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(54) **MULTI-CHANNEL NON-INVASIVE TISSUE OXIMETER**

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(21) Appl. No.: **11/219,298**

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Related U.S. Patent Documents

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A61B 5/00 (2006.01)
G01J 3/42 (2006.01)

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USPC **600/322**; 600/323; 600/336; 600/340; 356/319

(58) **Field of Classification Search**
USPC 600/310, 322, 323, 340
See application file for complete search history.

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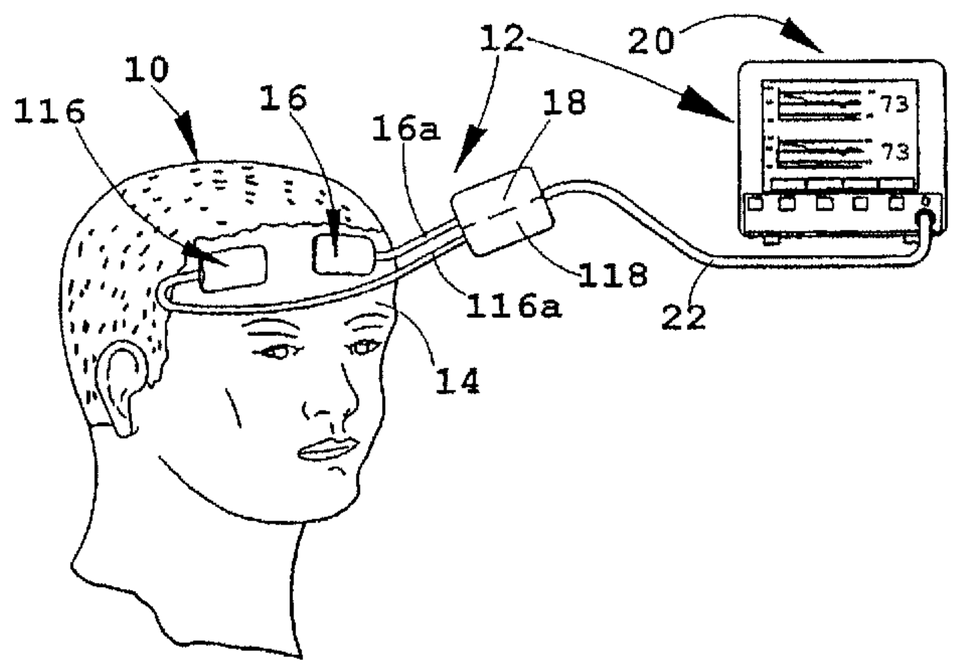
(57) **ABSTRACT**

A method and apparatus for spectrophotometric in vivo monitoring of blood metabolites such as hemoglobin oxygen concentration at a plurality of different areas or regions on the same organ or test site on an ongoing basis, by applying a plurality of spectrophotometric sensors to a test subject at each of a corresponding plurality of testing sites and coupling each such sensor to a control and processing station, operating each of said sensors to spectrophotometrically irradiate a particular region within the test subject; detecting and receiving the light energy resulting from said spectrophotometric irradiation for each such region and conveying corresponding signals to said control and processing station, analyzing said conveyed signals to determine preselected blood metabolite data, and visually displaying the data so determined for each of a plurality of said areas or regions in a comparative manner.

REEXAMINATION RESULTS

The questions raised in reexamination proceeding No.



90/010,128, filed Mar. 31, 2008, have been considered, and the results thereof are reflected in this reissue patent which constitutes the reexamination certificate required by 35 U.S.C. 307 as provided in 37 CFR 1.570(e) for *ex parte* reexaminations, or the reexamination certificate required by 35 U.S.C. 316 as provided in 37 CFR 1.997(e) for *inter partes* reexaminations.

125 Claims, 5 Drawing Sheets

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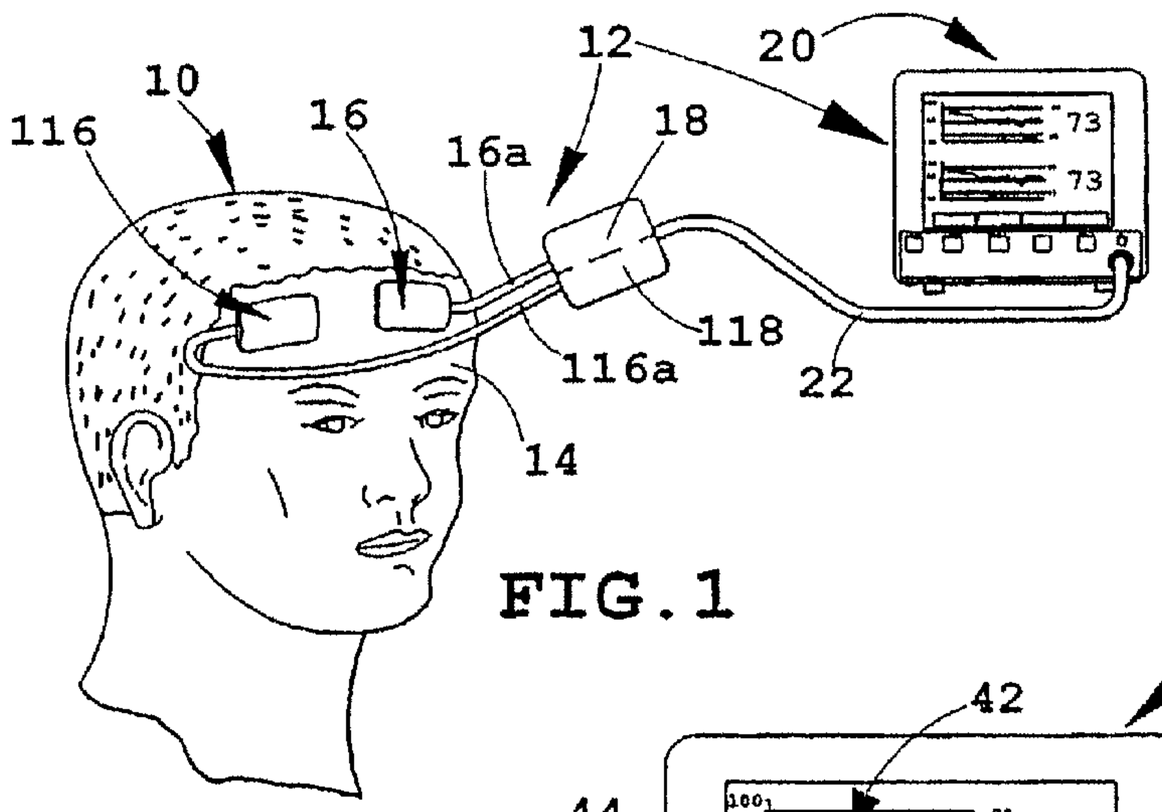


FIG. 1

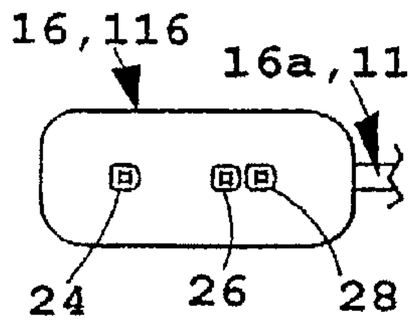


FIG. 2

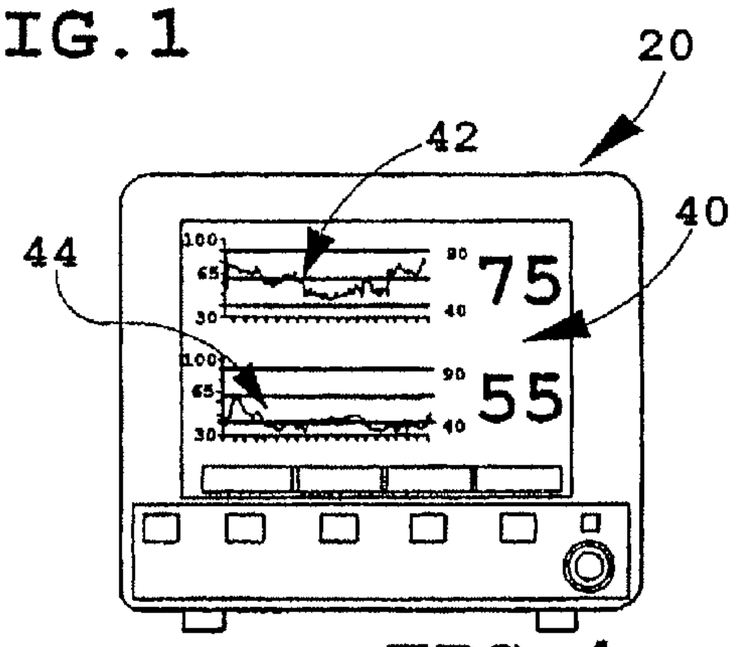
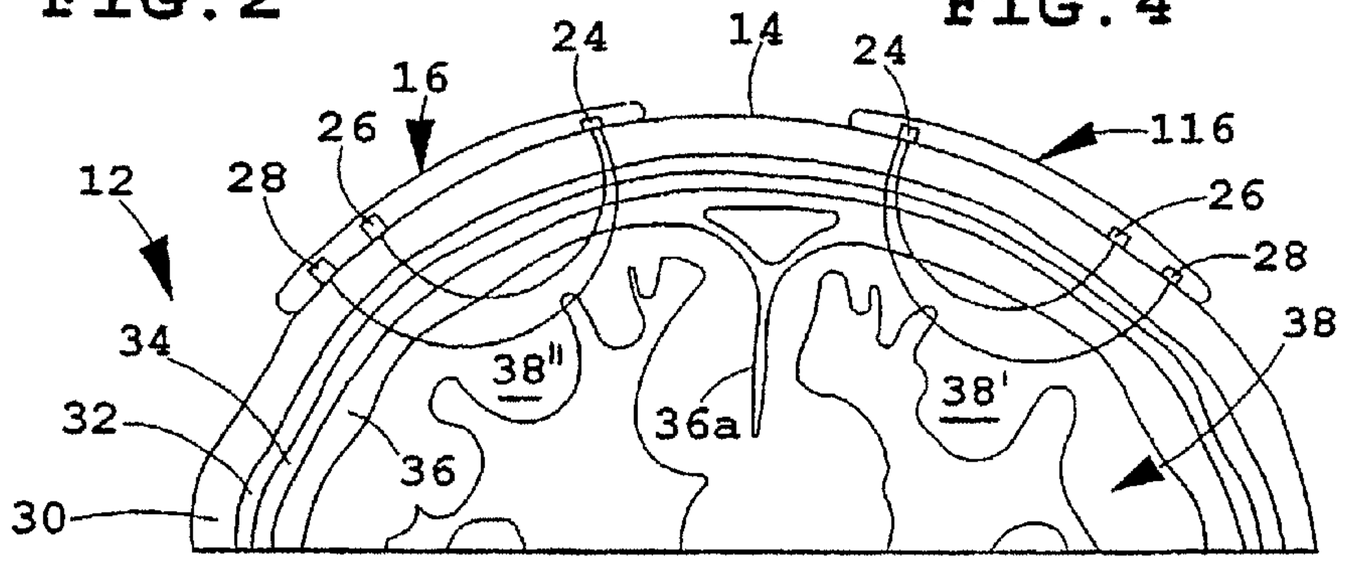


