



US 20130253362A1

(19) **United States**(12) **Patent Application Publication**
Scheib(10) **Pub. No.: US 2013/0253362 A1**(43) **Pub. Date: Sep. 26, 2013**(54) **METHOD AND SYSTEM FOR MONITORING
AND DISPLAYING PHYSIOLOGICAL
CONDITIONS**(76) Inventor: **Christopher Scheib**, Nicholasville, KY
(US)(21) Appl. No.: **13/487,986**(22) Filed: **Jun. 4, 2012****Related U.S. Application Data**(63) Continuation-in-part of application No. 12/925,295,
filed on Oct. 18, 2010, which is a continuation-in-part
of application No. 12/589,047, filed on Oct. 16, 2009,
now Pat. No. 8,352,021, which is a continuation-in-
part of application No. 12/082,842, filed on Apr. 15,
2008, now Pat. No. 7,720,531.(60) Provisional application No. 61/492,847, filed on Jun.
3, 2011.**Publication Classification**(51) **Int. Cl.**
A61B 5/00 (2006.01)
(52) **U.S. Cl.**
CPC **A61B 5/4821** (2013.01)
USPC **600/544**(57) **ABSTRACT**

A system and method is used for determining from EEG signals the lack of awareness and the depth of anesthesia of a patient to whom an anesthetic agent is being administered. In particular, a log-log representation of the EEG power spectrum of a current patient is compared to another log-log spectrum of a patient in a known condition. By comparison the awareness or depth of anesthesia of the current patient can be determined. The reference spectrum can be an average spectrum of many patients or a previously acquired spectrum of the current patient, or any other spectrum that can be statistically correlated with the current patient's spectrum.

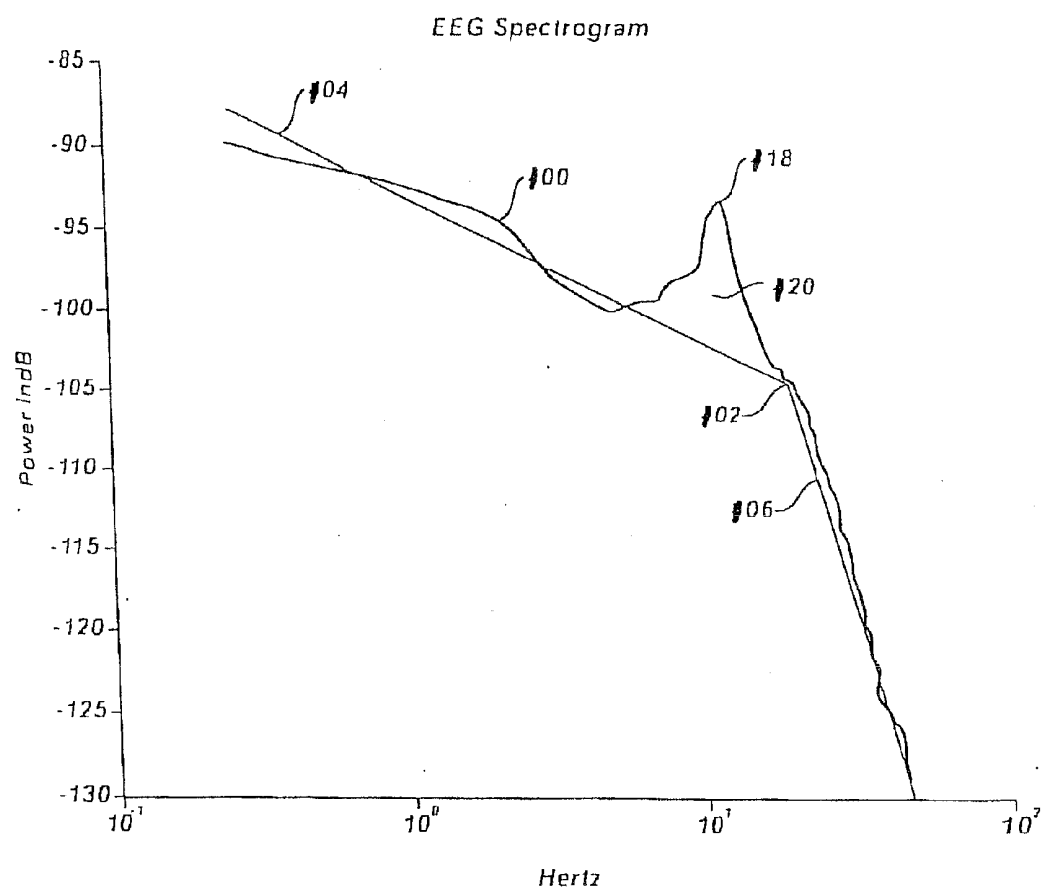


FIG 1

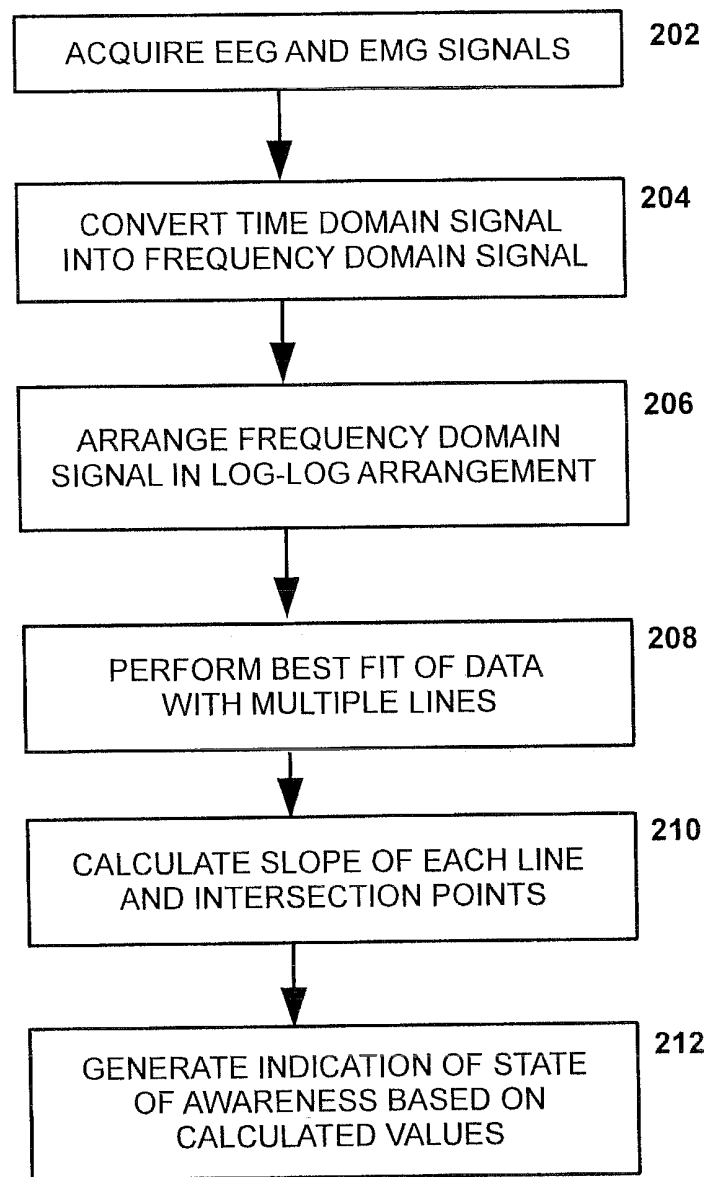
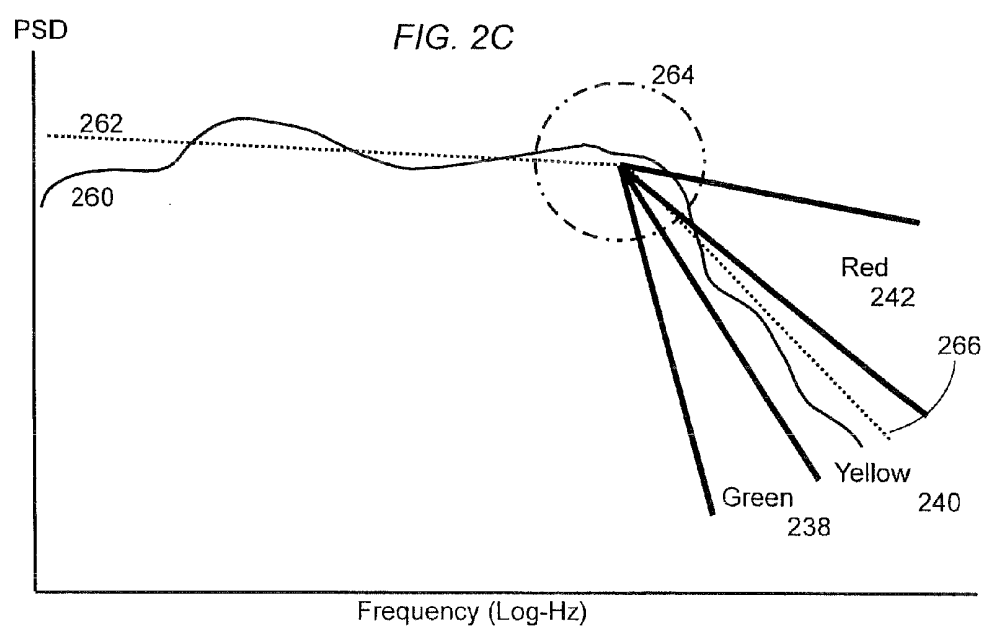
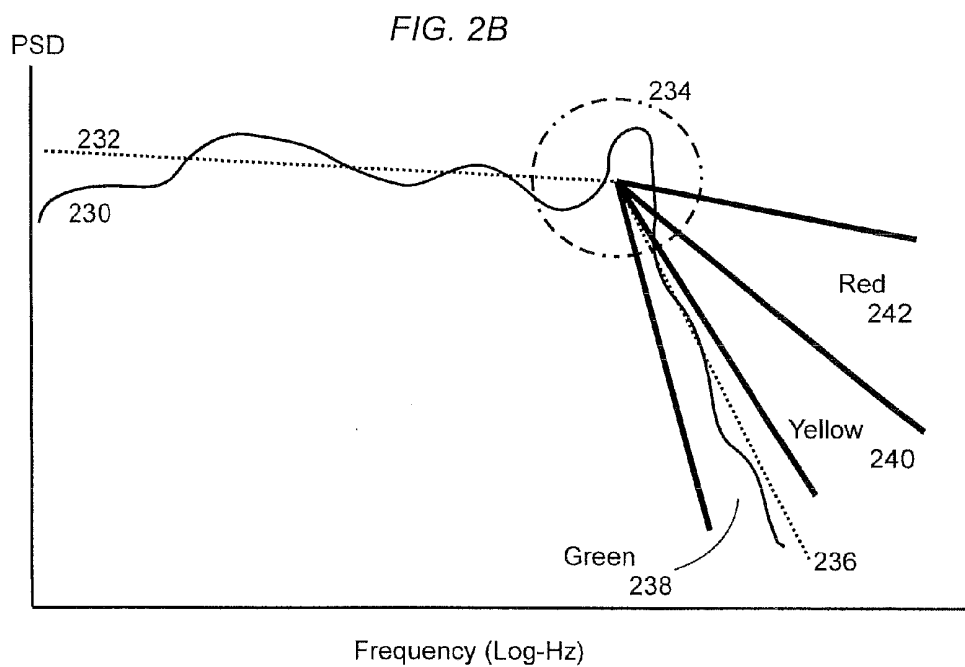


