symbols	
U.S.	128/632, 642, 691, 692, 693, 713, 734	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched *		
None		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category *	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
X	US, A, 3,326,207, Published 20 June 1967, Egan	1-5+11
X	US, A, 3,566,233, Published 23 February 1971, Kahn et al	6-8
X	US, A, 3,841,313, Published 15 October, 1974, Wesseling et al.	9
X	US, A, 3,985,123, Published 12 October 1976, Herzlinger et al	10
A	US, A, 3,726,269, Published 10 April 1973, Webster, Jr.	
A	US, A, 4,024,873, Published 24 May 1977, Antoshkiw et al	
A	US, A, 4,164,939, Published 21 August 1979, Kolin	
* Special categories of cited documents: ¹⁵ "A" document defining the general state of the art "E" earlier document but published on or after the international filing date "L" document cited for special reason other than those referred to in the other categories "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but on or after the priority date claimed "T" later document published on or 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		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ²		Date of Mailing of this International Search Report ³
1 July 1981		30 JUL 1981
International Searching Authority ¹		Signature of Authorized Officer ¹⁰
ISA/US		W.E. Kamm 