FIG. 4



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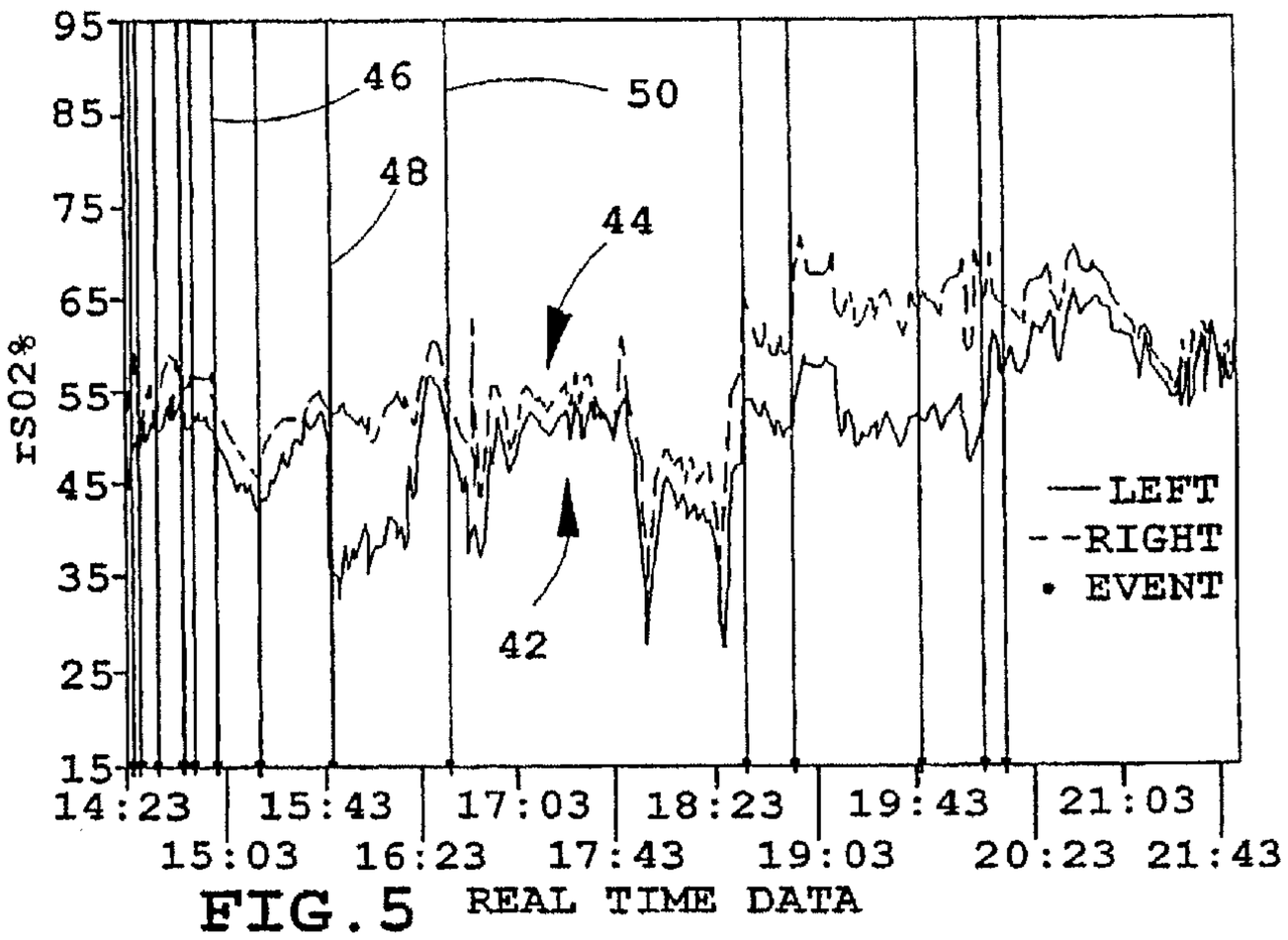
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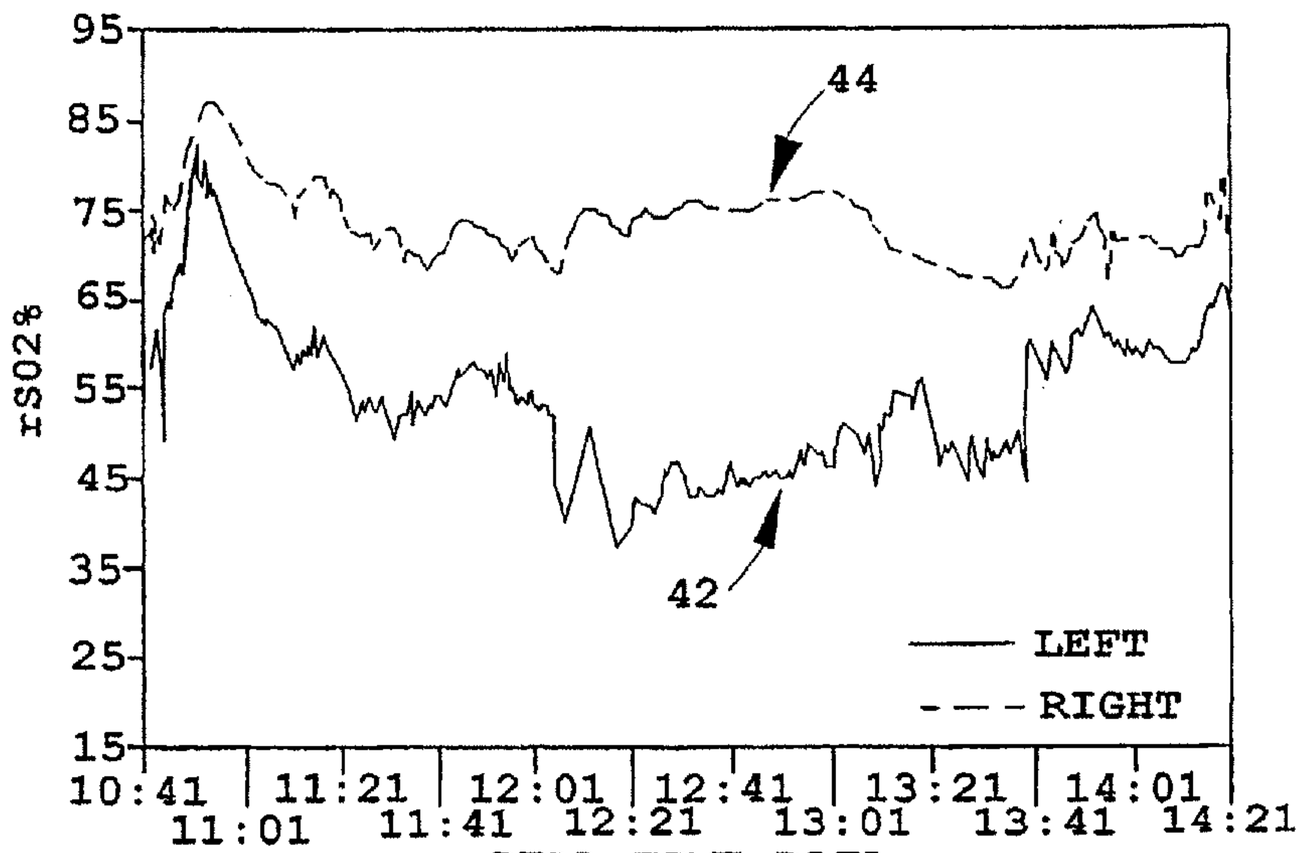
85
75
65
55
45
35
25
15
rS02%
46
48
50
44
42
LEFT
RIGHT
EVENT
14:23
15:03
15:43
16:23
17:03
17:43
18:23
19:03
19:43
20:23
21:03
21:43
REAL TIME DATA

FIG. 5


95
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rS02%
44
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LEFT
RIGHT
10:41
11:01
11:21
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12:01
12:21
12:41
13:01
13:21
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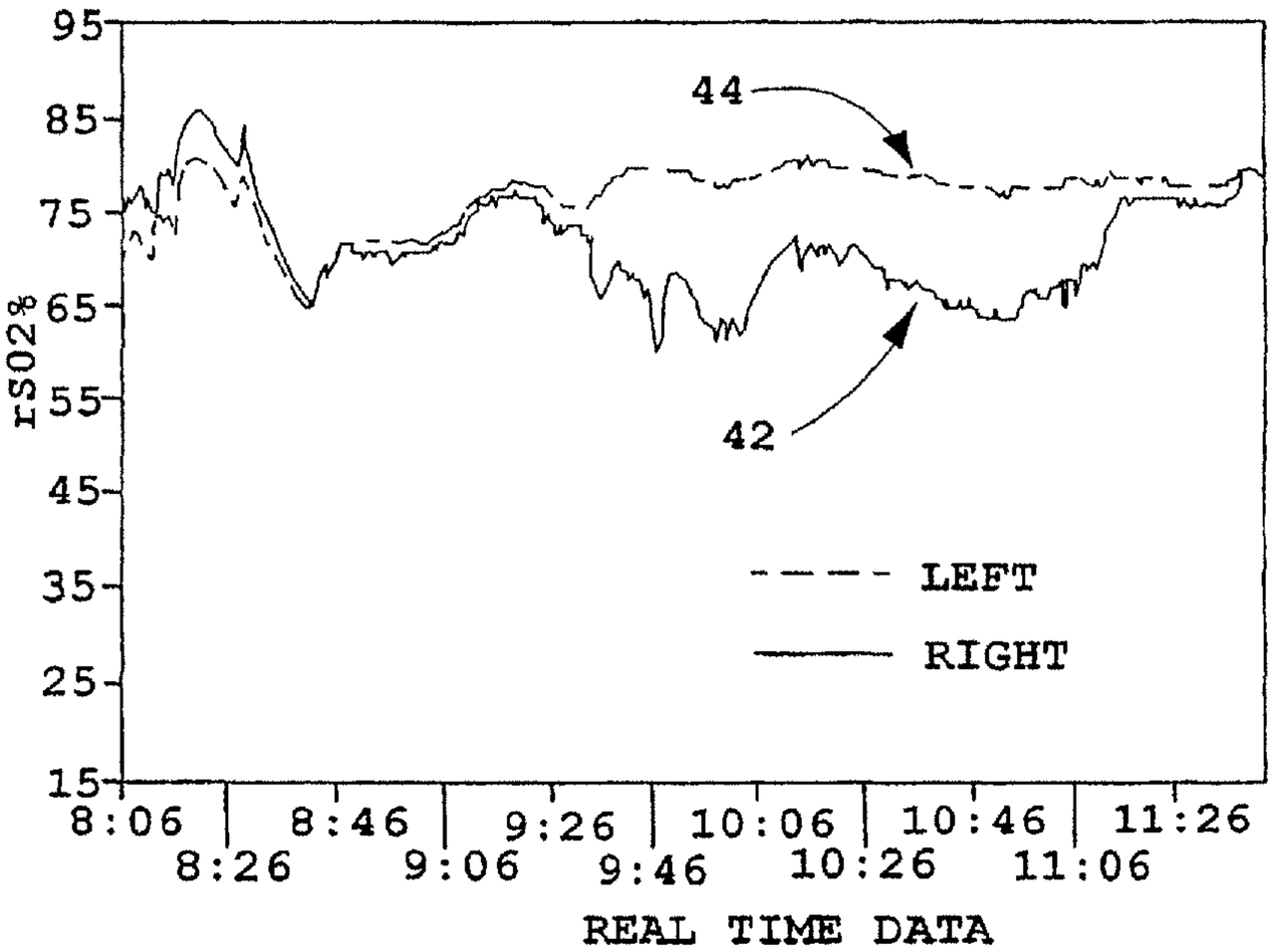
14:21
REAL TIME DATA

FIG. 6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45
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44
42
LEFT
RIGHT
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8:26
8:46
9:06
9:26
9:46
10:06
10:26
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11:26
REAL TIME DATA