FIG. 2A



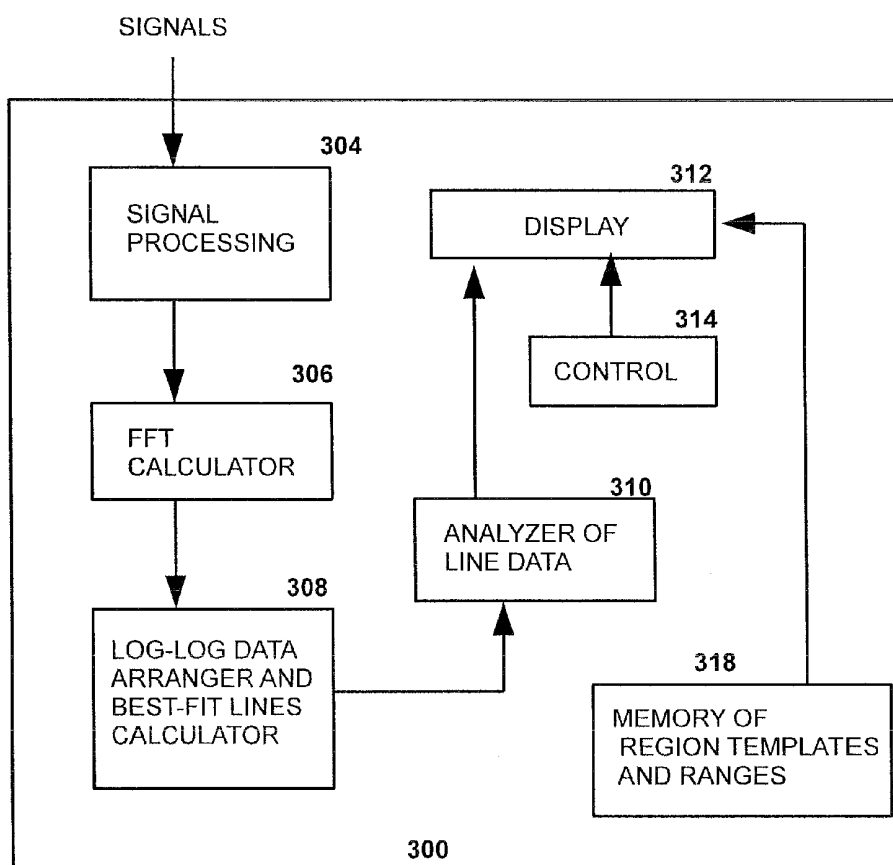


FIG. 3

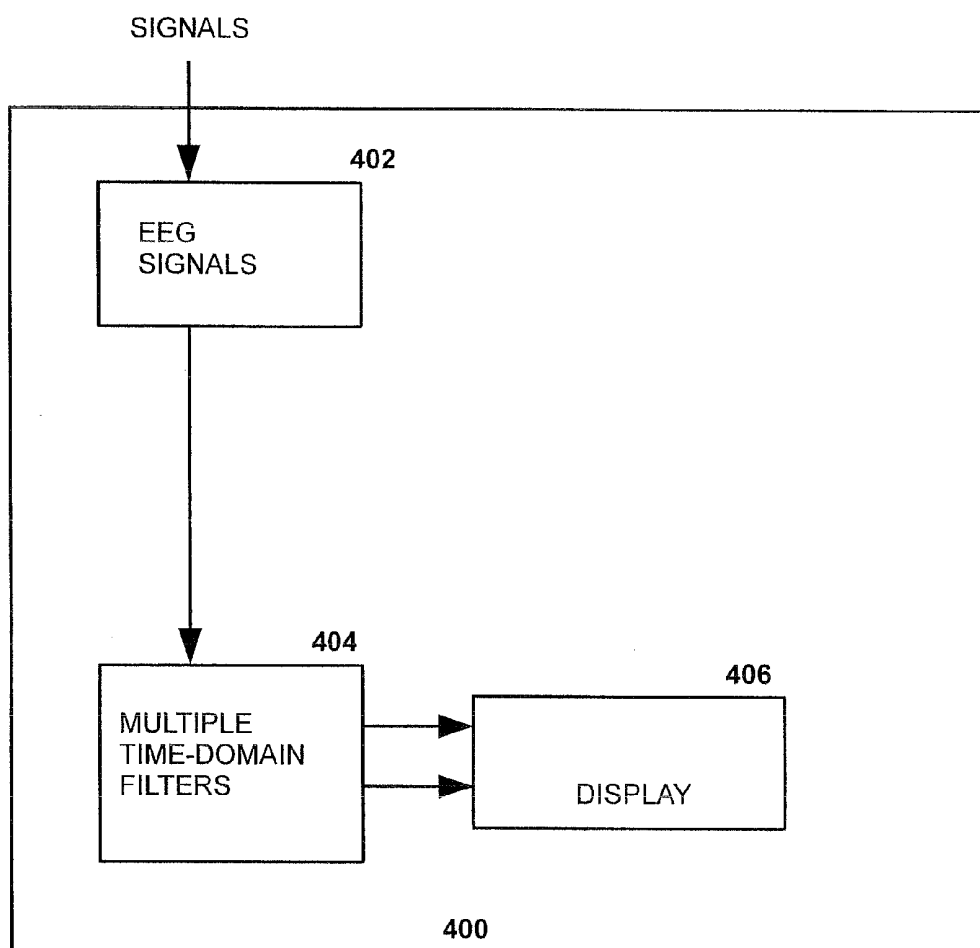


FIG. 4

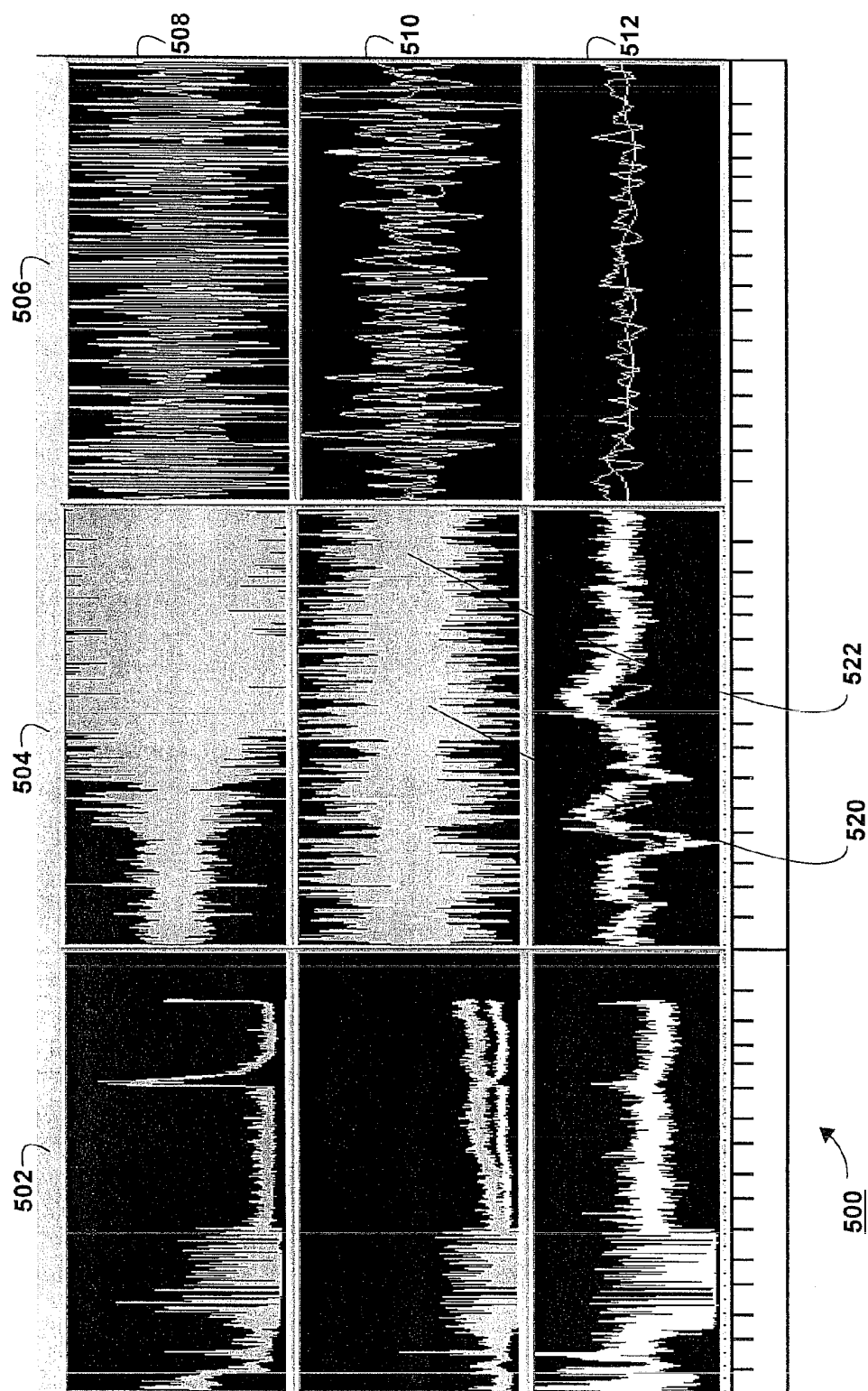


FIG. 5

The average value spectrums for 11 tubals and 13 diagnostic laparoscopies.

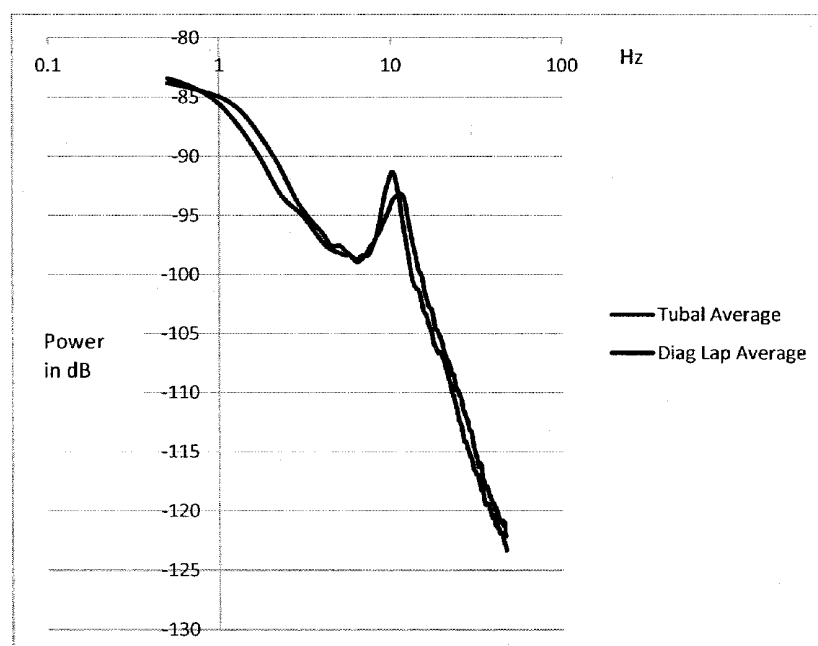


FIG. 6

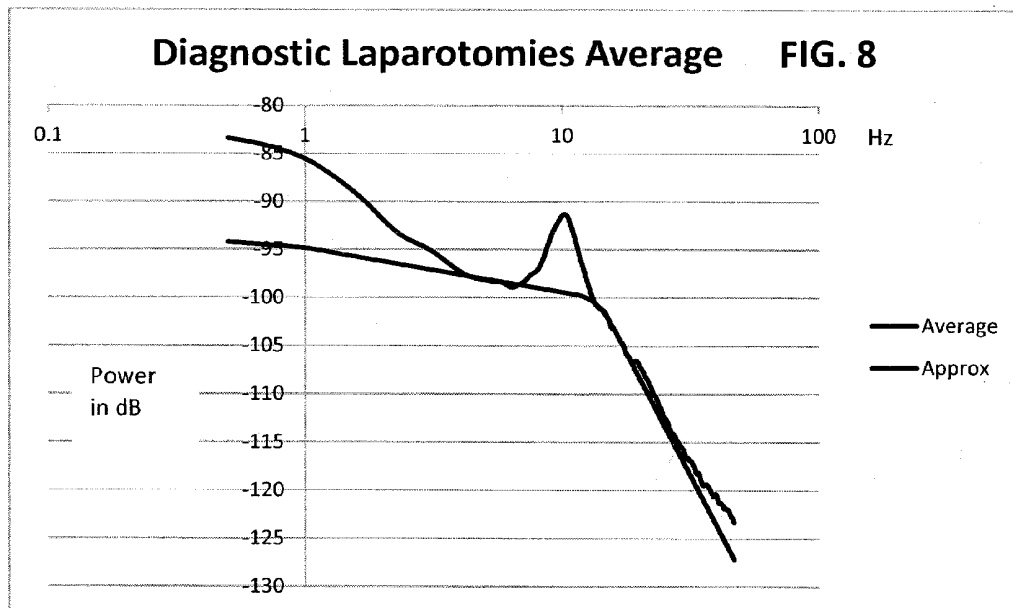
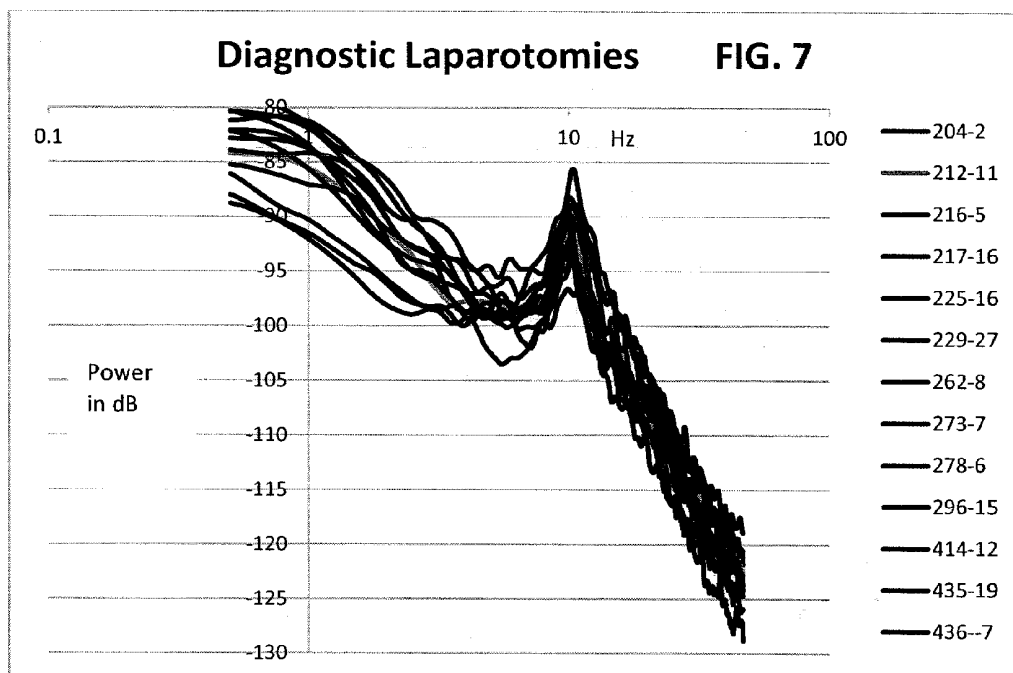