FIG. 7

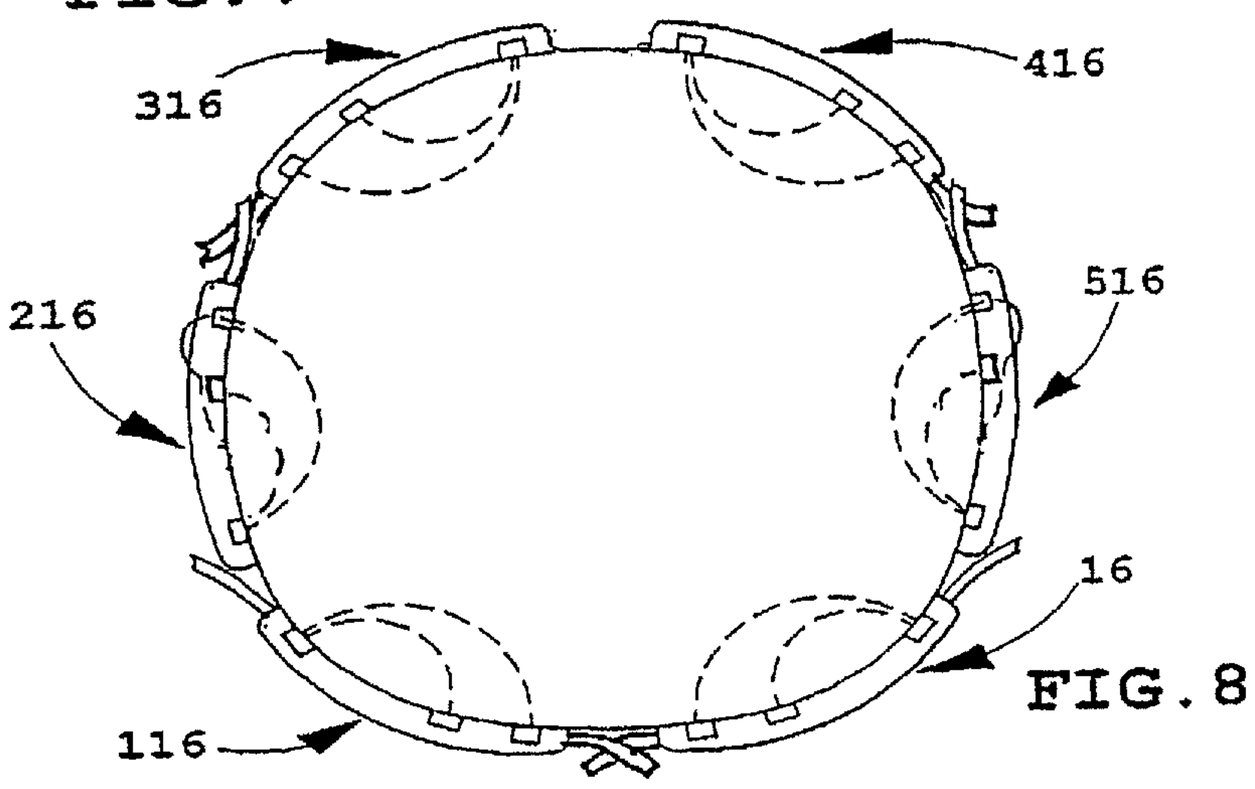
316
416
216
516
16
116

FIG. 8

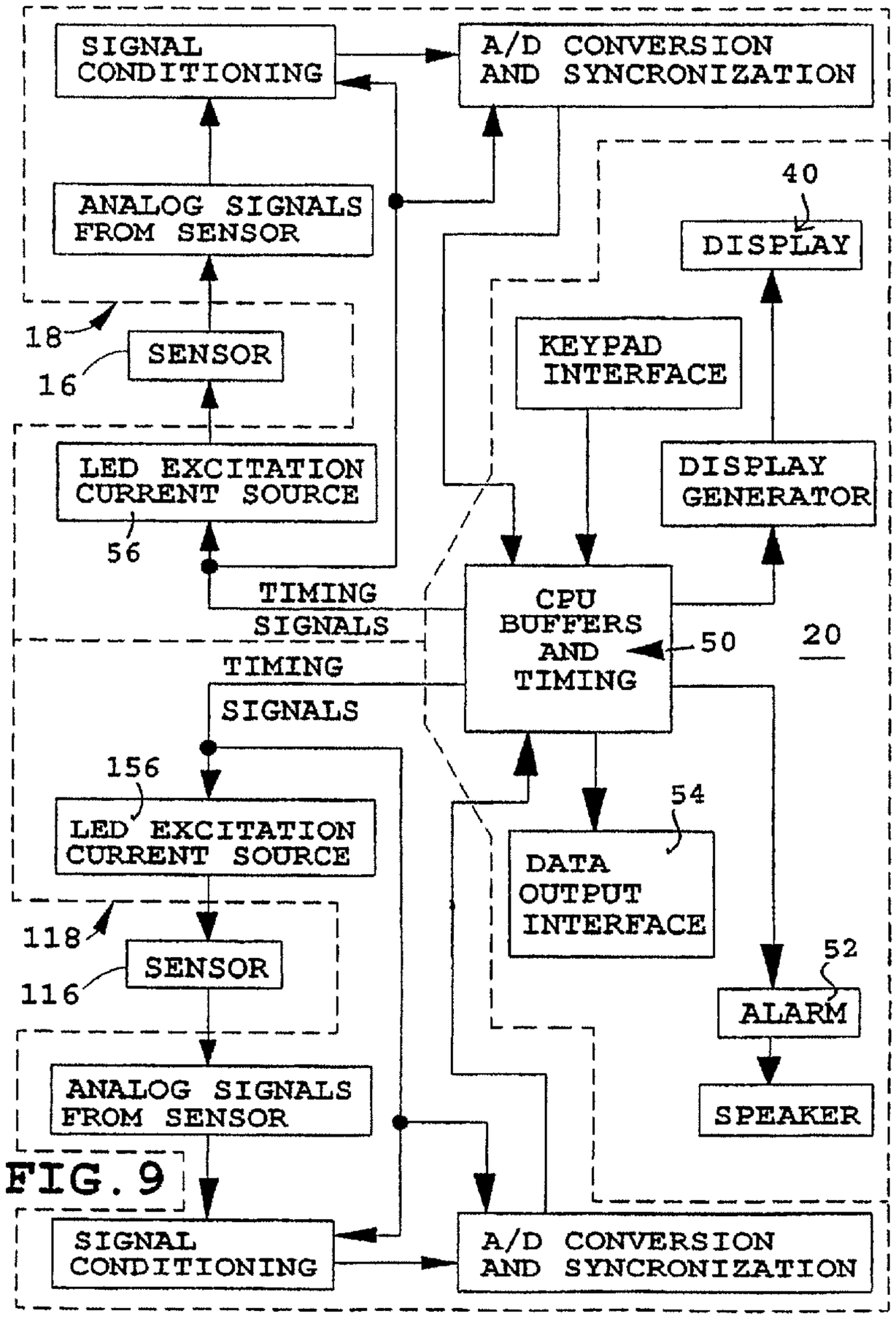
SIGNAL CONDITIONING
A/D CONVERSION AND SYNCRONIZATION
ANALOG SIGNALS FROM SENSOR
40
DISPLAY
18
SENSOR
16
KEYPAD INTERFACE
LED EXCITATION CURRENT SOURCE
56
DISPLAY GENERATOR
TIMING SIGNALS
CPU BUFFERS AND TIMING
50
20
TIMING SIGNALS
156
LED EXCITATION CURRENT SOURCE
54
DATA OUTPUT INTERFACE
118
SENSOR
116
52
ALARM
ANALOG SIGNALS FROM SENSOR
SPEAKER
SIGNAL CONDITIONING
A/D CONVERSION AND SYNCRONIZATION

FIG. 9

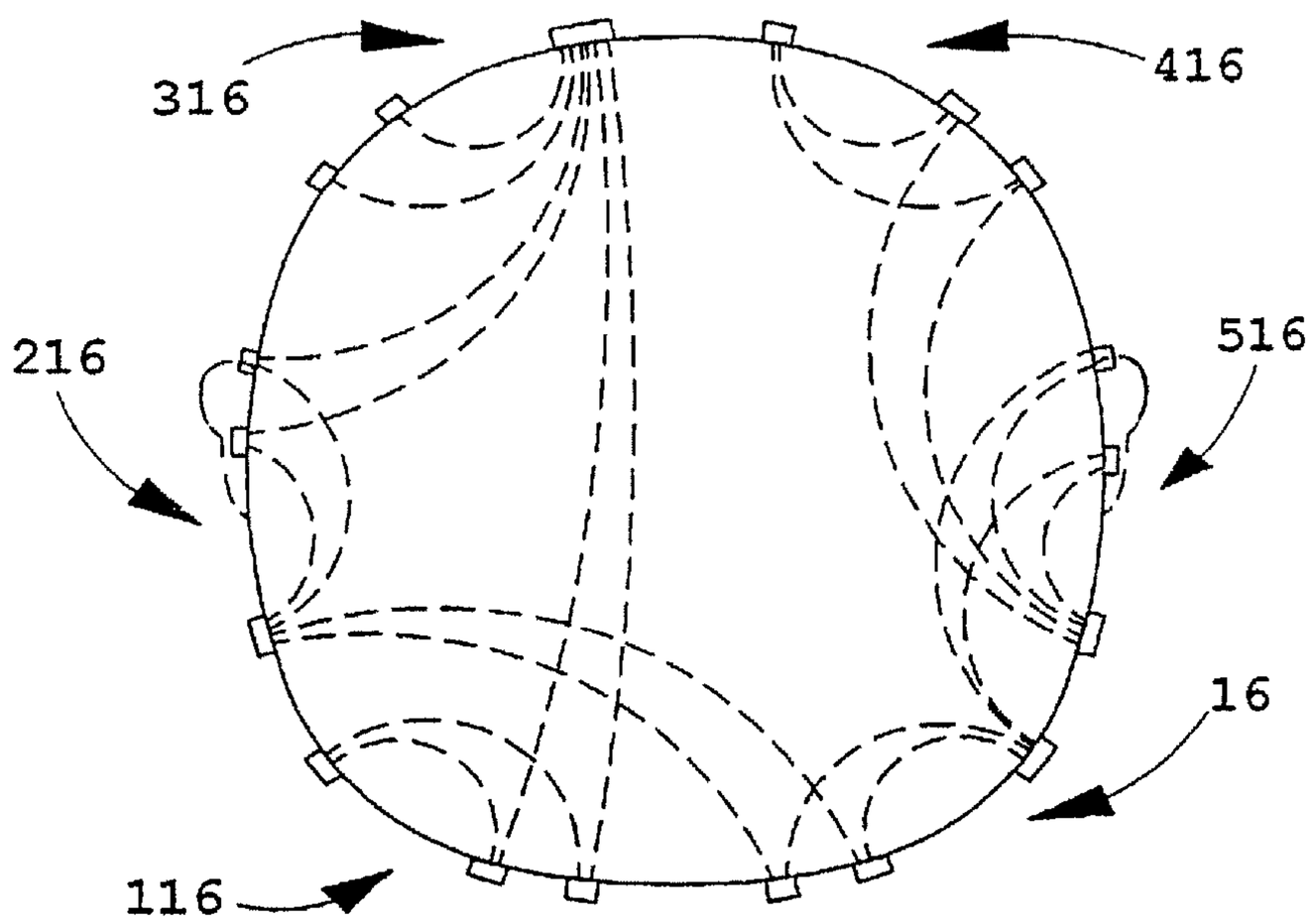

FIG.10

MULTI-CHANNEL NON-INVASIVE TISSUE OXIMETER

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

This application is a national stage of International Application No. PCT/US99/22940, filed Oct. 13, 1999, which claims the benefit of U.S. Provisional Application Ser. No. 60/103,985, filed Oct. 13, 1998.

This invention relates generally to in vivo spectrophotometric examination and monitoring of selected blood metabolites or constituents in human and/or other living subjects, e.g., medical patients, and more particularly to spectrophotometric oximetry, by transmitting selected wavelengths (spectra) of light into a given area of the test subject, receiving the resulting light as it leaves the subject at predetermined locations, and analyzing the received light to determine the desired constituent data based on the spectral absorption which has occurred, from which metabolic information such as blood oxygen saturation may be computed for the particular volume of tissue through which the light spectra have passed.

A considerable amount of scientific data and writings, as well as prior patents, now exist which is/are based on research and clinical studies done in the above-noted area of investigation, validating the underlying technology and describing or commenting on various attributes and proposed or actual applications of such technology. One such application and field of use is the widespread clinical usage of pulse oximeters as of the present point in time, which typically utilize sensors applied to body extremities such as fingers, toes, earlobes, etc., where arterial vasculature is in close proximity, from which arterial hemoglobin oxygenation may be determined non-invasively. A further and important extension of such technology is disclosed and discussed in U.S. Pat. No. 5,902,235, which is related to and commonly owned with the present application and directed to a non-invasive spectrophotometric cerebral oximeter, by which blood oxygen saturation in the brain may be non-invasively determined through the use of an optical sensor having light emitters and detectors that is applied to the forehead of the patient. Earlier patents commonly owned with the '235 patent and the present one pertaining to various attributes of and applications for the underlying technology include U.S. Pat. Nos. 5,139,025; 5,217,013; 5,465,714; 5,482,034; and 5,584,296.

The cerebral oximeter of the aforementioned '235 patent has proved to be an effective and highly desirable clinical instrument, since it provides uniquely important medical information with respect to brain condition (hemoglobin oxygen saturation within the brain, which is directly indicative of the single most basic and important life parameter, i.e. brain vitality). This information was not previously available, despite its great importance, since there really is no detectable arterial pulse within brain tissue itself with respect to which pulse oximetry could be utilized even if it could be effectively utilized in such an interior location (which is very doubtful), and this determination therefore requires a substantially different kind of apparatus and determination analysis. In addition, there are a number of uniquely complicating factors, including the fact that there is both arterial and venous vasculature present in the skin and underlying tissue through which the examining light spectra must pass during both entry

to and exit from the brain, and this would distort and/or obscure the brain examination data if excluded in some way. Furthermore, the overall blood supply within the skull and the brain itself consists of a composite of arterial, venous, and capillary blood, as well as some pooled blood, and each of these are differently oxygenated. In addition, the absorption and scatter effects on the examination light spectra are much greater in the brain and its environment than in ordinary tissue, and this tends to result in extremely low-level electrical signal outputs from the detectors for analysis, producing difficult signal-to-noise problems.

Notwithstanding these and other such problems, the cerebral oximeter embodying the technology of the aforementioned issued patents (now available commercially from Somanetics Corporation, of Troy, Mich.) has provided a new type of clinical instrument by which new information has been gained relative to the operation and functioning of the human brain, particularly during surgical procedures and/or injury or trauma, and this has yielded greater insight into the functioning and state of the brain during such conditions. This insight and knowledge has greatly assisted surgeons performing such relatively extreme procedures as carotid endarterectomy, brain surgery, and other complex procedures, including open-heart surgery, etc. and has led to a greater understanding and awareness of conditions and effects attributable to the hemispheric structure of the human brain, including the functional inter-relationship of the two cerebral hemispheres, which are subtly interconnected from the standpoint of blood perfusion as well as that of electrical impulses and impulse transfer.