FIG. 9

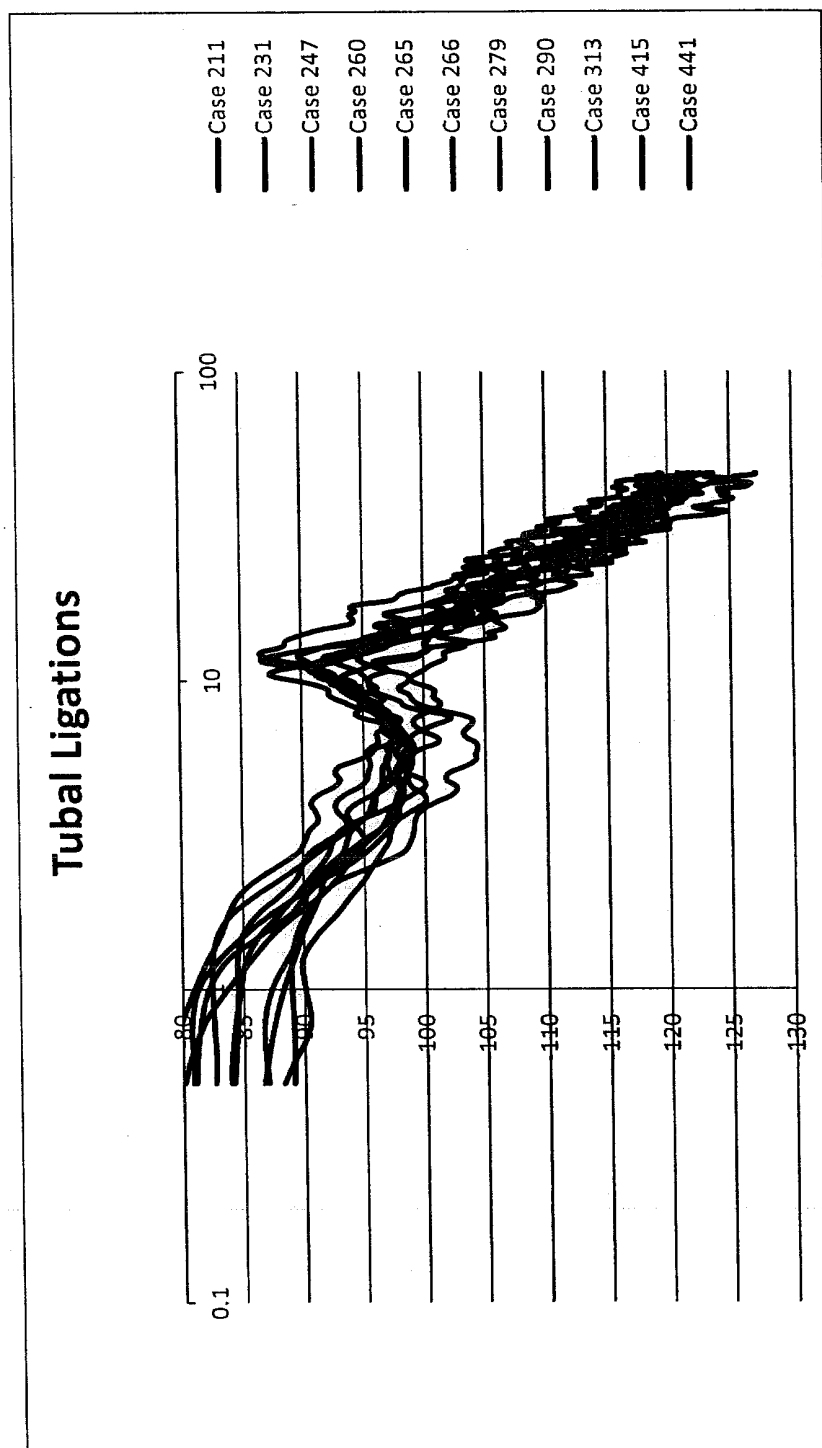


FIG. 10

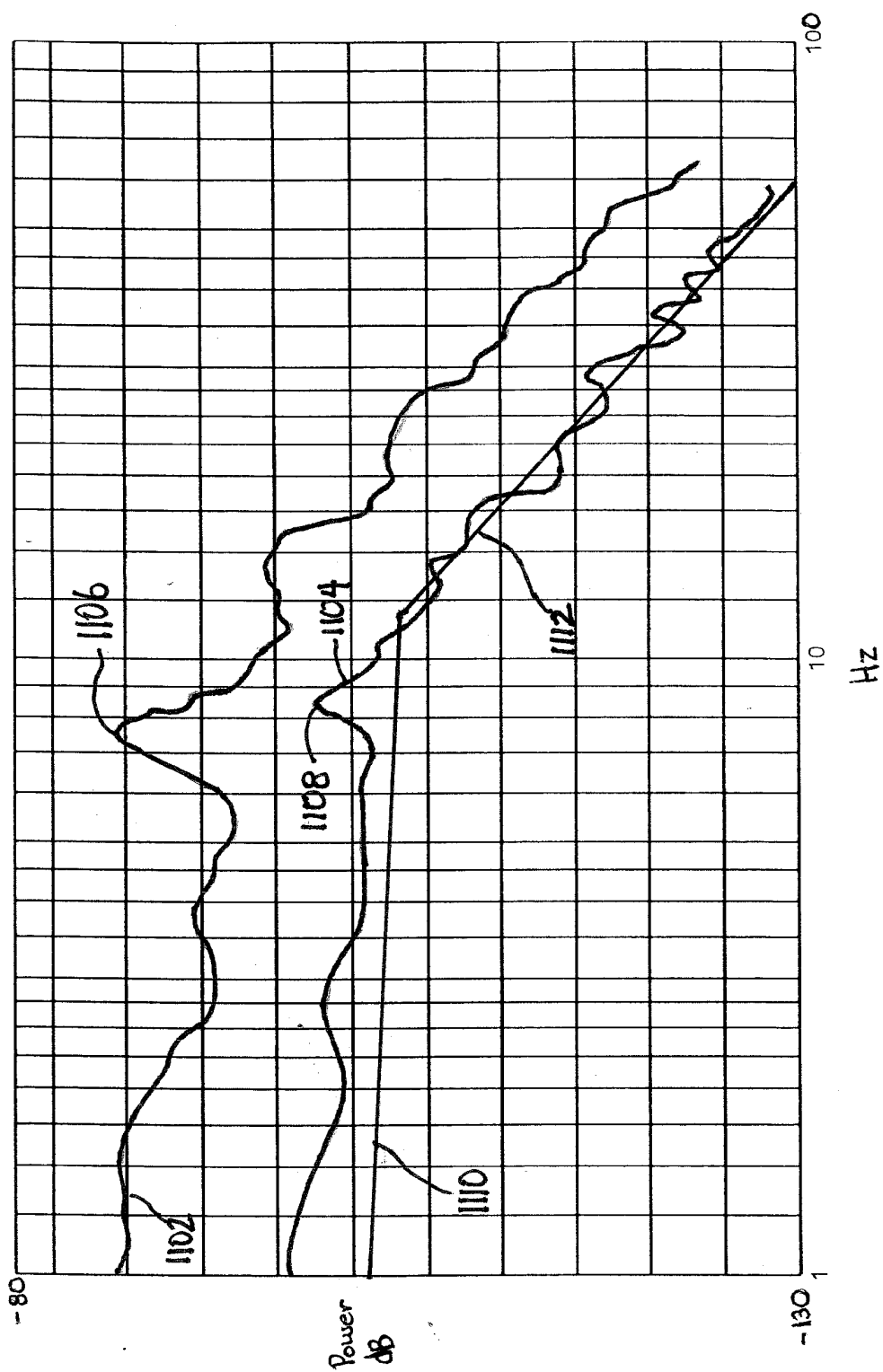


FIG. 11

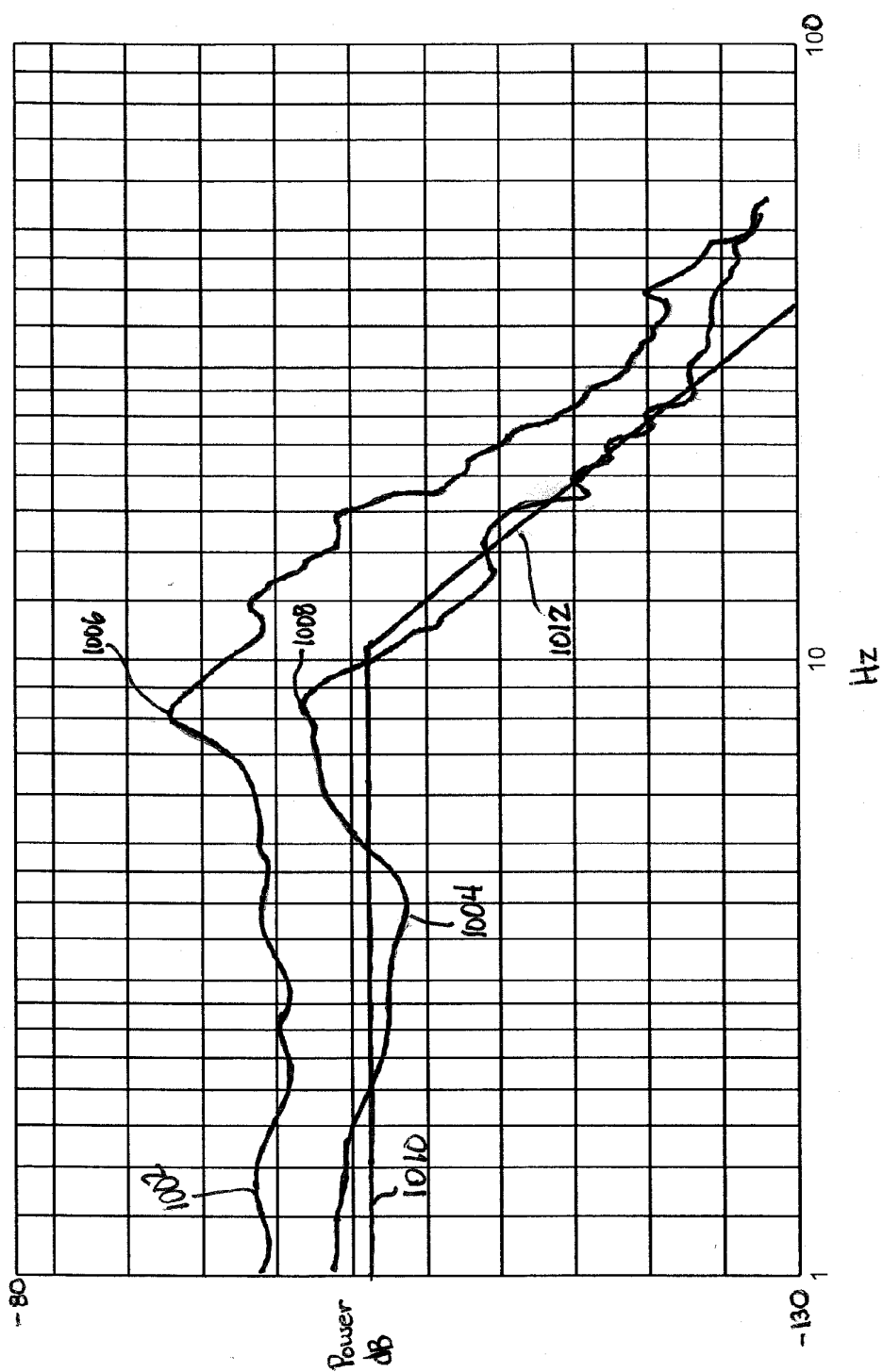
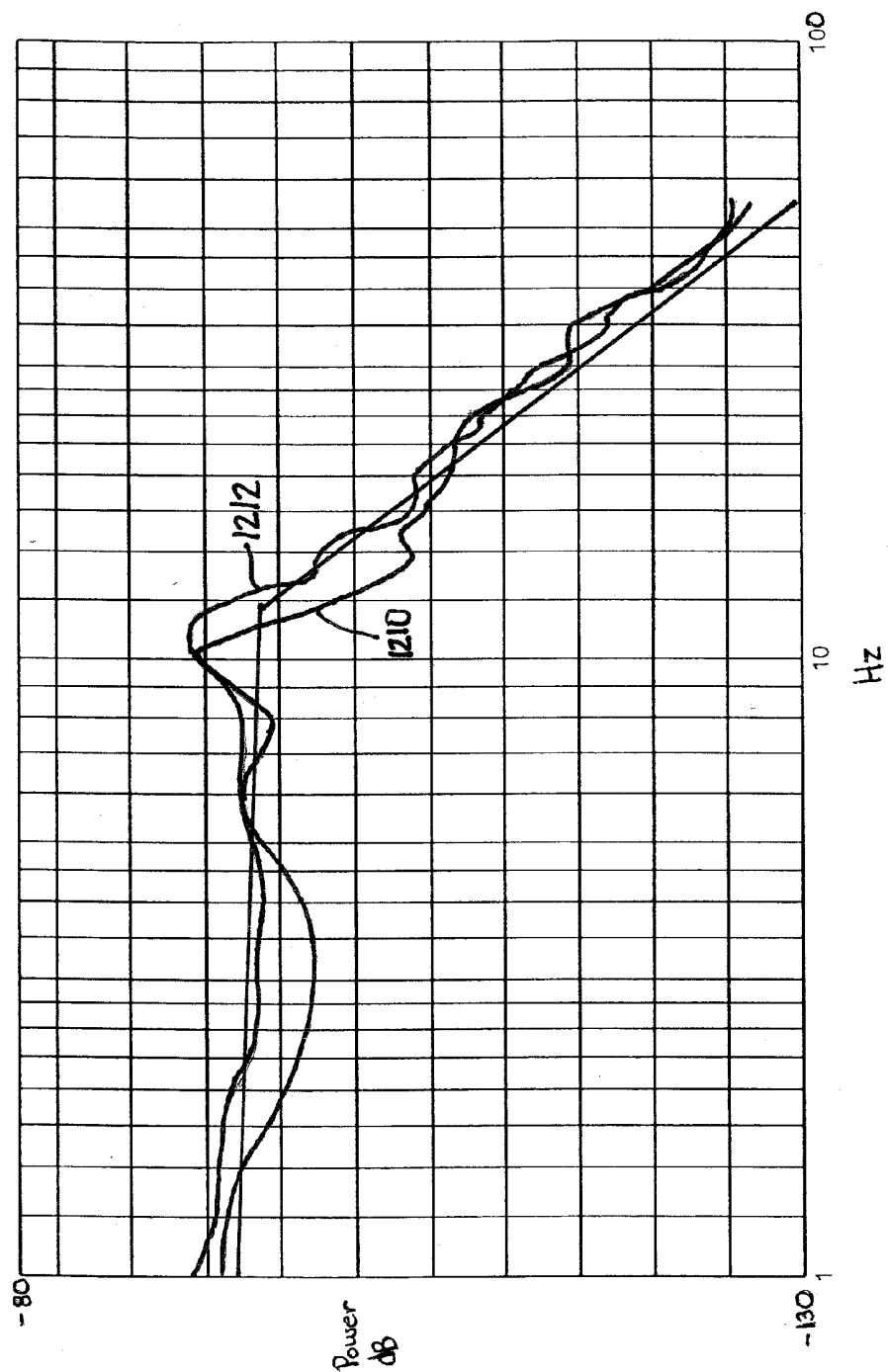
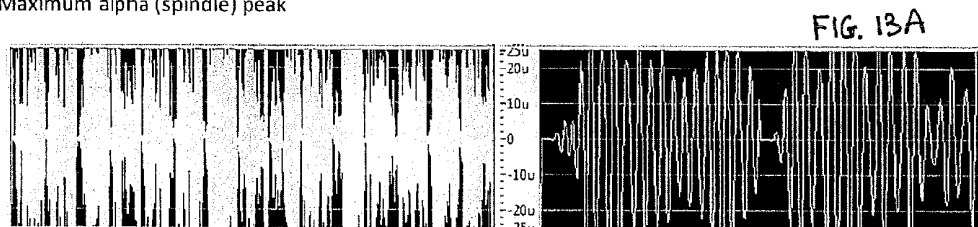