BRIEF SUMMARY OF INVENTION

The present invention results from the new insights into and increased understanding of the human brain referred to in the preceding paragraph, and provides a methodology and apparatus for separately (and preferably simultaneously) sensing and quantitatively determining brain oxygenation at a plurality of specifically different locations or regions of the brain, particularly during surgical or other such traumatic conditions, and visually displaying such determinations in a directly comparative manner. In a larger sense, the invention may also be used to monitor oxygenation (or other such metabolite concentrations or parameters) in other organs or at other body locations, where mere arterial pulse oximetry is a far too general and imprecise examination technique.

Further, and of considerable moment, the invention provides a method and apparatus for making and displaying determinations of internal metabolic substance, as referred to in the preceding paragraph, at a plurality of particular and differing sites, and doing so on a substantially simultaneous and continuing basis, as well as displaying the determinations for each such site in a directly comparative manner, for immediate assessment by the surgeon or other attending clinician, on a real-time basis, for direct support and guidance during surgery or other such course of treatment.

In a more particular sense, the invention provides a method and apparatus for spectrophotometric in vivo monitoring of blood metabolites such as hemoglobin oxygen concentration in any of a preselected plurality of different regions of the same test subject and on a continuing and substantially instantaneous basis, by applying a plurality of spectrophotometric sensors. In a more particular sense, the invention provides a method and apparatus for spectrophotometric in vivo monitoring of blood metabolites such as hemoglobin oxygen concentration in any of a preselected plurality of different regions of the same test subject and on a continuing and

substantially instantaneous basis, by applying a plurality of spectrophotometric sensors to the test subject at each of a corresponding plurality of testing sites, coupling each such sensor to a control and processing station, operating each such sensor to spectrophotometrically irradiate a particular region within the test subject associated with that sensor, detecting and receiving the light energy resulting from such spectrophotometric irradiation for each such region, conveying signals corresponding to the light energy so received to the control and processing station, analyzing the conveyed signals to determine preselected blood metabolite data, and displaying the data so obtained from each of a plurality of such testing sites and for each of a plurality of such regions, in a region-comparative manner.

The foregoing principal aspects and features of the invention will become better understood upon review of the ensuing specification and the attached drawings, describing and illustrating preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a pictorial representation of a patient on whom apparatus in accordance with the invention is being used;

FIG. **2** is a fragmentary plan view of a typical sensor used in accordance with the invention;

FIG. **3** is an enlarged, fragmentary, pictorial cross-sectional view of a human cranium, showing the sensors of FIG. **2** applied and in place, generally illustrating both structural and functional aspects of the invention;

FIG. **4** is a front view of a typical control and processing unit for use in the invention, illustrating a preferred display of data determined in accordance with the invention;

FIGS, **5**, **6**, and **7** are graphs representing data displays obtained in accordance with the invention which represent actual surgical procedure results from actual patients;

FIG. **8** is a pictorialized cross-sectional view representing a test subject on which a multiplicity of sensors are placed in sequence, further illustrating the multi-channel capability of the present invention;

FIG. **9** is a schematic block diagram generally illustrating the componentry and system organization representative of a typical implementation of the invention; and

FIG. **10** is a pictorialized cross-sectional view similar to FIG. **8**, but still further illustrating the multi-channel capability of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENT

FIG. **1** depicts an illustrative patient **10** on whom an instrument **12** in accordance with the present invention is being employed. As illustrated, the forehead **14** of patient **10** has a pair of sensors **16**, **116** secured to it in a bilateral configuration, i.e., one such sensor on each side of the forehead, where each may monitor a different brain hermisphere. Each of the sensors **16**, **116** is connected to a processor and display unit **20** which provides a central control and processing station (sometimes hereinafter, referred to as the "oximeter") by a corresponding electrical cable **16**A, **116**A, which join one another at a dual-channel coupler/pre-amp **18**, **118** and then (preferably) proceed to the control and processor **20** as an integrated, multiple-conductor cable **22**. As will be understood, the electrical cables just noted include individual conductors for energizing light emitters and operating the related light detectors contained in sensors **16**, **116**, all as referred to further hereinafter and explained in detail in the various prior patents.

The general nature of a typical structure and arrangement for the sensors **16**,**116** (which are identical in nature and which may if desired be incorporated into a single physical unit) is illustrated in FIG. **2**, and comprises the subject matter of certain of the earlier patents, in particular U.S. Pat. Nos. 5,465,714; 5,482,034; 5,584,296; and 5,795,292, wherein the structure and componentry of preferred sensors are set forth in detail. For present purposes, it is sufficient to note that the sensors **16**, **116** include an electrically actuated light source **24** for emitting the selected examination spectra (e.g., two or more narrow-bandwidth LEDs, whose center output wavelengths correspond to the selected examination spectra), together with a pair of light detectors **26**, **28** (e.g., photodiodes) which are preferably located at selected and mutually different distances from the source **24**. These electro-optical (i.e., "optode") components are precisely positioned upon and secured to, or within, a sensor body having a foam or other such soft and conformable outer layer which is adhesively secured to the forehead (or other desired anatomical portion) of the patient **10**, as generally illustrated in FIG. **1**, and individual electrical conductors in cables **16**A, **116**A provide operating power to the sources **24** while others carry output signals from the detectors **26**, **28**, which are representative of detected light intensities received at the respective detector locations and must be conveyed to the processor unit **20**, where processing takes place.

FIG. **3** generally illustrates, by way of a pictorialized cross-sectional view, the sensors **16**, **116** in place upon the forehead **14** of the patient **12**. As illustrated in this figure, the cranial structure of patient **12** generally comprises an outer layer of skin **30**, an inner layer of tissue **32**, and the frontal shell **34** of the skull, which is of course bone.

Inside the skull **34** is the Periosteal Dura Mater, designated by the numeral **36**, and inside that is the brain tissue **38** itself, which is comprised of two distinct hemispheres **38'**, **38"** that are separated at the center of the forehead inwardly of the superior sagital sinus by a thin, inwardly-projecting portion **36**a of the Dura **36**. Thus, in the arrangement illustrated in FIG. **3**, sensor **16** accesses and examines brain hemisphere **38"**, while sensor **116** does the same to brain hemisphere **38'**.

As explained at length in various of the above-identified prior patents, the preferred configuration of sensors **16**, **116** includes both a "near" detector **26**, which principally receives light from source **24** whose mean path length is primarily confined to the layers of skin, tissue, skull, etc., outside brain **38**, and a "far" detector **28**, which receives light spectra that have followed a longer mean path length and traversed a substantial amount of brain tissue in addition to the bone and tissue traversed by the "near" detector **26**. Accordingly, by appropriately differentiating the information from the "near" (or "shallow") detector **26** (which may be considered a first data set) from information obtained from the "far" (or "deep") detector **28** (providing a second such data set), a resultant may be obtained which principally characterizes conditions within the brain tissue itself, without effects attributable to the overlying adjacent tissue, etc. This enables the apparatus to obtain metabolic information on a selective basis, for particular regions within the test subject, and by spectral analysis of this resultant information, employing appropriate extinction coefficients, etc. (as set forth in certain of the above-identified patents), a numerical value, or relative quantified value, may be obtained which characterizes metabolites or other metabolic data (e.g., the hemoglobin oxygen saturation) within only the particular region or volume of tissue actually examined, i.e., the region or zone generally defined by the curved mean path extending from source **24** to the "far" or "deep" detector **28**, and between this path and the outer periphery of

the test subject but excluding the analogous region or zone defined by the mean path extending from source **24** to "near" detector **26**. As will be understood, particularly in view of Applicants' above-identified prior patents as well as is explained further hereinafter, this data analysis carried out by the "control and processing unit" **20** is accomplished by use if an appropriately programmed digital computer, as is now known by those skilled in the art (exemplified in particular by the Somanetics® model 4100 cerebral oximeter).

The present invention takes advantage of the primarily regional oxygen saturation value produced by each of the two (or more) sensors **16**, **116**, together with the natural hemispheric structure of brain **38**, by use of a comparative dual or other multi-channel examination paradigm that in the preferred embodiment or principal example set forth herein provides a separate but preferably comparatively displayed oxygen saturation value for each of the two brain hemispheres **38'**, **38"**. Of course, it will be understood that each such regional index or value of oxygen saturation is actually representative of the particular region within a hemisphere actually subjected to the examining light spectra, and while each such regional value may reasonably be assumed to be generally representative of the entire brain hemisphere in which it is located, and therefor useful in showing and contrasting the differing conditions between the two such hemispheres of the brain **38**, the specific nature and understanding of these hemispheric interrelationships and of interrelationships between other and different possible sensor locations relative to each different hemisphere **38'**, **38"** are not believed to be fully known and appreciated as of yet. Consequently, it may be useful or advantageous in at least some cases, and perhaps in many, to employ a more extensive distribution and array of sensors and corresponding inputs to the oximeter **20**, such as is illustrated for example in FIG. **8**.

Thus, as seen in FIG. **8**, a more extensive array of sensors **16**, **116**, **216**, etc., may be deployed around the entire circumference of the head or other such patient extremity, for example, each such sensor sampling a different regional area of each brain hemisphere or other such organ or test site and outputting corresponding data which may be contrasted in various ways with the analogous data obtained from the other such sensors for other test site regions. In this regard, it will be appreciated that the extent of each such regional area subjected to examination is a function of a number of different factors, particularly including the distance between the emitter or source **24** and detectors **26**, **28** of each such set and the amount of light intensity which is utilized, the greater the emitter/sensor distance and corresponding light intensity, the greater the area effectively traversed by the examining light spectra and the larger the size of the "region" whose oximetric or other metabolic value is being determined.

It may also be possible to use only a single source position and employ a series of mutually spaced detector sets, or individual detectors, disposed at various selected distances from the single source around all or a portion of the perimeter of the subject. Each such single source would actually illuminate the entire brain since the photons so introduced would scatter throughout the interior of the skull (even though being subject to increased absorption as a function of distance traversed), and each such emitter/detector pair (including long-range pairs) could produce information characterizing deeper interior regions than is true of the arrays illustrated in FIGS. **3** and **8**, for example. Of course, the smaller-region arrays shown in these figures are desirable in many instances, for a number of reasons. For example, the comparative analysis of information corresponding to a number of differing such regions, as represented by the array of FIG. **8**, lends itself readily to very meaningful comparative displays, including for example computer-produced mapping displays which (preferably by use of differing colors and a color monitor screen) could be used to present an ongoing real-time model which would illustrate blood or even tissue oxygenation state around the inside perimeter of and for an appreciable distance within a given anatomical area or part. The multiple detector outputs from such a single-source arrangement, on the other hand, would contain information relative to regions or areas deep within the brain, and might enable the determination of rSO_2 values (or other parameters) for deep internal regions as well as the production of whole-brain mapping, by differentially or additively combining the outputs from various selected detectors located at particular points.

The dual or bilateral examination arrangement depicted in FIGS. **1** and **3** will provide the highly useful comparative display formats illustrated in FIGS. **4**, **5**, **6**, and **7** (as well as on the face of the oximeter **20** shown at the right in FIG. **1**), for example. In the arrangement shown in FIGS. **1** and **4**, each sensor output is separately processed to provide a particular regional oxygen saturation value, and these regional values are separately displayed on a video screen **40** as both a numeric or other such quantified value, constituting a basically instantaneous real-time value, and as a point in a graphical plot **42**, **44**, representing a succession of such values taken over time. As illustrated, the plots or graphs **42**, **44** may advantageously be disposed one above the other in direct alignment, for convenient examination and comparison. While the instantaneous numeric displays will almost always be found useful and desirable, particularly when arranged in the directly adjacent and immediately comparable manner illustrated, the graphical trace displays **42**, **44** directly show the ongoing trend, and do so in a contrasting, comparative manner, as well as showing the actual or relative values, and thus are also highly useful.

Graphic displays **42**, **44** may also advantageously be arranged in the form shown in FIGS. **5**, **6**, and **7**, in which the two such individual traces are directly superimposed upon one another, for more immediate and readily apparent comparison and contrast. Each of the examples shown in FIGS. **5**, **6**, and **7** does in fact represent the record from an actual surgical procedure in which the present invention was utilized, and in each of these the vertical axis (labeled rSO_2) is indicative of regional oxygen saturation values which have been determined, while the horizontal axis is, as labeled, "real time," i.e., ongoing clock time during the surgical procedure involved. The trace from the "left" sensor (number **16** as shown in FIGS. **1** and **3**), designated by the numeral **42** for convenience, is shown in solid lines in these graphs, whereas the trace **44** from the right-band sensor **116** is shown in dashed lines. The sensors may be placed on any region of their respective test areas (e.g., brain hemispheres) provided that any underlying hair is first removed, since hair is basically opaque to the applied light spectra and thus greatly reduces the amount of light energy actually introduced to the underlying tissue, etc.

With further reference to FIGS. **5**, **6**, and **7**, and also inferentially to FIG. **4**, it will be seen that at certain times, (e.g., the beginning and end of each procedure, when the patient's condition is at least relatively normal) there is a certain amount of direct correspondence between the two different hemispheric traces **42**, **44**, and that in at least these time increments the shape of the two traces is reasonably symmetrical and convergent. An idealized such normal result is shown in FIG. **1**, wherein both the numeric values and the curves are basically the same. In each of the procedures shown in FIGS. **5**, **6**, and **7**, however, there are times when the

detected regional cerebral oxygen saturation differs markedly from one brain hemisphere to the other. This is particularly noticeable in FIG. **6**, in which it may be observed that the left band trace **42** is at times only about one half the height (i.e., value) of the right hand trace **44**, reaching a minimal value in the neighborhood of about 35% slightly before real time point 12:21 as compared to the initial level, at time 10:50-11:00, of more than 75%, which is approximately the level of saturation in the right hemisphere at the 12:21 time just noted, when the oxygenation of the left hemisphere bad decreased to approximately 35%.

As will be understood, the various differences in cerebral blood oxygenation shown by the superimposed traces of FIGS. **5**, **6**, and **7** occur as a result of measures taken during the corresponding surgical procedures, which in these cases are carotid endarterectomies and/or coronary artery bypass graft (CABG), which are sometimes undertaken as a continuing sequence. In the illustrated examples, FIG. **5** represents a sequential carotid endarterectomy and hypothermic CABG, in which the vertical lines along the time axis characterize certain events during surgery, i.e., index line **46** represents the time of the carotid arterial incision, line **48** represent the time the arterial clamp was applied and the shunt opened (resulting in reduced arterial blood flow to the left brain hemisphere), index line **50** represents a time shortly after the shunt was removed and the clamp taken off, and the area from about real time 17:43 to the end of the graph was when the hypothermic brain surgery actually took place, the lowest point (just prior to time 18:23) occurring when the heart-lung machine pump was turned on, and the indices at time 19:43 and 20:23 generally show the time for blood rewarming and pump off, respectively. While illustrative and perhaps enlightening, it is not considered necessary to give the specifics of the surgical procedures portrayed by the graphical presentations of FIGS. **6** and **7**, although it may be noted that the procedure of FIG. **6** was a carotid endarterectomy of the left side and that of FIG. **7** was a similar endarterectomy on the right side of a different patient. Sufficient to say that these graphs represent other such surgical procedures and show comparable states of differing hemispheric oxygenation.

The importance and value of the information provided in accordance with the present invention is believed self-apparent from the foregoing, particularly the graphical presentations of and comments provided with respect to FIGS. **5**, **6**, and **7**. Prior to the advent of the present invention, no such comparative or hemispheric-specific information was available to the surgeon, who did not in fact have any quantified or accurately representative data to illustrate the prevailing hemispheric brain oxygenation conditions during a surgery. Thus, even the use of a single such sensor (**16**, **116**) on the side of the brain on which a procedure is to be done is highly useful and, as of the present time, rapidly being recognized as essential. Of course, it is considerably more useful to have at least the bilateral array illustrated in FIG. **1**, to provide comparative data such as that seen in FIGS. **4-7** inclusive.

FIG. **9** is a schematic block diagram generally illustrating the componentry and system organization making up a typical implementation of the invention, as shown pictorially in FIG. **1** (to which reference is also made). As shown in FIG. **9**, the oximeter **20** comprises a digital computer **50** which provides a central processing unit, with a processor, data buffers, and timing signal generation for the system, together with a keypad interface (shown along the bottom of the unit **20** in FIG. **1**), display generator and display **40** (preferably implemented by use of a flat electro-luminescent unit, at least in applications where a sharp monochromatic display is sufficient), as well as an audible alarm **52** including a speaker, and a data output interface **54** by which the computer may be interconnected to a remote personal computer, disk drive, printer, or the like for downloading data, etc.

As also shown in FIG. **9**, each of the sensors **16**, **116** (and/or others, in the multi-site configuration illustrated in FIG. **8**) receives timing signals from the CPU **50** and is coupled to an LED excitation current source (**56**,**156**) which drives the emitters **24** of each sensor. The analog output signals from the detectors (photodiodes) **26**, **28** of each sensor are conveyed to the coupler/pre-amp **18**, **118** for signal conditioning (filtering and amplification), under the control of additional timing signals from the CPU. Following that, these signals undergo A-to-D conversion and synchronization (for synchronized demodulation, as noted hereinafter), also under the control of timing signals from CPU **50**, and they are then coupled to the CPU for computation of regional oxygen saturation rSO_2 data, storage of the computed data, and display thereof, preferably in the format discussed above in conjunction with FIGS. **4**, **5**, **6**, and **7**. As will be apparent, each sensor (**16**, **116**, etc.) preferably has its own signal-processing circuitry (pre-amp, etc.) upstream of CPU **50**, and each such sensor circuit is preferably the same.

While implementation of a system such as that shown in FIG. **9** is as a general matter well within the general skill of the art once the nature and purpose of the system and the basic requirements of its components, together with the overall operation (as set forth above and hereinafter) have become known, at least certain aspects of the preferred such system implementation are as follows. First, it is preferable that the light emitters **24** (i.e., LEDs) of each of the different sensors **16**, **116** etc., be driven out-of-phase, sequentially and alternatingly with one another (i.e., only a single such LED or other emitter being driven during the same time interval, and the emitters on the respective different sensors are alternatingly actuated, so as to ensure that the detectors **26**, **28** of the particular sensor **16**, **116** then being actuated receive only resultant light spectra emanating from a particular emitter located on that particular sensor, and no cross-talk between sensors takes place (even though significant levels of cross-talk are unlikely in any event due to the substantial attenuation of light intensity as it passes through tissue, which is on the order of about ten times for each centimeter of optical path length through tissue). Further, it is desirable to carefully window the "on" time of the detectors **26**, **28** so that each is only active during a selected minor portion (for example, 10% or less) of the time that the related emitter is activated (and, preferably, during the center part of each emitter actuation period). Of course, under computer control such accurate and intricate timing is readily accomplished, and in addition, the overall process may be carried on at a very fast rate.

In a multi-site (multiple sensor) system, such as that shown in FIG. **8**, the preferred implementation and system operation would also be in accordance with that shown in FIG. **9**, and the foregoing comments regarding system performance, data sampling, etc., would also apply, although there would of course be a greater number of sensors and sensor circuit branches interfacing with computer **50**. The same would also be basically true of a single-source multi-site detector configuration or grouping such as that referred to above, taking into consideration the fact that the detectors would not necessarily be grouped in specific or dedicated "near-far" pairs and bearing in mind that one or more detectors located nearer a source than another detector, or detectors, located further from the source could be paired with or otherwise deemed a "near" detector relative to any such farther detector. In any such multiple-site configuration, it may be advantageous to implement a prioritized sequential emitter actuation and data

detection timing format, in which more than one emitter may be operated at the same time, or some particular operational sequence is followed, with appropriate signal timing and buffering, particularly if signal cross-talk is not a matter of serious consideration due to the particular circumstances involved (detector location, size and nature of test subject, physiology, signal strength, etc.). As illustrated in FIG. **10**, a multi-sensor or multiple sector-emitter array may be so operated, by using a number of different emitter-detector pair groupings, with some detectors used in conjunction with a series of different emitters to monitor a number of differing internal sectors or regions.

A system as described above may readily be implemented to obtain on the order of about fifteen data samples per second even with the minimal detector "on" time noted, and a further point to note is that the preferred processing involves windowing of the detector "on" time so that data samples are taken alternatingly during times when the emitters are actuated and the ensuing time when they are not actuated (i.e., "dark time"), so that the applicable background signal level may be computed and utilized in analyzing the data taken during the emitter "on" time. Other features of the preferred processing include the taking of a fairly large number (e.g., **50**) of data samples during emitter "on" time within a period of not more than about five seconds, and processing that group of signals to obtain an average from which each updated rSO_2 value is computed, whereby the numeric value displayed on the video screen **40** is updated each five seconds (or less). This progression of computed values is preferably stored in computer memory over the entire length of the surgical procedure involved, and used to generate the graphical traces **42**,**44** on a time-related basis as discussed above. Preferably, non-volatile memory is utilized so that this data will not be readily lost, and may in fact be downloaded at a convenient time through the data output interface **54** of CPU **50** noted above in connection with FIG. **9**.

As will be understood, the foregoing disclosure and attached drawings are directed to a single preferred embodiment of the invention for purposes of illustration; however, it should be understood that variations and modifications of this particular embodiment may well occur to those skilled in the art after considering this disclosure, and that all such variations etc., should be considered an integral part of the underlying invention, especially in regard to particular shapes, configurations, component choices and variations in structural and system features. Accordingly, it is to be understood that the particular components and structures, etc. shown in the drawings and described above are merely for illustrative purposes and should not be used to limit the scope of the invention, which is defined by the following claims as interpreted according to the principles of patent law, including the doctrine of equivalents.

The invention claimed is:

[1. A method for comparative spectrophotometric in vivo monitoring and display of selected blood metabolites present in a plurality of different internal regions of the same test subject on a continuing and substantially concurrent basis, comprising the steps of:

applying separate spectrophotometric sensors to a test subject at each of a plurality of separate testing sites and coupling each of said sensors to a control and processing station;

operating a selected number of said sensors on a substantially concurrent basis to spectrophotometrically irradiate at least two separate internal regions of the test subject during a common time interval, each of said regions being associated with a different of said testing sites;

separately detecting and receiving light energy resulting from said spectrophotometric irradiation for each of said at least two separate internal regions, and conveying separate sets of signals to said control and processing station which correspond to the separately detected light energy from said at least two separate internal regions;

separately and concurrently analyzing said conveyed separate sets of signals to separately determine quantified data representative of a blood metabolite in each of said at least two separate internal regions; and

concurrently visually displaying said separately determined quantified data for each of said at least two separate internal regions for direct concurrent mutual comparison, wherein said sensors are applied to a head of the test subject and are used to monitor two mutually separate regions within a brain of the test subject.**]**

[2. The method of claim **1**, wherein said step of analyzing comprises quantitative determination of blood oxygenation levels within each of said at least two separate internal regions.**]**

[3. The method of claim **2**, wherein said analyzing step includes producing separate quantitative value determinations for hemoglobin oxygen saturation for each of said at least two separate internal regions.**]**

[4. The method of claim **3**, wherein said analyzing step includes production of ongoing graphical traces representing a plurality of said quantitative value determinations made at successive points in time.**]**

[5. The method of claim **4** including the step of visually displaying a plurality of said graphical traces at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.**]**

[6. The method of claim **5**, including the step of visually displaying a plurality of said quantitative value determinations at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.**]**

[7. The method of claim **3**, including the step of visually displaying a plurality of said quantitative value determinations at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.**]**

[8. The method of claim **1**, wherein said metabolite comprises hemoglobin oxygen.**]**

[9. The method of claim **1**, wherein said sensors are positioned in locations proximate to different brain hemispheres and said two mutually separate regions are located in a different brain hemisphere.**]**

[10. The method of claim **9**, wherein said metabolite comprises cerebral blood hemoglobin oxygenation.**]**

[11. An apparatus for concurrent comparative spectrophotometric in vivo monitoring of selected blood metabolites present in each of a plurality of different internal regions on a continuing basis, comprising:

a plurality of spectrophotometric sensors, each attachable to a test subject at different test locations and adapted to separately but concurrently spectrophotometrically irradiate at least two different internal regions within the test subject associated with each of said test locations;

a controller and circuitry coupling each of said sensors to said controller for separately and individually but concurrently operating certain of said sensors to spectrophotometrically irradiate each of said different internal regions within the test subject associated with each of said test locations;

said sensors each further adapted to receive light energy resulting from the separate spectrophotometric irradia-

tion of said sensors' associated one of said at least two different internal regions on a substantially concurrent basis with other said sensors, and to produce separate signals corresponding to the light energy received, said circuitry acting to convey said separate signals to said controller for separate analytic processing;

said controller adapted to analytically process said conveyed signals separately and determine separate quantified blood metabolite data therefrom for each of said sensors and said sensors' associated one of said at least two different internal regions; and

a visual display coupled to said controller and adapted to separately but concurrently display the quantified blood metabolite data determined for each of said sensors in a mutually-comparative manner, wherein said sensors are adapted to be applied to a head of the test subject and to monitor a brain of the test subject.]