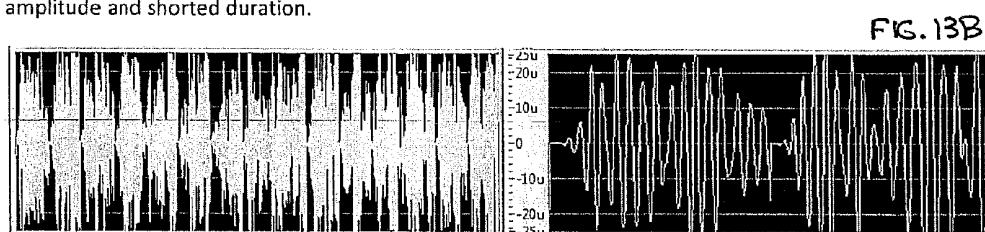
FIG. 12



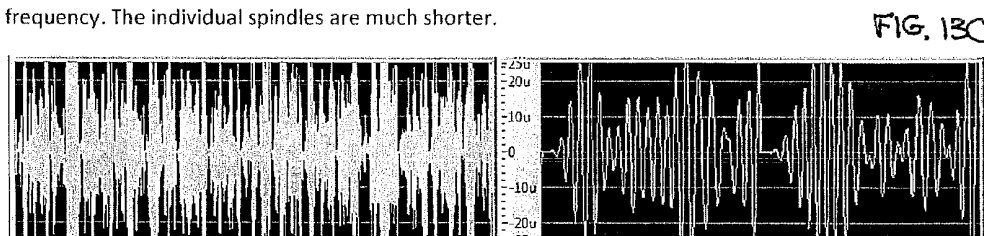
Maximum alpha (spindle) peak



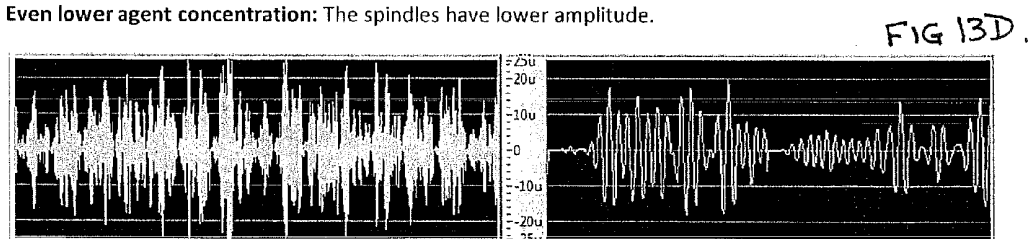
Higher agent concentration: The individual oscillations in the 4 second right window are at a slightly lower frequency with fewer cycles in a spindle. The 30 second window shows that the spindles have less amplitude and shorter duration.



Lower agent concentration: The individual oscillations in the 4 second window are at a higher frequency. The individual spindles are much shorter.

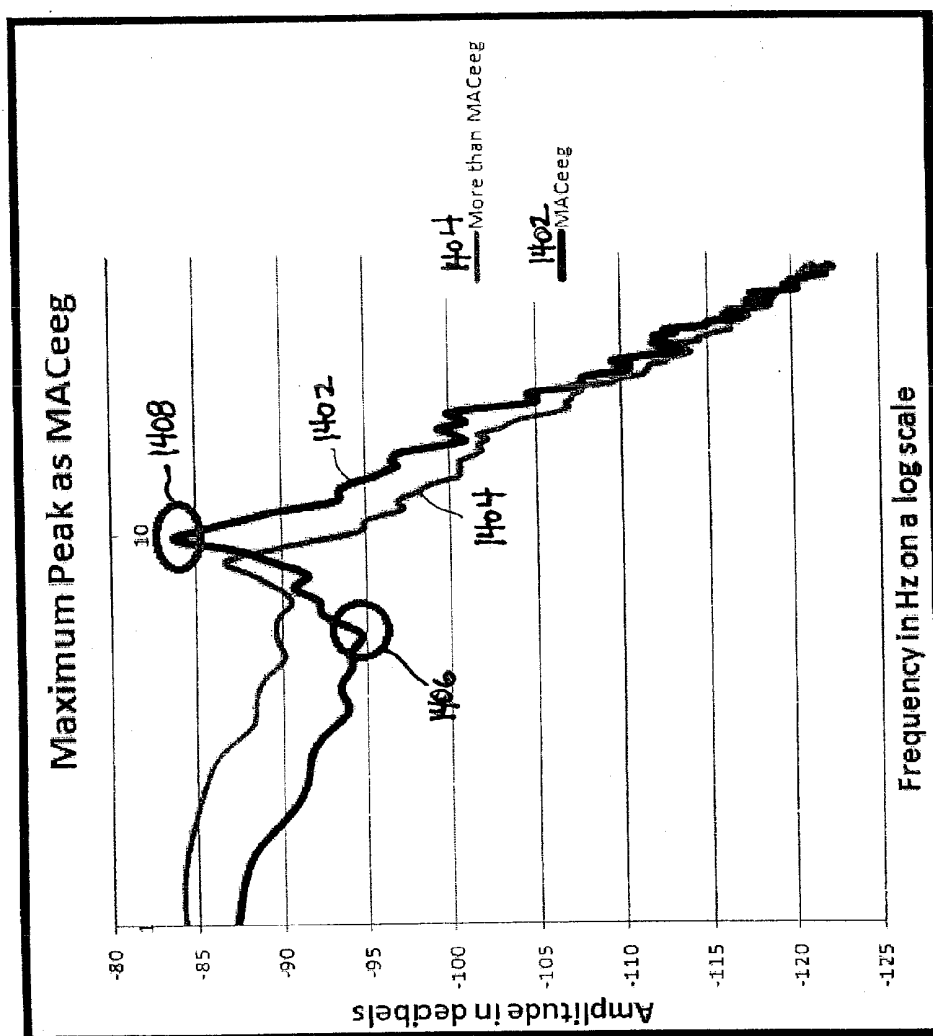


Even lower agent concentration: The spindles have lower amplitude.



A longer gap between spindles can occur but is not shown here.

FIG. 14A



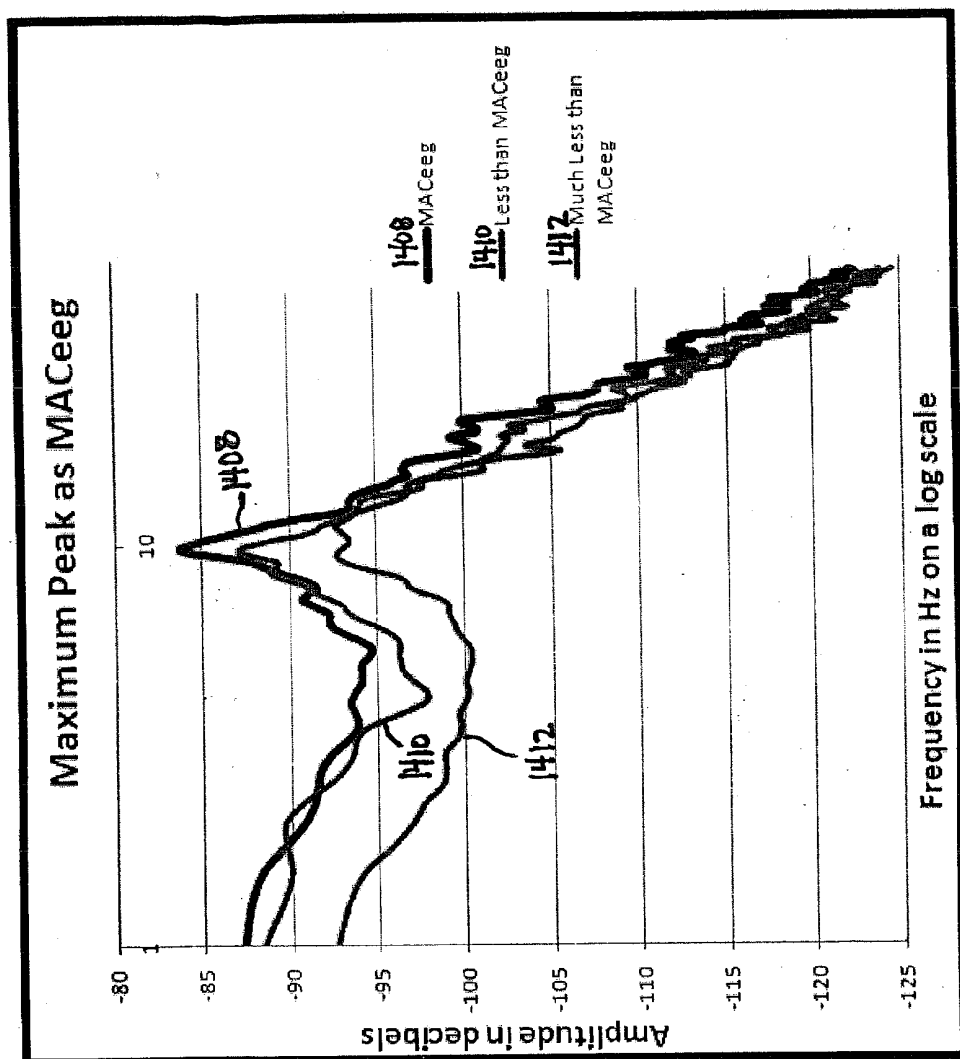


FIG. 14B

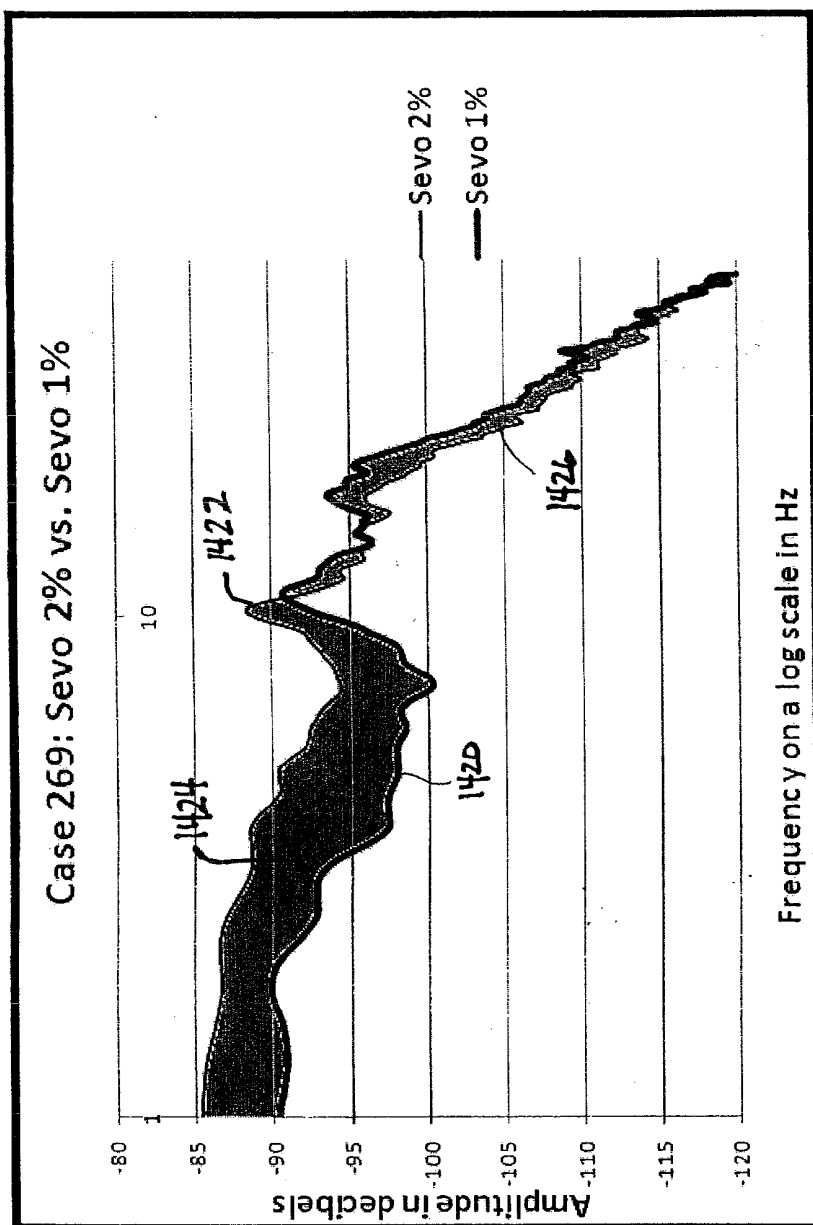


FIG. 14C

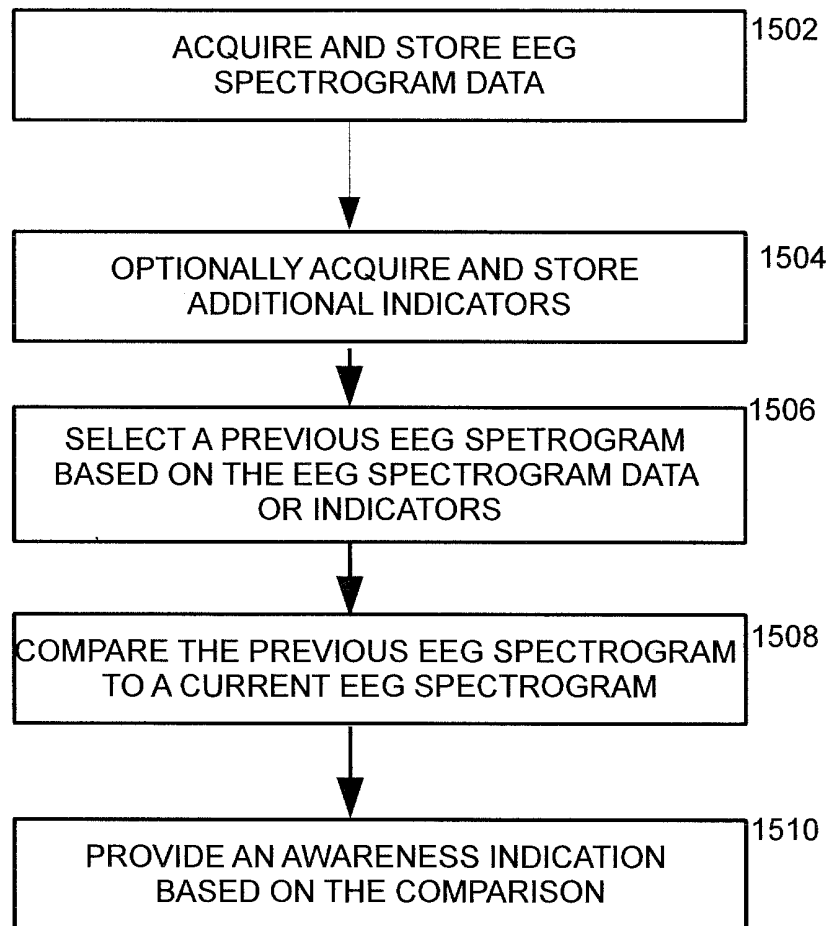


FIG. 15

METHOD AND SYSTEM FOR MONITORING AND DISPLAYING PHYSIOLOGICAL CONDITIONS

RELATED APPLICATIONS

[0001] The present invention is a continuation-in-part of the previously filed U.S. patent application Ser. Nos. 12/925,295 and 12/925,296 filed Oct. 18, 2010, which themselves are continuation-in-part applications of the previously filed U.S. patent application Ser. No. 12/589,047 filed Oct. 16, 2009 which is a continuation-in-part of the previously filed U.S. patent application Ser. No. 12/082,842 filed Apr. 15, 2008 (now U.S. Pat. No. 7,720,531), the disclosures of which are incorporated herein in their entirety. The present application claims priority to U.S. Provisional Patent Ser. No. 61/492,847 filed Jun. 3, 2011, the contents of which are incorporated herein by reference in their entirety.

BACKGROUND

FIELD

[0002] The present invention relates generally to monitoring brain function during different states of consciousness such as general anesthesia, coma or natural sleep and, more particularly, to using electroencephalogram (EEG) data and other physiological data to evaluate brain function.

[0003] The definition of the term “anesthesia” is—a lack of aesthesia—or lack of sensation. For surgical purposes this is generally achieved in two main ways: 1) infiltration of a peripheral or more central nerve bundle with a local anesthesia, which prevents the nerve impulse being processed by the central nervous system and, thus, sensation (of pain or otherwise is not perceived by the individual who remains conscious and aware; and 2) general anesthesia which requires a loss of consciousness in order for the sensation not to be perceived by the individual. To date no systems of monitoring brain function has produced a reference point beyond which one can absolutely state that there exists a complete lack of consciousness at an anesthetic dosage level low enough to be of practical value. Present systems merely produce a measure of probability of loss of consciousness when the anesthetic dosage level is at the low end of the practical range.

[0004] The “depth of anesthesia” generally describes the extent to which consciousness is lost following administration of an anesthetic agent. As the magnitude of anesthetization, or depth of anesthesia, increases, an anesthetized patient typically fails to successively respond to spoken commands, loses the eyelid reflex, loses other reflexes, undergoes depression of vital signs, and the like. Once consciousness is lost there is a progression of effects on brain function as higher concentrations or dose of anesthetic agent are administered.

[0005] For clinical use, it is desirable to simplify the results of EEG signal analysis of the foregoing, and other types, into a workable parameter that can be used by an anesthesiologist in a clinical setting when attending the patient. Prior techniques have included showing the EEG signal in a relatively unprocessed form or showing a number (or letter) without any other underlying data supporting that number. Neither solution is helpful in a clinical setting; especially, in the case of the “number” indicator, when the number is at best a probability that the patient is not aware or conscious. Ideally, what is desired is a simple indicator that accurately indicates the patient’s lack of awareness and how far below the transition to

awareness the patient is. The indicator should also account for phenomena that vary by patient such as, for example, the less pronounced a peak of older patients and the possible occurrence of a burst suppression event. Thus, there remains a need for such an indicator that reliably and quickly indicates awareness during general anesthesia and the depth of anesthesia.

SUMMARY

[0006] Embodiments of the present invention relate to a system and method for determining from EEG signals the lack of awareness and the depth of anesthesia of a patient to whom an anesthetic agent is being administered. In particular, a log-log representation of the EEG power spectrum of a current patient is compared to another log-log spectrum of a patient in a known condition. By comparing the awareness or depth of anesthesia of the current patient can be determined. The reference spectrum can be an average spectrum of many patients or a previously acquired spectrum of the current patient, or any other spectrum that can be statistically correlated with the current patient’s spectrum.

[0007] Other embodiments of the present invention relate to another system and method for determining from EEG signals the lack of awareness and the depth of anesthesia of a patient to whom an anesthetic agent is being administered. In particular, the spindle patterns of the EEG signal is used as an indicator of the state of the patient.

[0008] These systems and methods may also be used in an analysis of the brain function of a sleeping individual to distinguish between awareness, REM sleep, and the various levels of non-REM sleep. It may also be used to investigate the effect of various experimental pharmaceuticals on brain function.

[0009] It is understood that other embodiments of the present invention will become readily apparent to those skilled in the art from the following detailed description, wherein it is shown and described only various embodiments of the invention by way of illustration. As will be realized, the invention is capable of other and different embodiments and its several details are capable of modification in various other respects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Various aspects of a system and method for anesthesia monitoring are illustrated by way of example, and not by way of limitation, in the accompanying drawings, wherein:

[0011] FIG. 1 shows an exemplary log-log EEG power spectrogram in accordance with the principles of the present invention.

[0012] FIG. 2A shows a flowchart of an exemplary algorithm for analyzing EEG spectrograms in accordance with the principles of the present invention;

[0013] FIGS. 2B and 2C illustrate a display of the log-log EEG signal in accordance with the principles of the present invention.

[0014] FIG. 3 shows an apparatus on which the flowchart of FIG. 2A may be performed in accordance with the principles of the present invention;

[0015] FIG. 4 shows an apparatus which may operate in accordance with the principles of the present invention; and

[0016] FIG. 5 illustrates an exemplary display in accordance with the principles of the present invention.

[0017] FIGS. 6-9 illustrate spectrum of different sets of patients under anesthesia.

[0018] FIGS. 10-12 illustrate a display of two power spectra for comparison in accordance with the principles of the present invention.

[0019] FIGS. 13A-13D illustrate display of different spindle patterns in accordance with the principles of the present invention

[0020] FIGS. 14A -14C illustrate display of two power spectra for comparison in accordance with the principles of the present invention

[0021] FIG. 15 illustrates a flowchart of an exemplary method for comparing two power spectra in accordance with the principles of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] The detailed description set forth below in connection with the appended drawings is intended as a description of various embodiments of the invention and is not intended to represent the only embodiments in which the invention may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of the invention. However, it will be apparent to those skilled in the art that the invention may be practiced without these specific details. In some instances, well known structures and components are shown in block diagram form in order to avoid obscuring the concepts of the invention.

[0023] In the above-incorporated patent applications the frequency range of contemplated signals extended to about 40 Hz. FIG. 1 shows an exemplary log-log EEG power spectrogram in accordance with the principles of the referenced, incorporated patent application. The spectrogram 100 is that of a patient that is deeply under anesthesia. In other words, the patient has crossed the transition point into a lack of awareness and is relatively far from returning to that transition point. As shown, the power of frequencies above about 12 or 15 Hz significantly drops while the power at the lower frequencies is much higher. In accordance with providing the information in a log-log format, the spectrogram 100 can be transformed into the best-fit lines 104, 106. Regardless of the point of reference from which you measure, the respective slopes of the low frequency line 104 and the high frequency line 106 are vastly different. The intersection point 102 is at about 15 Hz. As noted, this display allows for simple analysis of the anesthetic state, or more generally, the brain function, of a patient.

[0024] Additional useful data can be extracted from the graph depicted in FIG. 1. In this graph, an alpha peak 118 is present that would typically be considered an outlier when calculating the best fit line 104. Other peaks may occur in the EEG signal 400 and may be useful as well. One beneficial analysis of such peaks is to use the best fit line 104 as a baseline and subtract it from the signal 100. For the alpha peak 118, for example, the area 120 above the baseline represents information about the alpha peak. For example, its amplitude, its spread, and the center frequency can all be determined by analyzing the area 120. Regression analysis of these parameters revealed that there is a correlation between the alpha peak frequency and concentration of the anesthetic agent. Thus, because the alpha peak generally shifts with concentration of anesthesia (decreasing frequency as concen-

tration increases), the changes in the alpha peak can be used as additional information or confirmation when making a determination about the state of awareness of the patient. In some tests, surgical stimulation (e.g., retracting an inflamed nerve root) also resulted in changes of the alpha peak size and location such as reducing the amplitude of the alpha peak and/or shifting it to a higher or lower frequency. These additional factors may be useful when determining the state of awareness of the patient.

[0025] However, additional investigation has established that extending the frequency range to about 130 Hz provides beneficial data and analysis as well. Going from 40 Hz to 130 Hz goes beyond what is traditionally thought of as EEG into the EMG range. Similarly, as before, the EEG (and now EMG) data is plotted in a log-log representation. This representation and extended frequency range allows more than two best-fit lines to be calculated. For example, the raw data can be modeled by 3, 4 or even more best-fit lines. Once these lines are calculated, analysis of the lines can occur. Within this patent application, the terms EEG and EMG are used for convenience to refer to sensing and collecting physiological responses in the frequency ranges from about 0 Hz to about 130 Hz. Use of these terms is not intended to limit the scope of the present invention to only EEG or EMG machines or techniques but, instead, is intended to encompass sensing of the electrical physiological responses produced by a person within the specified frequency range.

[0026] The differences in the heights and slopes of each line, the frequency and amplitude of the intersection points, and the angles formed at the intersections all provide useful data in evaluating brain function.

[0027] In addition, the presence and location of various peaks in the log-log data are useful as well. The frequency at which the alpha peak and the delta peak occur, for example, provide useful information for evaluating brain function. When used in conjunction with the best-fit line data, the peak locations provide further certainty that the analysis of brain function is accurate. The area under the peak and a corresponding best-fit line is useful as well. The more the peak spreads or the higher the peak is, generally the more area that will be under the peak which is useful information for evaluating brain function.

[0028] In one particular example, there is a correlation between the alpha peak frequency and concentration of the anesthetic agent. Thus, data about the alpha peak (e.g., frequency, height, area, etc.) are indicators of brain function in the presence of an anesthetic agent.

[0029] The flowchart of FIG. 2A depicts an exemplary algorithm for analyzing EEG and EMG spectrograms in accordance with the principles of the present invention. In step 202, the raw EEG signal and EMG signal is captured as is known in the art. For example, signals in the range of approximately 0 to 128 Hz are captured; however, it is contemplated that even higher frequencies may be captured and analyzed as well. Present techniques and devices as well as future-designed EEG and EMG devices may be utilized to acquire the raw signals. Also, as well known in the art, the raw signals may be filtered and processed to reduce noise and to remove artifacts that are known to be introduced into the signals. The raw signal is a time-domain series of samples that are sampled or converted to digital signals which can be then processed by computer platforms or specialized digital signal processors.

[0030] Once the digital signals are generated, the time-domain signal can be transformed into a frequency-domain signal in step **204**. While there are a number of techniques for converting between the time domain and the frequency domain, a common technique involves the fast Fourier transform method. A number of computationally efficient algorithms for performing fast Fourier transforms beneficially result in a technique that can occur in almost real time with even limited computational power. As one of ordinary skill will recognize, there are a number of parameters that can be selected to control how the transform operates and performs. As an example, in one embodiment of the present invention, a two-second window averaged for periods of about one minute, or even longer, is used to convert the time-domain signal.