[**12**. The apparatus of claim **11**, wherein said controller is adapted to analyze said data to quantitatively determine blood oxygenation within said at least two different internal regions.]

[**13**. The apparatus of claim **12**, wherein said controller is adapted to produce separate numeric value designations for hemoglobin oxygen saturation for said at least two different internal regions.]

[**14**. The apparatus of claim **13**, wherein said controller and said display are adapted to produce ongoing graphical traces representing a plurality of said numeric value designations for the same region taken over a period of time.]

[**15**. The apparatus of claim **14**, wherein said controller and said display are adapted to visually display at least two of said graphical traces on a substantially concurrent basis and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.]

[**16**. The apparatus of claim **15**, wherein said controller and said display are adapted to visually display at least two of said numeric value designations as well as at least two of said graphical traces on a substantially concurrent basis and in proximity to one another to facilitate rapid and accurate visual comparison.]

[**17**. The apparatus of claim **13**, wherein said controller and said display are adapted to visually display at least two of said numeric value designations on a substantially concurrent basis and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.]

[**18**. The apparatus of claim **11**, wherein said sensors are adapted to provide signals to said controller which comprise at least two separate data sets that cooperatively define at least portions of a particular area within a given one of said at least two different internal regions.]

[**19**. The apparatus of claim **18**, wherein said data sets provided by said sensors include a first set characterizing a first part of said particular area and a second set characterizing a second part of said particular area.]

[**20**. The apparatus of claim **19**, wherein said second part of said particular area characterized by said second set includes at least part of said first part of said area.]

[**21**. The apparatus of claim **11**, wherein said controller is adapted to determine blood oxygenation saturation in said brain.]

[**22**. The apparatus of claim **11**, wherein at least two of said sensors are adapted to be positioned in locations associated with mutually different hemispheres of the brain and each of said sensors is operable to separately monitor at least portions of each of said different hemispheres.]

[**23**. The apparatus of claim **22**, wherein said controller is adapted to determine cerebral blood oxygenation saturation within each of said different hemispheres.]

[**24**. The apparatus of claim **22**, wherein said sensors are adapted to provide signals to said controller which comprise at least two data sets that cooperatively define at least portions of a particular area within the same hemisphere of said brain.]

[**25**. The apparatus of claim **11**, wherein said sensors are adapted to be applied to the outside periphery of the test subject and to operate non-invasively.]

[**26**. A method for concurrent comparative in vivo monitoring of blood metabolites in each of a plurality of different internal regions in a selected test subject, comprising the steps of:

spectrophotometrically irradiating each of a plurality of different testing sites on said test subject;

detecting light energy resulting from said spectrophotometric irradiation of said testing sites, and providing separate sets of signals to a control and processing station which are representative of the light energy received by each of said testing sites and which cooperatively define blood metabolite data for an individual one of at least two different internal regions;

analyzing said separate signals to determine quantified blood metabolite data representative of at least one defined region within said at least one test subject associated with each of at least two different of said testing sites, each said defined region being different from the other; and

concurrently displaying data sets for each of said at least two different internal regions at substantially the same time for direct mutual comparison, wherein said at least two different internal regions are located within different brain hemispheres of said test subject.]

[**27**. The method of claim **26**, wherein said data sets include a first set which characterizes a first zone within one of said at least two different internal regions and a second set which characterizes a second zone that is at least partially within the same one of said at least two different internal regions.]

[**28**. The method of claim **26**, wherein said spectrophotometric irradiation comprises application of at least two different wavelengths applied in an alternating sequence of timed pulses, and wherein detection of light energy corresponding to each of said at least two different wavelengths is done on a timed periodic basis using detection periods whose occurrence generally corresponds to that of said applied spectrophotometric irradiation.]

[**29**. The method of claim **28**, wherein the duration of each of said detection periods is limited to a length which is less than that of each pulse of applied spectrophotometric irradiation.]

[**30**. The method of claim **29**, wherein the duration of each of said detection periods is less than half that of a pulse of said applied spectrophotometric irradiation.]

[**31**. The method of claim **30**, wherein a plurality of said detection periods are used during pulses of said applied spectrophotometric irradiation, and a corresponding energy detection occurs during each of a plurality of said detection periods.]

[**32**. The method of claim **31**, further including the steps of averaging a selected number of energy detection event values to obtain a resultant value therefor, and using said resultant value to compute a metabolite value which is representative thereof.]

[**33**. The method of claim **32**, wherein said display includes said computed representative metabolite value.]

[34. The method of claim 33, wherein said display is refreshed periodically by using a sequence of computed representative metabolite values which are based upon and represent the averaged detection event values produced during the different time intervals corresponding to the intervals of said periodic display refreshment.]

[35. Apparatus for spectrophotometric in vivo monitoring of a selected metabolic condition in each of a plurality of different test subject regions on a substantially concurrent basis, comprising:

a plurality of spectrophotometric emitters, each adapted to separately spectrophotometrically irradiate a designated region within a test subject from a test location on said test subject;

a controller and circuitry coupling each of said emitters to said controller for individually operating selected ones of said emitters to spectrophotometrically irradiate at least two particular regions within the test subject;

a plurality of detectors, each adapted to separately receive light energy resulting from the spectrophotometric irradiation of said at least two particular regions, and to produce at least one separate set of signals for each one of said at least two particular regions; and circuitry acting to convey said at least one separate set of signals to said controller for analytic processing;

said controller adapted to analytically process said at least one separate set of signals to determine separate sets of quantified data representative of a metabolic condition in said at least two particular regions; and

a visual display coupled to said controller and adapted to display separate representations of said separate sets of quantified data for each of said at least two particular regions in a mutually-comparative manner and on a substantially concurrent basis, wherein at least two of said at least two particular regions are located in mutually separate regions of a brain of said test subject.]

[36. The apparatus of claim 35, wherein said controller includes a computer programmed to analyze said signals to separately determine a blood oxygenation state within each of said at least two particular regions.]

[37. The apparatus of claim 36, wherein said computer comprises a processor, data buffers, and a timing signal generator, said data buffers adapted to store data representative of said blood oxygenation state and said timing signal generator adapted to control actuation of said emitters and detectors.]

[38. The apparatus of claim 36, wherein said controller comprises a unitary device which includes said computer and said display.]

[39. The apparatus of claim 38, wherein said unitary device further includes a keyboard interface to said computer.]

[40. The apparatus of claim 38, wherein said unitary device further includes a data output interface.]

[41. The apparatus of claim 40, wherein said unitary device further includes an integral keyboard interface to said computer.]

[42. The apparatus of claim 38, wherein said display comprises a flat electroluminescent visual display screen.]

[43. The apparatus of claim 42, wherein said unitary device further includes an integral keyboard interface to said computer.]

[44. The apparatus of claim 35, wherein at least certain of said detectors and certain of said emitters comprise operational pairs, and said controller is arranged to operate the emitters and detectors of at least certain of said operational pairs in predetermined timed relationship while maintaining the emitters and detectors of other of said operational pairs in a non-operating condition.]

[45. The apparatus of claim 44, wherein said controller is adapted to sequence the operation of said at least certain of said operational pairs.]

[46. The apparatus of claim 45, wherein at least one of said operational pairs include a plurality of said detectors arranged at mutually spaced locations which are spaced at differing distances from the emitter of said at least one of said operational pairs.]

[47. The apparatus of claim 46, wherein said controller is adapted to operate the emitter and a selected number less than all of the detectors of at least one of said operational pairs substantially in unison while holding the other detectors of said at least one of said operational pairs in a non-operating condition, and said controller is further arranged to operate said other detectors substantially in unison with said emitter at another time during which said selected number of said detectors are maintained in a non-operating condition.]

[48. The apparatus of claim 44, wherein at least one of said operational pairs includes a first detector and a second detector, and wherein the first detector is located nearer the emitter than the second detector to thereby provide near and far detector groupings for said at least one of said operational pairs.]

[49. The apparatus of claim 48, wherein said controller is adapted to sequence the operation of said at least one of said operational pairs.]

50. A method for comparative spectrophotometric in vivo monitoring and display of selected blood metabolites present in a plurality of different internal regions of the same test subject on a continuing and substantially simultaneous basis, comprising the steps of:

applying separate spectrophotometric sensors to a test subject at each of a plurality of separate testing sites on a head of said test subject and coupling each of said sensors to a control and processing station;

electronically controlling a selected number of said sensors in sequence on a substantially simultaneous basis to spectrophotometrically irradiate at least two separate internal regions within a brain of the test subject during a common time interval in a manner that reduces cross-talk between said sensors, each of said regions being associated with different ones of said testing sites;

separately detecting and receiving light energy resulting from said spectrophotometric irradiation for each of said at least two separate internal regions, and conveying separate sets of signals to said control and processing station which correspond to the separately detected light energy from said at least two separate internal regions;

separately and simultaneously analyzing said conveyed separate sets of signals to separately determine data representative of a blood metabolite level in each of said at least two separate internal regions; and

substantially simultaneously visually displaying said separately determined data for each of said at least two separate internal regions for direct simultaneous mutual comparison.

51. The method of claim 50, wherein said step of analyzing comprises quantitative determination of blood oxygenation levels within each of said at least two separate internal regions.

52. The method of claim 51, wherein said analyzing step includes producing separate quantitative value determinations for hemoglobin oxygen saturation for each of said at least two separate internal regions.

53. The method of claim 52, wherein said analyzing step includes production of ongoing graphical traces representing a plurality of said quantitative value determinations made at successive points in time.

54. The method of claim 53 including the step of visually displaying a plurality of said graphical traces at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

55. The method of claim 54, including the step of visually displaying a plurality of said quantitative value determinations at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

56. The method of claim 52, including the step of visually displaying a plurality of said quantitative value determinations at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

57. The method of claim 50, wherein said metabolite comprises hemoglobin oxygen.

58. The method of claim 50, wherein said sensors are positioned in locations proximate to different brain hemispheres and said two mutually separate regions are located in a different brain hemisphere.

59. The method of claim 58, wherein said metabolite comprises cerebral blood hemoglobin oxygenation.

60. The method of claim 50, wherein said data representative of a blood metabolite level includes regional blood oxygen saturation.

61. The method of claim 50, wherein said light energy is detected after traveling each of at least two different distances through tissue of the test subject.

62. The method of claim 50, wherein said electronically controlling in sequence comprises actuating said sensors in an alternating manner.

63. The method of claim 50, wherein said data is determined so as to principally characterize blood metabolite within each of the separate internal regions without effects attributable to adjacent tissue overlying said separate internal regions.

64. The method of claim 63, wherein said effects attributable to said adjacent tissue are minimized by comparing spectrophotometric irradiation that penetrates different depths into said test subject.

65. An apparatus for substantially simultaneous comparative spectrophotometric in vivo monitoring of selected blood metabolites present in each of a plurality of different internal regions on a continuing basis, comprising:

a plurality of spectrophotometric sensors, each attachable to a test subject at different test locations on a head of said subject and configured to separately but substantially simultaneously spectrophotometrically irradiate at least two different internal regions within a brain of the test subject associated with each of said test locations;

a controller and circuitry coupling each of said sensors to said controller configured for separately and individually but substantially simultaneously operating certain of said sensors in sequence to spectrophotometrically irradiate each of said different internal regions within the test subject associated with each of said test locations in a manner that reduces cross-talk between said sensors;

said sensors each further configured to receive light energy resulting from the separate spectrophotometric irradiation of said sensors' associated one of said at least two different internal regions on a substantially simultaneous basis with other said sensors, and to produce separate signals corresponding to the light energy received, said circuitry acting to convey said separate signals to said controller for separate analytic processing;

said controller configured to analytically process said conveyed signals separately and determine separate blood metabolite levels therefrom for each of said sensors and said sensors' associated one of said at least two different internal regions; and

a visual display coupled to said controller and configured to separately but substantially simultaneously display the blood metabolite levels determined for each of said sensors in a mutually-comparative manner.

66. The apparatus of claim 65, wherein said controller is adapted to analyze said data to quantitatively determine blood oxygenation within said at least two different internal regions.

67. The apparatus of claim 66, wherein said controller is adapted to produce separate numeric value designations for hemoglobin oxygen saturation for said at least two different internal regions.

68. The apparatus of claim 67, wherein said controller and said display are adapted to produce ongoing graphical traces representing a plurality of said numeric value designations for the same region taken over a period of time.

69. The apparatus of claim 68, wherein said controller and said display are adapted to visually display at least two of said graphical traces on a substantially simultaneous basis and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

70. The apparatus of claim 69, wherein said controller and said display are adapted to visually display at least two of said numeric value designations as well as at least two of said graphical traces on a substantially simultaneous basis and in proximity to one another to facilitate rapid and accurate visual comparison.