[0031] One novel realization reached by the present inventor is that the frequency domain signals are visually informative when arranged in a log-log format, in step **206**. In particular, the y-axis represents the power, or power spectral density (PSD), of a frequency in the signal and the x-axis represent the frequency. Both axes, though, are scaled logarithmically. What results is a visual display that reveals that the resulting frequency-domain data can generally be split into multiple regions—a first region from about 0 to about 10 or 20 Hz, a second region representing the frequencies above the first (to about 40 Hz); and a third region typically associated with EMG signals between about 40 Hz and 130 Hz. The first range can extend further as well, especially when the patient is in a state of awareness. These regions will be conveniently referred to a low frequency segment, a high frequency segment, and an EMG segment. Those labels are used as a way of convenience and of comparison to each other and are not intended to limit the segments in any way to a particular range of frequencies.

[0032] Once the frequency-domain data points are arranged in this log-log format, a best-fit line is calculated in steps **208**. In particular, one or more best fit lines are calculated for each segment. One of the easiest best-fit approaches is to use a least-squares approach but one of ordinary skill will recognize that there are numerous other data regression schemes that may be used to approximate a line while minimizing error. In one example, the best fit lines were accomplished using an iterative least-squares approach where the slope and y-intercept of a line providing the minimum mean square between the log of the spectral magnitude and that line were obtained. Also, one of ordinary skill will recognize that optional methods of fitting the data may be accomplished during the least-squares fit as well. For example, points that are statistical outliers can be discarded if their error size suggests that they should not be used when fitting the data to the best-fit line. The best-fit line can then be recalculated with the outliers ignored. As mentioned, different regression methods other than the least-squares may be used to calculate the best fit lines and furthermore, one regression method may be used for the high frequency line and a different regression method used for the low frequency line and yet a third regression method may be used for the best fit line of the EMG segment.

[0033] The determination of when the best fit lines are complete can be accomplished in a number of different ways. The determination can be based on an event in the EEG or EMG signal itself. For example, the EEG signal may exhibit an alpha-peak at a certain frequency and that value is used for the endpoints of the two best-fit lines of the high and low frequency segments. For example, the first best-fit line is

calculated from the lowest frequency to the alpha-peak frequency and the second best-fit line is calculated from the alpha-peak frequency to the highest frequency. The alpha-peak frequency, itself, can be selected in different ways such as at the beginning of the peak, a center frequency, or at the end of the peak. Alternatively, the decision to stop the least-squares fitting can be determined on the fly as the best-fit lines are being calculated. For example, an analysis can be made to determine when a similar frequency is reached from both directions at which both the first best-fit line and the second best-fit line start deviating significantly (e.g., some percentage, such as, for example 3% to 8%) from the previously calculated best-fit line. This frequency, then, is the dividing point between the two best-fit line segments.

[0034] Once the best-fit lines are determined, then the slope of each line can be calculated and the intersection point as well with the neighbor segment (see step **210**). Of particular interest is the frequency at the intersection point. Based on the relative slopes of the best-fit lines and the frequency of the intersection points, an indication is generated, in step **212**, that relates to the state of anesthesia, or the state of awareness, of the patient.

[0035] FIG. 2B depicts a log-log display of an EEG signal **230** that is represented with two best fit lines **232** and **236**. The peak **234** appears to be present but a clinician can benefit from additional indicators regarding the state of the patient. Thus, in accordance with the principles of the present invention, the region to the right of the intersection point is broken into different sections **238**, **240**, and **242** that are graphically displayed to the clinician. While more or fewer sections could be utilized, three sections are beneficial because it allows a comfortable granularity for quick decision making. The sections **238**, **240**, and **242** represent different angular areas with respect to the intersection point **234** and the slope of the higher frequency line(s) **236**. The slope of the line depends, of course, on the scale of the x and y-axis of the graph. Generally speaking, however, a line **236** with a small steep slope (e.g., more negative than -40 dB/decade) would be located in region **238**; a line **236** with a relatively shallow slope (e.g., more shallow than about -30 dB/decade) would be located within the top region **242**, and a line **236** in-between these approximate values would be located in the middle region **240**.

[0036] Using the additional information provided by the three sections, a clinician can confirm that peak, or spindle, activity is indicative of the state of the patient. For example, when the line **236** is in the lower region **238** and there is an apparent alpha-peak (as shown in FIG. 2B), then these two pieces of evidence allow the clinician to be more certain that the patient is properly anesthetized. FIG. 2C depicts a different situation. The EEG signal **260** is depicted by a first line **262**, an intersection point **264**, and a second line **266**. Although there may be a peak in this display, the location of the higher frequency line(s) **266** is within the middle region **240** and near the top region **242** instead of near the lower region **238**. Given this display, the clinician can become concerned that the patient is becoming more awake and adjust anesthesia accordingly.

[0037] One current monitor that tracks anesthetic effects on the brain, Aspect's Bispectral Index monitor (BIS) is less than ideal. BIS is an index value that at best correlates with a probability of awareness. BIS was empirically developed based on a theory of anesthetic action as it relates to electroencephalography (EEG) analysis which has never been

proven. BIS is composed of 3 sub-parameters. One is suppression ratio. Another is the beta ratio which is the log of the ratio of power in 30-47 Hz to 11-20 Hz. The third sub-parameter is a Bispectral parameter called SynchFastSlow. The visual technique of displaying the EEG signal as described above can be used as a sole indicator of patient awareness or could also be used along with another indicator, such as BIS, as a way to verify that other indicator.

[0038] The starting and ending values of each of the three regions as well as their sizes relative to one another can vary according to patient type. Thus, the age and other factors about a patient can be used to customize the location and size of the three regions. However, the intersection of the two best-fit lines is the most beneficial place from which to define the different angular sections because the intersection point accounts for variance in both amplitude and frequency of features of the EEG spectrum. While the intersection point remains in generally the same neighborhood on the graph, this intersection point can move slightly based on characteristics of the EEG spectrum. Thus, the intersection point can be represented by an average of the instantaneous values of the intersection point over a predetermined time window. For example, a time window that varies from about two seconds to about 30 seconds could be used to calculate a moving average intersection point.

[0039] It is possible to achieve similar, although inferior results, using the EEG spectrum itself without the benefit of calculating the best-fit lines and their intersection point. In the EEG spectrum there is a "spectral edge" that can be identified where the general trend of the higher frequencies (e.g., about 10 Hz) drops dramatically lower than the general trend of the lower frequencies. This "spectral edge" value can be used as the originating point of the angular sections of the template discussed above. One formal definition of "spectral edge" is the frequency below which 95% of the power in the power spectrum resides; however, embodiments of the present invention contemplate that a beneficial result can be obtained by varying the spectral edge frequency from about $\pm 3\%$ from the typical 95% threshold. In the techniques described above, a best-fit line was calculated for the higher frequencies. As one alternative, instead of calculating a best fit line for the higher frequencies, the EEG spectrum itself is considered when determining which of the angular sections it occupies. Thus, a template can be used with just the EEG spectrum to provide an indication or a verification of the awareness of a patient.

[0040] While the above techniques have been discussed solely within the context of a log-log graph, similar techniques would also work with a log-linear graph but the lines would be curved. Additionally, when more than two best-fit lines are calculated there is more than a single intersection point that can be useful in defining a template. Thus, at each of the other intersection points a respective set of additional angular sections can be defined for the template. It is contemplated that each intersection point would have its own set of three angular sections defined similar to the techniques described above; however, defining only two angular sections for the additional intersection points is contemplated as well. As a result, the clinician may be presented with a display in which a certain portion of the EEG power spectrum is in a "green" portion of the template for one range of frequencies but in a "yellow" or "red" portion of the template for a different range of frequencies. Based on this type of multi-

part template the clinician can draw further conclusions about the state of awareness of the patient.

[0041] The description above specifically used a plurality of angular sections as the template by which to compare an EEG signal or the best fit lines. However, this is only one specific example of a template that can be used. In the more general case, a number of templates can be defined from empirical evidence that describe the EEG signals of a history of different patients. As a current patient's EEG signal is acquired, and possibly filtered or transformed, it can be compared with the database of possible templates. The current EEG signals can be mathematically compared with the templates to determine which template is most similar to the current signal. Based on that determination and prior knowledge about the matching template, an indication can be provided about the state of the patient's awareness. In other words, if a template is known to show a person starting to become more awake and the current EEG signals match that template, then the clinician can receive a warning indication that the patient may be awakening.

[0042] FIG. 3 illustrates an automated platform on which the algorithm described above may be implemented. In practice, the device 300 would be used during surgery to monitor the anesthesia state of the patient to allow an anesthesiologist to modify the delivery of an anesthetic agent as appropriate. The device 300 is shown in functional block form in FIG. 3 because the different functional blocks may be implemented in a variety of ways without departing from the scope of the present invention. For example, a programmable computer with a typical microprocessor may implement a variety of the functions in software programs that are stored on an accessible media and executed during operation. Alternatively, some of the functions may be implemented using specialized hardware including DSP chips and microcontrollers. One of ordinary skill will recognize that various combinations of hardware and software may be utilized to accomplish the functions of the blocks shown in FIG. 3.

[0043] The EEG and EMG signals 302 are received and then filtered and converted by a signal processor 304. That signal can then be transformed into the frequency domain by a fast Fourier transformer 306. The power spectrum of the frequency domain signal can then be calculated in a log-log arrangement so that an interpolator 308 can calculate multiple best-fit lines for the spectrum. An analyzer 310 analyzes the best fit lines to determine their respective slopes and the frequency at which they intersect.

[0044] Based on the calculations of the analyzer 310 a display 312 provides an indication of the anesthesia state of the patient. The display 312 may be multifaceted to provide the viewer of the display with different information. Two particularly relevant pieces of data are a) the difference between the slopes of the best-fit lines and b) the frequency at which the lines intersect. Thus, these values may be displayed as raw numeric information. A graphical display may be included which graphs these values in a historical fashion so that the viewer of the display can see how the values have been changing in some preset time period. For example, the display could show the values over a window depicting the last 5 minutes. A control 314 for the display 312 can be used to allow the viewer to change between different formats of output as desired. The display 312 can also be configured to display the best-fit lines in near real-time with (or without) the additional values discussed above.

[0045] There is a memory 318 that stores the values for different region templates based on patient parameters (e.g., sex, age, drug use, head injury history, etc.). Using these patient factors, an appropriate template is also displayed along with the best fit lines and/or the raw EEG signal in order to give the clinician additional confirmation of suspected spindle activity. The display of the template having these three (or more) angular sections can be accomplished in a variety of ways. For example, the colors of the regions (e.g., red, yellow, green) can be used to provide additional visual clues regarding the patient's condition. For example, if the best-fit line is in the lower region, then the background of that section of the display can be green. If the best-fit line is in other angular sections of the template, then the background of those sections can be red or yellow. In this way, the clinician can be alerted by simply seeing which color is being displayed in the higher frequency region of the display.

[0046] Also, (not shown) the device 300 may include a storage function that records various signals and calculations during the duration of the surgery.

[0047] Other aspects of the present invention include filtered time domain EEG. (display and use for analysis). "Raw EEG" displays are filtered but over a broad range such as >1 Hz and <100 Hz and a 60 Hz notch filter. However, a more narrow filtered time domain allows the clinician to see the oscillation that creates the alpha peak without the interference of either low frequency baseline changes or high frequency EMG noise. It also enables the clinician to verify the interpretation of the spectrogram.

[0048] For example, one filtered signal could include a display in the operating room of narrow range filtered time domain signal such as 7-14 Hz to show the spindle oscillation. A declining amplitude of this oscillation indicates either light or deep anesthesia.

[0049] Other examples include multiple filtered ranges to show changes in other oscillations. This can help with interpreting changes in the spindle oscillation.

[0050] Additionally, the filter widths can be adjusted to capture the activity of a changing peak width and center frequency (and the changing values over time of the width height and center frequency of the peak controlling the filter.)

[0051] Essentially, the filtering of the signals can accomplish filtering out of the EMG noise. The spectral data itself of the signal can be used to determine what type of filtering will occur. In particular, the location and amplitude of one or more of the peaks (and their shape) can be used to determine how filtering takes place.

[0052] FIG. 4 illustrates an automated platform on which the filtering functions described above may be implemented. In practice, the device 400 would be used during surgery to monitor the anesthesia state of the patient to allow an anesthesiologist to modify the delivery of an anesthetic agent as appropriate. The device 400 is shown in functional block form in FIG. 4 because the different functional blocks may be implemented in a variety of ways without departing from the scope of the present invention. For example, a programmable computer with a typical microprocessor may implement a variety of the functions in software programs that are stored on an accessible media and executed during operation. Alternatively, some of the functions may be implemented using specialized hardware including DSP chips and microcontrollers. One of ordinary skill will recognize that various combinations of hardware and software may be utilized to accomplish the functions of the blocks shown in FIG. 4.

[0053] The EEG signals (analog) are received and initially filtered in a receiver 402. For example, the raw signals can initially be filtered such that signals from about 1 Hz to about 100 Hz are analyzed. Other ranges of frequency filtering can be used as well without departing from the scope of the present invention. Next, this signal can be fed to multiple time-domain filters 404. For example, there can be a filter that passes only the alpha waves, another filter that passes only the beta waves, another filter that passes on the gamma waves, and another filter that passes only the delta waves. The different filtered waveforms can then be displayed visually on a display 406.

[0054] Frequency domain methods require 30 to 60 seconds to assess the EEG spectrum. The time domain can give instant information that the situation has changed. Currently utilized time domain methodology is a single unfiltered "raw" EEG signal. Multiple neurophysiologic processes can occur simultaneously making the "raw" signal difficult to interpret. Multiple filtered displays can help to identify the different processes and create an indication of the neurophysiologic state.