71. The apparatus of claim 67, wherein said controller and said display are adapted to visually display at least two of said numeric value designations on a substantially simultaneous basis and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

72. The apparatus of claim 65, wherein said sensors are adapted to provide signals to said controller which comprise at least two separate data sets that cooperatively define at least portions of a particular area within a given one of said at least two different internal regions.

73. The apparatus of claim 72, wherein said data sets provided by said sensors include a first set characterizing a first part of said particular area and a second set characterizing a second part of said particular area.

74. The apparatus of claim 73, wherein said second part of said particular area characterized by said second set includes at least part of said first part of said area.

75. The apparatus of claim 65, wherein said controller is adapted to determine blood oxygenation saturation in said brain.

76. The apparatus of claim 65, wherein at least two of said different test locations are associated with mutually different hemispheres of the brain and at least two of said plurality of sensors are operable to separately monitor at least portions of each of said different hemispheres.

77. The apparatus of claim 76, wherein said controller is adapted to determine cerebral blood oxygenation saturation within each of said different hemispheres.

78. The apparatus of claim 77, wherein said sensors are adapted to provide signals to said controller which comprise

at least two data sets that cooperatively define at least portions of a particular area within the same hemisphere of said brain.

79. The apparatus of claim 78, wherein said sensors are adapted to be applied to the outside periphery of the test subject and to operate non-invasively.

80. The apparatus of claim 65, wherein said blood metabolite levels represent regional blood oxygen saturation.

81. The apparatus of claim 65, wherein said sensors are adapted to receive light energy that has traveled each of at least two different distances through tissue of the test subject.

82. The apparatus of claim 65, wherein said controller is adapted to operate said sensors to spectrophotometrically irradiate out of phase with one another.

83. The apparatus of claim 65, wherein said blood metabolite levels are determined by said controller so as to principally characterize blood metabolite within each of the different internal regions without effects attributable to adjacent tissue overlying said different internal regions.

84. The apparatus of claim 83, wherein said effects attributable to said adjacent tissue are minimized by said controller comparing signals for spectrophotometric irradiation that penetrates different depths into said test subject.

85. A method for substantially simultaneous comparative in vivo monitoring of blood metabolites in each of a plurality of different internal regions in a selected test subject, comprising the steps of:

spectrophotometrically irradiating, in sequence on a substantially simultaneous basis, each of a plurality of different testing sites on said test subject via electronic control in a manner that reduces cross-talk between said spectrophotometric irradiation of said testing sites;

detecting light energy resulting from said spectrophotometric irradiation of said testing sites, and providing separate sets of signals to a control and processing station which are representative of the light energy received by each of said testing sites and which cooperatively define blood metabolite data for an individual one of at least two different internal regions located within different brain hemispheres of said test subject;

analyzing said separate signals to determine a blood metabolite level representative of at least one defined region within said at least one test subject for each of at least two different of said testing sites, each said defined region being different from the other; and

substantially simultaneously displaying data sets for each of said at least two different internal regions at substantially the same time for direct mutual comparison.

86. The method of claim 85, wherein said data sets include a first set which characterizes a first zone within one of said at least two different internal regions and a second set which characterizes a second zone that is at least partially within the same one of said at least two different internal regions.

87. The method of claim 85, wherein said spectrophotometric irradiation comprises application of at least two different wavelengths applied in an alternating sequence of timed pulses, and wherein detection of light energy corresponding to each of said at least two different wavelengths is done on a timed periodic basis using detection periods whose occurrence generally corresponds to that of said applied spectrophotometric irradiation.

88. The method of claim 87, wherein the duration of each of said detection periods is limited to a length which is less than that of each pulse of applied spectrophotometric irradiation.

89. The method of claim 88, wherein the duration of each of said detection periods is less than half that of a pulse of said applied spectrophotometric irradiation.

90. The method of claim 89, wherein a plurality of said detection periods are used during pulses of said applied spectrophotometric irradiation, and a corresponding energy detection occurs during each of a plurality of said detection periods.

91. The method of claim 90, further including the steps of averaging a selected number of energy detection event values to obtain a resultant value therefor, and using said resultant value to compute a metabolite value which is representative thereof.

92. The method of claim 91, wherein said display includes said computed representative metabolite value.

93. The method of claim 92, wherein said display is refreshed periodically by using a sequence of computed representative metabolite values which are based upon and represent the averaged detection event values produced during the different time intervals corresponding to the intervals of said periodic display refreshment.

94. The method of claim 85, wherein said determining of blood metabolite levels includes determining regional blood oxygen saturation.

95. The method of claim 85, wherein said light energy is detected after traveling each of at least two different distances through tissue of the test subject.

96. The method of claim 85, wherein said spectrophotometrically irradiating comprises emitting light at said testing sites where said emitting at one of said testing sights is out of phase with said emitting at another of said testing sites.

97. The method of claim 85, wherein said blood metabolite levels are determined so as to principally characterize blood metabolite within each of the different internal regions without effects attributable to adjacent tissue overlying said different internal regions.

98. The method of claim 97, wherein said effects attributable to said adjacent tissue are minimized by comparing spectrophotometric irradiation that penetrates different depths into said test subject.

99. Apparatus for spectrophotometric in vivo monitoring of a selected metabolic condition in each of a plurality of different test subject regions on a substantially simultaneous basis, comprising:

a plurality of spectrophotometric emitters, each configured to separately spectrophotometrically irradiate a designated region within a test subject from a test location on said test subject;

a controller and circuitry coupling each of said emitters to said controller configured for individually operating selected ones of said emitters in sequence on a substantially simultaneous basis to separately spectrophotometrically irradiate at least two particular regions within the test subject in a manner that reduces cross-talk between said spectrophotometric irradiation of said at least two particular regions;

a plurality of detectors, each configured to separately receive light energy resulting from the spectrophotometric irradiation of an associated one of said at least two particular regions, and to produce at least one separate set of signals for said associated one of said at least two particular regions; and circuitry acting to convey said at least one separate set of signals to said controller for analytic processing;

said controller configured to analytically process said at least one separate set of signals to determine separate sets of data representative of a blood metabolite level in said at least two particular regions; and

a visual display coupled to said controller and configured to display separate representations of said separate sets

of data for each of said at least two particular regions in a mutually-comparative manner and on a substantially simultaneous basis, wherein at least two of said at least two particular regions are located in mutually separate regions of a brain of said test subject.

100. The apparatus of claim 99, wherein said controller includes a computer programmed to analyze said signals to separately determine a blood oxygenation state within each of said at least two particular regions.

101. The apparatus of claim 100, wherein said computer comprises a processor, data buffers, and a timing signal generator, said data buffers adapted to store data representative of said blood oxygenation state and said timing signal generator adapted to control actuation of said emitters and detectors.

102. The apparatus of claim 101, wherein said controller comprises a unitary device which includes said computer and said display.

103. The apparatus of claim 102, wherein said unitary device further includes a keyboard interface to said computer.

104. The apparatus of claim 102, wherein said unitary device further includes a data output interface.

105. The apparatus of claim 104, wherein said unitary device further includes an integral keyboard interface to said computer.

106. The apparatus of claim 102, wherein said display comprises a flat electroluminescent visual display screen.

107. The apparatus of claim 106, wherein said unitary device further includes an integral keyboard interface to said computer.

108. The apparatus of claim 99, wherein at least certain of said detectors and certain of said emitters comprise operational pairs, and said controller is arranged to operate the emitters and detectors of at least certain of said operational pairs in predetermined timed relationship while maintaining the emitters and detectors of other of said operational pairs in a non-operating condition.

109. The apparatus of claim 108, wherein said controller is adapted to sequence the operation of said at least certain of said operational pairs.

110. The apparatus of claim 109, wherein at least one of said operational pairs include a plurality of said detectors arranged at mutually spaced locations which are spaced at differing distances from the emitter of said at least one of said operational pairs.

111. The apparatus of claim 110, wherein said controller is adapted to operate the emitter and a selected number less than all of the detectors of at least one of said operational pairs substantially in unison while holding the other detectors of said at least one of said operational pairs in a non-operating condition, and said controller is further arranged to operate said other detectors substantially in unison with said emitter at another time during which said selected number of said detectors are maintained in a non-operating condition.

112. The apparatus of claim 108, wherein at least one of said operational pairs includes a first detector and a second detector, and wherein the first detector is located nearer the emitter than the second detector to thereby provide near and far detector groupings for said at least one of said operational pairs.

113. The apparatus of claim 112, wherein said controller is adapted to sequence the operation of said at least one of said operational pairs.

114. The apparatus of claim 99, wherein said blood metabolite levels represent regional blood oxygen saturation.

115. The apparatus of claim 99, wherein said detectors are adapted to receive light energy that has traveled at least two different distances through tissue of the test subject.

116. The apparatus of claim 99, wherein said data is determined by said controller so as to principally characterize blood metabolite within each of the different internal regions without effects attributable to adjacent tissue overlying said different internal regions.

117. The apparatus of claim 116, wherein said effects attributable to said adjacent tissue are minimized by said controller comparing signals for spectrophotometric irradiation that penetrates different depths into said test subject.

118. A method for comparative spectrophotometric in vivo monitoring and display of selected blood metabolites present in a plurality of different internal regions of the same test subject on a continuing and substantially simultaneous basis, comprising the steps of:

applying separate spectrophotometric sensors to a test subject at each of a plurality of separate testing sites on the body at which blood metabolite measurements may be made and coupling each of said sensors to a control and processing station;

electronically controlling a selected number of said sensors in sequence on a substantially simultaneous basis to spectrophotometrically irradiate at least two separate internal regions of the test subject during a common time interval in a manner that reduces cross-talk between said sensors, each of said regions being associated with different ones of said testing sites;

separately detecting and receiving light energy resulting from said spectrophotometric irradiation for each of said at least two separate internal regions, and conveying separate sets of signals to said control and processing station which correspond to the separately detected light energy from said at least two separate internal regions;

separately and simultaneously analyzing said conveyed separate sets of signals to separately determine data representative of a blood metabolite level in each of said at least two separate internal regions; and

substantially simultaneously visually displaying said separately determined data for each of said at least two separate internal regions for direct simultaneous mutual comparison and observation of relative changes.

119. The method of claim 118, including the step of visually displaying a plurality of graphical traces at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison and the observation of relative changes.

120. The method of claim 118, including the step of visually displaying a plurality of quantified value determinations at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison and the observation of relative changes.

121. The method of claim 118, wherein said analyzing step includes producing separate quantitative value determinations for regional hemoglobin oxygen saturation for each of said at least two separate internal regions.

122. The method of claim 121, including the step of visually displaying a plurality of said quantitative value determinations at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison and the observation of relative changes.

123. The method of claim 118, wherein said data representative of a blood metabolite level includes regional blood oxygen saturation.

124. The method of claim 118, wherein said two separate regions are hemispheres within said brain of the test subject.

125. The method of claim 118, wherein said light energy is detected after traveling each of at least two different distances through tissue of the test subject.

126. The method of claim 118, wherein said electronically controlling in sequence comprises actuating said sensors in an alternating manner.

127. An apparatus for substantially simultaneous comparative spectrophotometric in vivo monitoring of selected blood metabolites present in each of a plurality of different internal regions on a continuing basis, comprising:

a plurality of spectrophotometric sensors, each attachable to a test subject at different test locations on the body at which blood metabolite measurements may be made and configured to separately but substantially simultaneously spectrophotometrically irradiate at least two different internal regions within the test subject associated with each of said test locations;

a controller and circuitry coupling each of said sensors to said controller configured for separately and individually but substantially simultaneously operating certain of said sensors in sequence to spectrophotometrically irradiate each of said different internal regions within the test subject associated with each of said test locations in a manner that reduces cross-talk between said sensors;

said sensors each further configured to receive light energy resulting from the separate spectrophotometric irradiation of said sensors' associated one of said at least two different internal regions on a substantially simultaneous basis with other said sensors, and to produce separate signals corresponding to the light energy received, said circuitry acting to convey said separate signals to said controller for separate analytic processing;

said controller configured to analytically process said conveyed signals separately and determine separate blood metabolite levels therefrom for each of said sensors and said sensors' associated one of said at least two different internal regions; and

a visual display coupled to said controller and configured to separately but substantially simultaneously display the blood metabolite levels determined for each of said sensors in a mutually-comparative manner through direct simultaneous mutual comparison and observation of relative changes.

128. The apparatus of claim 127, wherein said controller and said display are adapted to visually display at least two graphical traces representative of said levels on a substantially simultaneous basis and in predetermined relationship to one another to facilitate rapid and accurate visual comparison and the observation of relative changes.