[0055] One such process is the spindle oscillation. Verification that this process is occurring can indicate that the patient is in an unconscious state. To verify the spindle it is useful to have displays that are filtered to exclude activity outside of the spindle range which is 7-14 Hz. One display is at a sufficient speed to identify oscillations that have a wavelength of about 100 msec. One inch per second is a good example. Since the spindle oscillations occur in packets with gaps in between packets (not a continuous oscillation) it is useful to have a second window at a speed that is about one inch per ten seconds. A third display that shows the trend for long periods of time is also useful.

[0056] Another process worth monitoring with a filtered time domain display is the gamma band which is above 25 Hz and extending to 40 or 50 Hz. Increased activity in this frequency range could indicate that the patient is becoming aware. (Gamma could also be EMG.) Arranging gamma band windows at the same speed as the alpha band displays is useful to create an indication of the neurophysiologic state. Having the different frequency bands arranged one frequency directly above the other helps to make the assessment. Packets of spindles do not begin and end at the same time as packets of gamma band activity. Burst suppression is a neurophysiologic state where packets of oscillations begin at the same moment at multiple frequency bands. Burst suppression is usually identified by the periods of electrical silence (suppression). However, there can be continuous bursting with few or no periods of electrical silence. When that occurs the multiple filtered band displays are useful to identify bursting from spindling.

[0057] The filtering and display of the different time domain bands utilize different display window sizes (in the time dimension) and different frequency bands. For example, the display of the alpha wave signals in one window may show a 2 to 4 second snapshot of the wave while another display shows about a 30 second snapshot of the same wave. In this way, the clinician can see the current activity of a particular frequency band as well as the recent trend of that frequency band. A third window can be used to display the historical trend of a particular frequency band since a procedure was started.

[0058] In at least one embodiment, the different frequency bands are shown in separate windows while in other embodi-

ments, the signals of the different frequency bands can be super-imposed within the same window.

[0059] FIG. 5 illustrates an exemplary display in accordance with the principles of the present invention. The display **500** is an example only and is not intended to limit the present invention to a 3x3 grid of windows. In general, the display **500** shows that multiple frequency bands of EEG time domain signals are displayed in windows having different time scales. In addition, the different waveforms can be shown in different colors so as to visually distinguish each signal from another.

[0060] In FIG. 5, there are three different time scale windows represented by the columns **502**, **504** and **506**. The physical size of the apparatus which presents the display **500** plays a factor but typically the time scales for the different windows are chosen to provide useful, visual information to a clinician. For example, alpha waves range from about 7 Hz to about 14 Hz, so a two second window (column **506**) displays the individual cycles of the alpha waves. However, a 30 second window of about the same size (as depicted in column **504**) will show packets of alpha wave peaks rather than the individual cycles themselves. A third time value window **502** can show a long period of time so that the trend or RMS power, or peak-to-peak values, of a signal can be evaluated. More than one frequency band can be trended in the third column. If the alpha band has more amplitude than the theta band, then it indicates that there is a peak in the alpha range. This can be used to help locate the point where the spindle peak is at the maximum. For this purpose, tracking the highest point in the alpha range and the lowest point in the theta range provide the most benefit. Similarly, the beta range can also be tracked to detect a beta peak.

[0061] The rows **508**, **510**, **512** of the display **500** represent different frequency bands. For example, the top row **508** can show delta or theta waves or might even show the raw EEG signal. The second row **510** can show the alpha wave band and the bottom row **512** can show another frequency band such as the gamma waves. Thus, each row can represent a different frequency band of the EEG signal. Of course one of ordinary skill will appreciate that the positions of the different bands can vary; for example, the bottom row **512** can be used to display the raw EEG signal and the top row **508** could be used to display the gamma band or some other frequency band. In addition, it is beneficial to superimpose different frequency bands over one another as well. For example, the middle window shows two signals **520**, **522** having different colors. If for example, the white signal **522** is the beta wave band and the gray signal **520** is the alpha wave band, then the amount of the different colors that are visible will visually alert a clinician when the beta activity is increasing and the alpha activity is decreasing. Thus, there is an indication to the clinician that the patient may be awakening or that there is little fear of the patient awakening. Alternatively, the two bands could be the alpha band and the theta band and the visual information provided by the two colors could reveal spindle activity.

[0062] There are at least two concepts for utilizing the electroencephalogram (EEG) for monitoring and understanding the mechanism of anesthesia. One concept is to use mathematical processes to extract a parameter which is presumed to correlate with the amount of anesthetic effect. This is the quantitative EEG or “qEEG” approach. The mechanism of anesthesia which this parameter is presumed to correlate with is a progressive dysfunction of the brain. The original brain dysfunction or depression theory was Meyer-Overton which

proposed disruption when ether dissolved in the lipids of neuron membranes. Today the depression theory is that anesthetic agents affect ion channels enhancing inhibitory and reducing excitatory synaptic processes.

[0063] An alternative view is that the EEG contains signals created by oscillatory processes in the thalamus and cortex. These thalamocortical oscillations, in particular spindle oscillations, occur during natural slow wave sleep. There is evidence that anesthetic agents affect ion channels that control these natural thalamocortical oscillations in ways that prevent the natural wake-up processes from terminating the oscillations. Spindle oscillations are not compatible with consciousness but are not brain dysfunction or brain depression. They imply a functional state that is different from the functional state of the brain which creates consciousness. Spindle oscillations are not a total mechanism of anesthesia. They may occur after loss of consciousness and be terminated before return of consciousness. Thalamocortical oscillations are not a mechanism of surgical immobility. However, detecting spindle oscillations during anesthesia may be a reliable way to insure a lack of awareness for individual surgical patients.

[0064] The proposed method for detecting spindle oscillations in the EEG during anesthesia is to evaluate the shape of the EEG spectrum on a log-log graph. In this presentation the EEG spectrum can be approximated by two straight lines. The low frequency approximation line has a shallow slope and a peak in the 7-14 Hertz range rises above it that results from spindle oscillations. The high frequency approximation line has a steep slope. This is the shape that occurs in the anesthetic range with maximum spindle activity. If the anesthetic agent concentration is increased or decreased, the shape of the spectrum will change in predictable ways. The limited number of, and the consistent progression of log-log EEG spectral shapes enables an alternative to the parameter approach. This alternative is an EEG spectral feature analysis method which could be called “visual qEEG”. The patient’s log-log EEG spectrum would be compared to a library of spectra from other patients to determine the anesthetic state. Also, the patient’s EEG spectra can be recorded during the procedure and used for comparison to track changes in the anesthetic state.

[0065] Applicants recognize that there is a conventional EEG “CSA” (compressed spectral array) display. At regular time intervals a new spectrum (log-linear) is produced at a set distance below the previous one. The process is repeated until the top spectrum scrolls off the display. What happens is a new spectrum is produced at the same spot and the previous spectra scroll up. However, such a display is different than the presently contemplated invention in that the conventional display does not permit useful comparisons between different spectra and, in particular, does not permit comparison of the amplitudes of different spectra.

[0066] Thus, according to certain embodiments of the present invention, the EEG spectrum on a log-log graph can be used (with or without approximation lines or drawing lines on the background) with another spectrum for comparison. The other spectrum can be from the same patient recorded earlier in the procedure. The other spectrum can be from another patient. A spectrum from another patient can be adjusted to compensate for differences in amplitude. The approximation lines can be used to compensate for differences in amplitude. Also, the other spectrum can be an average spectrum of a number of other patients and, in particular,

the other patients can be selected so as to have similar age, gender, demographic, or medical profiles that are similar to the patient. Thus, the reference spectrum may be an actual spectrum observed for that patient, or another patient. The reference spectrum can also be an artificial construct that statistically combines different spectra that are relevant. Additionally, the reference spectrum can be a scaled version of another spectrum to account for amplitude differences or other variations. These reference spectra can be stored in computer-accessible memory and local processing can retrieve them as is for display or can combine them to form a reference spectrum. For example, parameters about the current patient such as age, sex, drug use, lifestyle habits, health history, etc. can be input so that a reference spectrum can be customized from a library of reference spectra depending on each particular patient.

[0067] There is evidence that there is a relation between an anesthetic agent concentration and the maximum peak in the alpha (7-14 Hz) range. Changing the anesthetic agent concentration from that point changes the spectrum in predictable ways. Increasing produces one sequence of changes and decreasing produces a different sequence. In general, the maximum spindle point can be a reference in the progression of spectral changes with changing agent concentration. Both higher concentrations and lower concentrations will result in a smaller spindle peak. Thus, a patient's maximum spindle point can be used to determine the patient's sensitivity to anesthetic agents.

[0068] Also, the use of multiple filtered bands of signals discussed previously can be extended by using a mathematical approach to quantify the number and amplitude of the individual cycles within a spindle and the number of spindles in a unit of time or the time interval between spindles. These values can be used to determine the state of awareness of the individual. For different patients, the number of spindles, their spacing, and their amplitude may vary and thus previous data for that individual, or similar individuals, may be used in conjunction with the raw data to determine the state of awareness of the individual.

[0069] FIGS. 6-9 are graphs of different power spectra for various sets of patients. In particular, the graphs include 13 TIVA (i.e., total intravenous anesthesia, for example, propofol as opposed to an inhaled agent) Diagnostic Laparoscopies (FIG. 7) and their average spectrum (FIG. 8), and compared it to the average spectrum for 11 tubal ligations (FIG. 6 and FIG. 9). The infusion rates were 75-100 mcg/kg/min. It is clear that similar TIVA anesthetic conditions in 24 young adult women produced a similarly shaped spectrum. This result supports the assertion that if an index, or some other value, reflects anesthetic conditions then some part of the spectrum should be substantially similar. Accordingly, although the discussion above focuses on visually comparing a current spectrum with another spectrum on the same display, this same type of comparison can be performed mathematically and an index, or other value, can be calculated that indicates the similarity between the two spectra. One of ordinary skill will recognize that there are a number of conventional methods that can be used to determine two graphs similarity to one another. Embodiments of the present invention contemplate any such methods that allow such a determination to be made. Techniques such as a cross-correlation analysis or principal component analysis can be utilized to determine the similarity between two waveforms in either the time-domain or the frequency-domain. However, as discussed above, an EEG

power spectrogram can be characterized by a log-log arrangement of frequency versus power. The resulting arrangement of data can be approximated using multi-segment, best-fit lines for different frequency regions of the spectrogram. Thus, the comparison of two EEG waveforms can be accomplished by comparison of their best-fit approximation lines as well (whether or not such lines are visually displayed for a user).

[0070] FIGS. 10-12 illustrate a display of two power spectra for comparison in accordance with the principles of the present invention. FIG. 10 shows a first spectra 1002 that was acquired while an anesthesia agent was being administered. The second spectra 1004 is for the same patient but represents the EEG after the agent has been turned off. There may be some similarities between the two spectra 1002 and 1004 but the drop in power is evident. There are respective alpha peak regions 1006, 1008 in each spectra but the alpha peak 1008 of the second spectra 1004 is noticeably lower in amplitude. FIG. 11 shows two spectra 1102 and 1104 that may be from different patients but are similar in appearance. Because of the similarity, these two spectra can be overlaid on one another as shown by the spectra 1210 and 1212 of FIG. 12. The visual similarity between the two spectra can be observed. In particular, the location of the alpha peak (respectively 1106, 1108), the general slope of the low frequency portion and the general slope of the high frequency portion can be seen to be similar in both spectra. Thus, if one of the spectra is a reference spectrum of a known state of awareness then the other spectrum of a current patient can be determined to be similar and a conclusion can be made that the patient is in the known state of awareness or pharmacologic state. For purposes of the present description, the "known" state of awareness of a patient may include knowing the level or depth of anesthesia; however, the term generally means that there are known facts (e.g., gas concentration) or conditions (e.g., vital signs) that are known to have occurred or be associated with a particular EEG spectrogram. Furthermore, experiments and other empirical methods and observations can be used to associate "known" information with a particular EEG spectrogram. It is this more general meaning of the phrase that is meant herein when referring to an EEG spectrogram associated with a "known" state of awareness of a patient.

[0071] However, the two spectra have different amplitudes and thus, the similarity may be somewhat obscured. As mentioned, in FIG. 12 a display is illustrated where the two spectra are overlaid on one another. In this instance, the similarities between the two spectra may become more apparent. Additionally, in all three displays, "best-fit lines" are depicted (respectively, 1010, 1012 and 1110, 1112 and 1210, 1212). However, inclusion of such lines is not required to practice embodiments of the present invention. The two spectra can be displayed without the inclusion of any other lines if desired.

[0072] One particular method to adjust the amplitude of one of the spectra (e.g., 1102, 1104) is to utilize the respective high frequency best-fit line that can be calculated for each of the spectra. The amplitude of one of the spectra can then be adjusted so that, if displayed, the two best-fit lines would at least partially overlap. The more similar in slope that the two best-fit lines are, the more easily they can be amplitude adjusted for comparison.

[0073] The memory 318 (see FIG. 3) or other computer-accessible memory can be configured in communication with the apparatus acquiring and/or processing the EEG signals.

This memory stores both the EEG signals as they are acquired as well as other physiological or surgical information about the patient. Thus, a previous EEG spectrogram for a patient can be retrieved from memory and compared to a current EEG spectrogram for the patient.

[0074] In particular, while anesthesia is being administered, there are particular points in time that may provide beneficial comparison opportunities in order to investigate the pharmacological state, or awareness state, of the patient. For example, vital signs such as heart rate, blood pressure, and respiratory parameters may change during a procedure. It may be beneficial for a clinician to compare a current EEG spectrogram with one that occurred coincident with various values (e.g., minimum or maximum) of the different vital signals. Also, previous times when gas

[0075] Attorney Docket No.: 256-008-CIP concentration levels were adjusted or additional drugs were administered (or predetermined time periods after such occurrences) may result in an example EEG spectrogram that the clinician may want to compare to a current EEG spectrogram. Other currently known indicators (e.g., surgical conditions) and future developed indicators all provide data that can be stored along with a coincident EEG spectrogram so that a clinician can choose particular EEG spectrograms to compare to a current EEG spectrogram of the patient in order to make a more certain determination of the state of awareness of the patient.

[0076] The indicators discussed above can be point-in-time values or can be represented by trend lines to assist the clinician in identifying a reference EEG spectrogram for comparison. Some of the indicators may be measured, physiological parameters, while others can be calculated according to models (e.g., propofol blood levels as in TIVA). Some of the indicators may be from the EEG spectrograms themselves. For example, the maximum spindle point, the lowest theta trough, the difference between the alpha peak and the theta trough, etc. can all be indicators that a clinician could use to select a previous EEG spectrogram for comparison.

[0077] One benefit of having an EEG spectrogram history available is that it allows the current EEG to be analyzed with more certainty. For example, the power ratio of different bands of an EEG spectrogram may provide some insight into a patient's state of awareness (e.g., (power in the 30-47 Hz)/(power in the 11-20 Hz)). If a current EEG spectrogram is acquired in which the amplitude of the entire EEG spectrogram were to be reduced across all frequency bands, then the ratio would remain approximately the same. However, comparison of the current EEG spectrogram with the original EEG spectrogram would allow for a determination of the amplitude drop which, for example, may be due to a reduction in the anesthetic agent.

[0078] FIGS. 13A-13D illustrate display of different spindle patterns in accordance with the principles of the present invention. The commentary above each figure helps explain their significance. However, in general each figure depicts two different views of the alpha peak, or spindle portion, of the EEG signal. The left side is a longer time period and the right side is a relatively short time period. The two different time periods can be varied but, in general, they are selected to allow identification of sudden changes in the spindle pattern as well as show the general trends of the spindle patterns.

[0079] As mentioned above, the spindle patterns can be characterized mathematically and this characterization can be used to generate an index, or other value, that indicates the

state of awareness of the patient. Also, as shown in FIGS. 13A-13D, the spindles patterns can be displayed so that a determination can be made visually about the patient's state of awareness. The more pronounced the pattern looks like a spindle rather than random oscillations, the more certain an observer is that the patient is not aware. In other words, there is a particular anesthetic agent concentration that is associated with the maximum spindle peak of the spectrum. If the concentration falls below that particular concentration level, then the spindle pattern changes in predictable ways (e.g., number of oscillations, space between spindles, amplitude of the spindles, etc.). Also, if the concentration level rises above that particular concentration level associated with maximum spindle peak, then the spindle pattern changes in predictable ways as well. Accordingly, changes in a patient's EEG resulting from a known anesthesia change can be compared to how an average patient's EEG would have changed. The difference between the patient's changed EEG and the average, or expected change, may indicate if the patient is more sensitive or more resistance than average to the anesthetic affects that produce unconsciousness.

[0080] Additionally, the number of spindles, the spacing between spindles, the height of the spindles is also characterized within the EEG spectrum and the approximation lines discussed earlier. The angle between the two best-fit lines, and their respective slopes, reveal the spindle information that can be calculated by other techniques as well.

[0081] FIG. 14A-14C depict exemplary EEG spectrograms illustrating how such spectrograms may change depending on, for example, an agent concentration. These examples are helpful in understanding how a progression of EEG spectrograms can be analyzed to help determine the state of awareness of a patient or their pharmacological state. The spectrogram 1402 represents the spectrum at which the maximum alpha peak, or maximum spindle, occurs. This spectrogram 1402 includes an alpha peak maximum 1408 and a theta minimum 1406. The spectrogram 1404 represents a resulting EEG spectrogram when more agent is administered. In particular, the second spectrogram 1404 has a lower alpha peak maximum, the frequency of the alpha peak is lower and the theta minimum point is higher.

[0082] FIG. 14B illustrates the effect of lowering the anesthetic agent for a patient from the amount that produced the maximum alpha peak. As compared to the maximum alpha peak spectrum 1408, the spectrograms 1410 and 1412 are "less". The patterns that are revealed by analyzing a progression of EEG spectrograms, or by comparing spectrograms from different points in time, can be beneficial for a clinician to predict with more certainty the time needed for a patient to wake up after discontinuing use of the agent.

[0083] FIG. 14C illustrates how the display of two spectrograms can be enhanced. In particular, a spectrogram 1422 with Sevo at 2% and a spectrogram 1420 with Sevo at 1% are concurrently displayed. The region 1424 can be filled with one color to show the gain (or loss) of amplitude between the two EEG spectrograms, while the region 1426 could be filled with a contrasting color. In this manner, an enhanced display can be produced showing how the high frequency regions and low frequency regions are different between two EEG spectrograms.

[0084] FIG. 15 provides a flowchart that summarizes one aspect of how the principles of the present invention may operate. The flowchart depicts the steps of an automated method that can be performed by a computer, microprocessor

or other general purpose programmable device that can communicate with an apparatus for acquiring EEG signals.

[0085] In operation, the process begins in step **1502** with the acquisition of EEG spectrogram data. This data can be acquired in a number of different formats and can be processed and filtered in a variety of different ways. One particular technique described above is to arrange the data in a log-log, power vs. frequency arrangement. Of particular benefit, the EEG spectrogram data is stored for later retrieval. One of ordinary skill will recognize that “storing” of the EEG spectrograms can occur in a variety of ways without departing from the scope of the present invention. For example, the raw EEG data may be stored and then used to recalculate a particular EEG spectrogram when desired.

[0086] In step **1504** other indicators can be acquired and stored as well. These indicators such as vital signs, surgical conditions, etc. are described in more detail above. In particular, the indicators are stored in such a way that they are associated with particular EEG spectrogram data. In other words, if a clinician identifies when the highest value for blood pressure occurred, then the EEG spectrogram coincident with that occurrence can be retrieved. The EEG spectrogram data has intrinsic indicators such as maximum alpha peak, minimum theta trough, for example, that also correspond to specific EEG spectrogram data.

[0087] Thus, in step **1506**, a previous EEG spectrogram can be selected from storage based on either the intrinsic EEG spectrogram data or the optional extrinsic indicators. Once a previous EEG spectrogram is retrieved, it can be compared to a current EEG spectrogram, in step **1508**.

[0088] Based on the comparison, a determination can be made regarding how similar (or dissimilar) the current EEG spectrogram is as compared with the previous EEG spectrogram. This similarity (or difference) can be used to provide an indication, in step **1510**, of the state of awareness, or pharmacological condition, of the patient.

[0089] The previous description is provided to enable any person skilled in the art to practice the various embodiments described herein. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments. Thus, the claims are not intended to be limited to the embodiments shown herein, but are to be accorded the full scope consistent with each claim’s language, wherein reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” All structural and functional equivalents to the elements of the various embodiments described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase “means for” or, in the case of a method claim, the element is recited using the phrase “step for.”

What is claimed is:

1. A method for providing an indication of a state of awareness for a patient, comprising the steps of:

acquiring a first EEG power spectrogram of a patient exposed to anesthesia;

comparing the first EEG power spectrogram to a second EEG power spectrogram, wherein the second EEG power spectrogram is associated with a known state of awareness; and

based on a similarity between the first EEG power spectrogram and the second EEG power spectrogram, providing an indication of a state of awareness of the patient.

2. The method of claim 1, further comprising:

acquiring the second EEG power spectrogram when the patient has the known state of awareness.

3. The method of claim 2, wherein the second EEG power spectrogram is acquired from the patient at a time prior to when the first EEG power spectrogram is acquired.

4. The method of claim 1, wherein the second EEG power spectrogram comprises an average EEG power spectrogram calculated from a plurality of respective EEG power spectrograms from a plurality of different persons.

5. The method of claim 1, wherein the second EEG power spectrogram is that of at least one person other than the patient.

6. The method of claim 5, wherein the at least one person is demographically similar to the patient.

7. The method of claim 6, wherein demographically similar comprises one or more of a same sex, a similar age, a similar medical history, and a similar drug use history.

8. The method of claim 1, further comprising:

before comparing the first EEG power spectrogram and the second EEG power spectrogram, arranging respective data of each power spectrogram to provide a respective first and second power versus frequency waveform in a log-log arrangement.

9. The method of claim 8, further comprising:

concurrently displaying the first power versus frequency waveform and the second power versus frequency waveform in an overlaid arrangement.

10. The method of claim 9, wherein the indication of the state of awareness of the patient comprises the concurrent display of the first and second waveforms in an overlaid arrangement

11. The method of claim 9, further comprising:

before displaying the first and second waveforms, adjusting an amplitude of at least one of the waveforms.

12. The method of claim 11, wherein adjusting the amplitude of at least one of the waveforms comprises:

calculating a first best-fit line for a first high-frequency portion of the first waveform;

calculating a second best-fit line for a second high-frequency portion of the second waveform; and

adjusting a respective amplitude of at least one of the first and second power versus frequency waveforms such that the first best-fit line and the second best-fit line at least partially overlap.

13. The method of claim 8, further comprising:

calculating a multi-segment best-fit line corresponding to the first power versus frequency waveform.

14. The method of claim 13, further comprising:

concurrently displaying the first power versus frequency waveform and the second power versus frequency waveform; and the first line in an overlaid arrangement.

15. The method of claim 13, further comprising:

calculating a multi-segment best-fit second line corresponding to the second power versus frequency waveform, wherein the similarity between the first EEG

power spectrogram and the second EEG power spectrogram is based at least in part on how similar the first line is to the second line.

16. The method of claim **1**, wherein comparing the first EEG power spectrogram and the second EEG power spectrogram comprises comparing a first alpha peak associated with the first EEG power spectrogram with a second alpha peak associated with the second EEG power spectrogram.

17. The method of claim **1**, wherein:

the first EEG power spectrogram comprises first spindle information related to a number of cycles within a spindle, an amplitude of a spindle cycle, a number of spindles in a unit time, and a time interval between adjacent spindles, within the first EEG power spectrogram; and

the second EEG power spectrogram comprises second spindle information related to a number of cycles within a spindle, an amplitude of a spindle cycle, a number of spindles in a unit time, and a time interval between adjacent spindles, within the second EEG power spectrogram.

18. The method of claim **17**, wherein comparing the first EEG power spectrogram to a second EEG power spectrogram, comprises:

comparing at least a portion of the first spindle information with at least a portion of the second spindle information.

19. The method of claim **1**, further comprising:

acquiring a temporally-spaced sequence of EEG power spectrograms subsequent to the first power EEG power spectrogram; and

monitoring the state of awareness of the patient by respectively comparing each of the sequence of EEG power spectrograms with the second EEG power spectrogram

to determine how a respective difference between each compared EEG power spectrogram is changing over time.

20. A method for providing an indication of a state of awareness for a patient, comprising the steps of:

acquiring and storing a first EEG power spectrogram of a patient exposed to anesthesia;

acquiring a second EEG power spectrogram, wherein the second EEG power spectrogram is acquired at a point in time after the first EEG power spectrogram;

comparing the first EEG power spectrogram to a second EEG power spectrogram; and

based on a similarity between the first EEG power spectrogram and the second EEG power spectrogram, providing an indication of a current state of awareness of the patient.

21. The method of claim **20**, further comprising:

retrieving the first EEG power spectrogram from storage before comparing with the second EEG power spectrogram, wherein the storage includes EEG power spectrogram data for a plurality of different EEG power spectrograms.

22. The method of claim **21**, further comprising:

selecting the first EEG power spectrogram based on a value of an indicator associated with the first EEG power spectrogram.

23. The method of claim **22**, wherein the indicator is one of a vital sign, a surgical condition, a modeled parameter, and an intrinsic attribute of the first EEG power spectrogram.

* * * * *

专利名称(译)	用于监测和显示生理状况的方法和系统		
公开(公告)号	US20130253362A1	公开(公告)日	2013-09-26
申请号	US13/487986	申请日	2012-06-04
[标]申请(专利权)人(译)	SCHEIB CHRISTOPHER		
申请(专利权)人(译)	SCHEIB , CHRISTOPHER		
当前申请(专利权)人(译)	SCHEIB , CHRISTOPHER		
[标]发明人	SCHEIB CHRISTOPHER		
发明人	SCHEIB, CHRISTOPHER		
IPC分类号	A61B5/00		
CPC分类号	A61B5/7425 A61B5/4821 A61B5/048		
优先权	61/492847 2011-06-03 US		
外部链接	Espacenet USPTO		

摘要(译)

一种系统和方法用于从EEG信号中确定对其施用麻醉剂的患者缺乏认识和麻醉深度。具体地，将当前患者的EEG功率谱的对数 - 对数表示与已知病症中的患者的另一对数 - 对数谱进行比较。通过比较，可以确定当前患者的麻醉意识或深度。参考光谱可以是许多患者的平均光谱或先前获得的当前患者的光谱，或可以与当前患者的光谱统计相关的任何其他光谱。

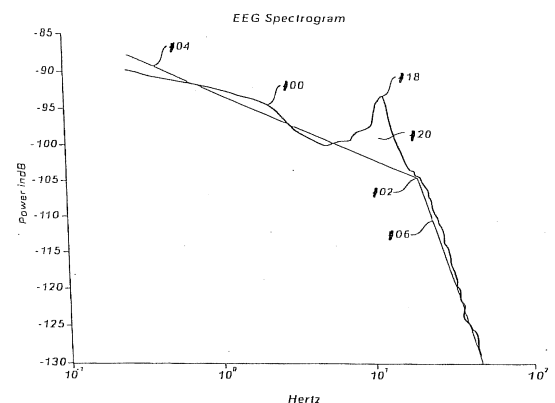


FIG. 1