129. The apparatus of claim 128, wherein said controller and said display are adapted to visually display at least two numeric value designations representative of said levels as well as said at least two graphical traces on a substantially simultaneous basis and in proximity to one another to facilitate rapid and accurate visual comparison and the observation of relative changes.

130. The apparatus of claim 127, wherein said controller is adapted to produce separate numeric value designations for regional hemoglobin oxygen saturation for said at least two different internal regions.

131. The apparatus of claim 130, wherein said controller and said display are adapted to visually display at least two of said numeric value designations on a substantially simultaneous basis and in predetermined relationship to one another to facilitate rapid and accurate visual comparison and the observation of relative changes.

132. The apparatus of claim 127, wherein said blood metabolite levels represent regional blood oxygen saturation.

133. The apparatus of claim 127, wherein said sensors are adapted to receive light energy that has traveled each of at least two different distances through tissue of the test subject.

134. The apparatus of claim 127, wherein said controller is adapted to operate said sensors to spectrophotometrically irradiate out of phase with one another.

135. A method for substantially simultaneous comparative in vivo monitoring of blood metabolites in each of a plurality of different internal regions in a selected test subject, comprising the steps of:

spectrophotometrically irradiating each of a plurality of different testing sites on said test subject via electronic control, in sequence on a substantially simultaneous basis, in a manner that reduces cross-talk between said spectrophotometric irradiation of said testing sites, said sites being locations on the body at which blood metabolite measurements are made;

detecting light energy resulting from said spectrophotometric irradiation of said testing sites, and providing separate sets of signals to a control and processing station which are representative of the light energy received by each of said testing sites and which cooperatively define blood metabolite data for an individual one of at least two different internal regions;

analyzing said separate signals to determine a blood metabolite level representative of at least one defined region within said at least one test subject for each of at least two different of said testing sites, each said defined region being different from the other; and

substantially simultaneously displaying data sets for each of said at least two different internal regions at substantially the same time for direct mutual comparison and observation of relative changes.

136. The method of claim 135, wherein said determining of quantified blood metabolite levels includes determining regional blood oxygen saturation.

137. The method of claim 135, wherein said light energy is detected after traveling each of at least two different distances through tissue of the test subject.

138. The method of claim 135, wherein said spectrophotometrically irradiating comprises emitting light at said testing sites where said emitting at one of said testing sights is out of phase with said emitting at another of said testing sites.

139. Apparatus for spectrophotometric in vivo monitoring of a selected metabolic condition in each of a plurality of different test subject regions on a substantially simultaneous basis, comprising:

a plurality of spectrophotometric emitters, each configured to separately spectrophotometrically irradiate a designated region within a test subject from a test location on said test subject, said test location being a site on the body at which a blood metabolite measurement may be made;

a controller and circuitry coupling each of said emitters to said controller configured for individually operating, in sequence on a substantially simultaneous basis, selected ones of said emitters to separately spectrophotometrically irradiate at least two particular regions within the test subject in a manner that reduces cross-talk between said spectrophotometric irradiation of said at least two particular regions;

a plurality of detectors, each configured to separately receive light energy resulting from the spectrophotometric irradiation of an associated one of said at least two particular regions, and to produce at least one separate set of signals for said associated one of said at least two particular regions; and circuitry acting to convey said at least one separate set of signals to said controller for analytic processing;

said controller configured to analytically process said at least one separate set of signals to determine separate sets of data representative of a blood metabolite level in said at least two particular regions; and

a visual display coupled to said controller and configured to display separate representations of said separate sets of data for each of said at least two particular regions in a mutually-comparative manner and on substantially simultaneous basis through direct simultaneous mutual comparison and observation of relative changes.

140. The apparatus of claim 139, wherein said blood metabolite levels represent regional blood oxygen saturation.

141. The apparatus of claim 139, wherein said detectors are adapted to receive light energy that has traveled at least two different distances through tissue of the test subject.

142. A method for comparative spectrophotometric in vivo monitoring and display of selected blood metabolites present in a plurality of different internal regions of the same test subject on a continuing and substantially simultaneous basis, comprising the steps of:

applying separate spectrophotometric sensors to a test subject at each of a plurality of separate testing sites and coupling each of said sensors to a control and processing station;

electronically controlling a selected number of said sensors in sequence on a substantially simultaneous basis to spectrophotometrically irradiate at least two separate internal regions of the test subject during a common time interval in a manner that reduces cross-talk between said sensors, each of said regions being associated with different ones of said testing sites;

separately detecting and receiving light energy resulting from said spectrophotometric irradiation for each of said at least two separate internal regions, and conveying separate sets of signals to said control and processing station which correspond to the separately detected light energy from said at least two separate internal regions;

separately and simultaneously analyzing said conveyed separate sets of signals to separately determine data representative of a blood metabolite level in each of said at least two separate internal regions; and

substantially simultaneously visually displaying information reflecting said separately determined data for each of said at least two separate internal regions for direct simultaneous mutual comparison.

143. The method of claim 142, wherein said data representative of a blood metabolite level includes regional blood oxygen saturation.

144. The method of claim 142, wherein said two separate regions are hemispheres within said brain of the test subject.

145. The method of claim 142, further comprising visually displaying a plurality of graphical traces representing a plurality of quantitative value determinations made at successive points in time, said displaying of said plurality of graphical traces occurring at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

146. The method of claim 142, further comprising visually displaying a plurality of quantitative value determinations at substantially the same time and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

147. The method of claim 142, wherein said sensors are positioned in locations proximate to different brain hemispheres and said two mutually separate regions are located in a different brain hemisphere.

148. The method of claim 142, wherein said light energy is detected after traveling each of at least two different distances through tissue of the test subject.

149. The method of claim 142, wherein said electronically controlling in sequence comprises actuating said sensors in an alternating manner.

150. The method of claim 142, wherein said step of applying separate spectrophotometric sensors to the test subject further comprises individually applying said separate spectrophotometric sensors.

151. An apparatus for substantially simultaneous comparative spectrophotometric in vivo monitoring of selected blood metabolites present in each of a plurality of different internal regions on a continuing basis, comprising:

a plurality of spectrophotometric sensors, each attachable to a test subject at different test locations in the body and configured to separately but substantially simultaneously spectrophotometrically irradiate at least two different internal regions within the test subject associated with each of said test locations;

a controller and circuitry coupling each of said sensors to said controller configured for separately and individually but substantially simultaneously operating certain of said sensors in sequence to spectrophotometrically irradiate each of said different internal regions within the test subject associated with each of said test locations in a manner that reduces cross-talk between said sensors;

said sensors each further configured to receive light energy resulting from the separate spectrophotometric irradiation of said sensors' associated one of said at least two different internal regions on a substantially simultaneous basis with other said sensors, and to produce separate signals corresponding to the light energy received, said circuitry acting to convey said separate signals to said controller for separate analytic processing;

said controller configured to analytically process said conveyed signals separately and determine separate blood metabolite levels therefrom for each of said sensors and said sensors' associated one of said at least two different internal regions; and

a visual display coupled to said controller and configured to separately but substantially simultaneously display information reflecting the blood metabolite levels determined for each of said sensors in a mutually-comparative manner.

152. The apparatus of claim 151, wherein said blood metabolite levels represent regional blood oxygen saturation.

153. The apparatus of claim 151, wherein said controller is adapted to produce separate numeric value designations for hemoglobin oxygen saturation for said at least two different internal regions.

154. The apparatus of claim 151, wherein said controller and said display are adapted to produce ongoing graphical traces representing a plurality of said numeric value designations for the same region taken over a period of time, and wherein said controller and said display are adapted to visu-

ally display at least two of said graphical traces on a substantially simultaneous basis and in predetermined relationship to one another to facilitate rapid and accurate visual comparison.

155. The apparatus of claim 151, wherein at least two of said sensors are adapted to be positioned in locations associated with mutually different hemispheres of the brain and each of said sensors is operable to separately monitor at least portions of each of said different hemispheres.

156. The apparatus of claim 151, wherein said sensors are adapted to receive light energy that has traveled each of at least two different distances through tissue of the test subject.

157. The apparatus of claim 151, wherein said controller is adapted to operate said sensors to spectrophotometrically irradiate out of phase with one another.

158. The apparatus of claim 151, wherein said spectrophotometric sensors attachable to the test subject at different test locations in the body are each configured to be attached individually to said test subject.

159. A method for substantially simultaneous comparative in vivo monitoring of blood metabolites in each of a plurality of different internal regions in a selected test subject, comprising the steps of:

spectrophotometrically irradiating each of a plurality of different testing sites on said test subject via electronic control, in sequence on a substantially simultaneous basis, in a manner that reduces cross-talk between said spectrophotometric irradiation of said testing sites;

detecting light energy resulting from said spectrophotometric irradiation of said testing sites, and providing separate sets of signals to a control and processing station which are representative of the light energy received by each of said testing sites and which cooperatively define blood metabolite data for an individual one of at least two different internal regions;

analyzing said separate signals to determine a blood metabolite level representative of at least one defined region within said at least one test subject for each of at least two different of said testing sites, each said defined region being different from the other; and

substantially simultaneously displaying information determined from data sets for each of said at least two different internal regions at substantially the same time for direct mutual comparison.

160. The method of claim 159, wherein said determining of blood metabolite levels includes determining regional blood oxygen saturation.

161. The method of claim 159, wherein said testing sites are selected as being proximate to different brain hemispheres and said defined regions are two mutually separate regions located in different brain hemispheres of the test subject.

162. The method of claim 159, further comprising averaging a selected number of energy detection event values to obtain a resultant value therefor, and using said resultant value to compute a metabolite value which is representative thereof, and wherein said display includes said computed representative metabolite value.

163. The method of claim 162, wherein said display is refreshed periodically by using a sequence of computed representative metabolite values which are based upon and represent the averaged detection event values produced during the different time intervals corresponding to the intervals of said periodic display refreshment.

164. The method of claim 159, wherein said light energy is detected after traveling each of at least two different distances through tissue of the test subject.

165. The method of claim 159, wherein said irradiating and said detecting is performed by a plurality of spectrophotometric sensors, and wherein said spectrophotometric sensors are each applied individually to said test subject.

166. Apparatus for spectrophotometric in vivo monitoring of a selected metabolic condition in each of a plurality of different test subject regions on a substantially simultaneous basis, comprising:

a plurality of spectrophotometric emitters, each configured to separately spectrophotometrically irradiate a designated region within a test subject from a test location on said test subject;

a controller and circuitry coupling each of said emitters to said controller configured for individually operating selected ones of said emitters in sequence on a substantially simultaneous basis to separately spectrophotometrically irradiate at least two particular regions within the test subject in a manner that reduces cross-talk between said spectrophotometric irradiation of said at least two particular regions;

a plurality of detectors, each configured to separately receive light energy resulting from the spectrophotometric irradiation of an associated one of said at least two particular regions, and to produce at least one separate set of signals for said associated one of said at least two particular regions; and circuitry acting to convey said at least one separate set of signals to said controller for analytic processing;

said controller configured to analytically process said at least one separate set of signals to determine separate sets of data representative of a blood metabolite level in said at least two particular regions; and

a visual display coupled to said controller and configured to display separate representations of said separate sets of data for each of said at least two particular regions in a mutually-comparative manner and on a substantially simultaneous basis.

167. The apparatus of claim 166, wherein said blood metabolite levels represent regional blood oxygen saturation.

168. The apparatus of claim 166, wherein at least certain of said detectors and certain of said emitters comprise operational pairs, and said controller is arranged to operate the emitters and detectors of at least certain of said operational pairs in predetermined timed relationship while maintaining the emitters and detectors of other of said operational pairs in a non-operating condition.

169. The apparatus of claim 166, wherein said controller is adapted to sequence the operation of said at least certain of said operational pairs.

170. The apparatus of claim 169, wherein said controller is adapted to operate the emitter and a selected number less than all of the detectors of at least one of said operational pairs substantially in unison while holding the other detectors of said at least one of said operational pairs in a non-operating condition, and said controller is further arranged to operate said other detectors substantially in unison with said emitter at another time during which said selected number of said detectors are maintained in a non-operating condition.

171. The apparatus of claim 166, wherein at least two of said emitters are adapted to be positioned in locations associated with mutually different hemispheres of the brain such that said apparatus is operable to separately monitor at least portions of each of said different hemispheres.

172. The apparatus of claim 166, wherein said detectors are adapted to receive light energy that has traveled at least two different distances through tissue of the test subject.

173. The apparatus of claim 166, wherein said separate representations comprise actual or relative values corresponding to said quantified data.

174. The apparatus of claim 166, wherein a plurality of spectrophotometric sensors are formed by said emitters and said detectors, and wherein said spectrophotometric sensors are each configured to be attached individually to said test subject.

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