The invention provides a system and method for regional assessment of lung physiology. The system includes a plurality of sound transducers configured to be fixed on a surface of the individual over the thorax. A processor is configured to receive signals generated by the transducers and to determine from the signals a value of a parameter in each of one or more regions of the lungs. The method of the invention includes obtaining signals indicative of pressure waves at locations over the thorax, and determining from the signals a value of a parameter in each of the regions of the lungs.
METHOD AND SYSTEM FOR REGIONAL ASSESSMENT OF LUNG PHYSIOLOGY

The invention provides a system and method for regional assessment of lung physiology. The system includes a plurality of sound transducers configured to be fixed on a surface of the individual over the thorax. A processor is configured to receive signals generated by the transducers and to determine from the signals a value of a parameter in each of one or more regions of the lungs. The method of the invention includes obtaining signals indicative of pressure waves at locations over the thorax; and determining from the signals a value of a parameter in each of the regions of the lungs.
METHOD AND SYSTEM FOR REGIONAL ASSESSMENT OF LUNG PHYSIOLOGY

FIELD OF THE INVENTION

This invention relates to medical devices and methods, and more particularly to such devices and methods for analyzing body sounds.

BACKGROUND OF THE INVENTION

Regional assessment of lung physiology has been carried out using radionucleotide perfusion also known as the "$Q$ scan". In this technique, radioactive particles are either injected into the subject's blood system or the subject is allowed to inhale suspended radioactive particles. X-ray images of the lungs are obtained and one or both of the lungs in the image is divided into two or more regions. A separate analysis of each lung region is then performed. In most regional lung assessments, each of the two lung images is divided into three parts (top, middle and bottom), and an assessment of lung function or physiology in each region is obtained. Typically, regional assessment involves determining the fraction of the total detected radioactivity detected in each region. The amount of radioactivity detected in each part may be correlated with the lung condition in each part.

Body sounds are routinely used by physicians in the diagnosis of various disorders. A physician may place a stethoscope on a person’s chest or back and monitor the patient’s breathing in order to detect adventitious (i.e. abnormal or unexpected) lung sounds. The identification and classification of adventitious lung sounds often provides important information about pulmonary abnormalities.
It is also known to fix one or more microphones onto a subject’s chest or back and to record lung sounds. U.S. Patent No. 6,139,505 discloses a system in which a plurality of microphones are placed around a patient’s chest. The recordings of the microphones during inhalation and expiration are displayed on a screen, or printed on paper. The recordings are then visually examined by a physician in order to detect a pulmonary disorder in the patent. Kompis et al. (Chest, 120(4), 2001) disclose a system in which M microphones are placed on a patient’s chest, and lung sounds are recorded. The recordings generate M linear equations that are solved using a least-squares fit. The solution of the system is used to determine the location in the lungs of the source of a sound detected in the recordings.

US Patent No. 6,887,208 to Kushnir et al., provides a system and method for recording and analyzing sounds produced by the respiratory tract. Respiratory tract sounds are recorded at a plurality of locations over an individual’s thorax and the recorded sounds are processed to produce an image of the respiratory tract. The processing involves determining from the recorded signals an average acoustic energy, at a plurality of locations over the thorax over a time interval from \( t_1 \) to \( t_2 \). The term “acoustic energy” at a location is used herein to refer to a parameter indicative of or approximating the product of the pressure and the mass propagation velocity at that location. The image may be used to analyze respiratory tract physiology and to detect pathological conditions. Additionally, a time interval can be divided into a plurality of sub-intervals, and an average acoustic energy determined over the thorax for two or more of the sub-intervals. An image of for each of these sub intervals may then be determined and displayed sequentially on a display monitor. This generates a movie showing dynamic changes occurring in the acoustic energy in the respiratory tract over the time interval.

**SUMMARY OF THE INVENTION**

The present invention provides a system and method for regional assessment of lung functioning. In accordance with the invention, microphones are affixed to
the body surface at a plurality of locations over the thorax, and signals indicative of
lung sounds are recorded. The signals are analyzed in order to produce a value of a
predetermined parameter at each of two or more locations on the body surface over
the lungs. The two or more locations at which the parameter was determined is
clustered into groups, where each group consists of locations on the body surface
overlying a particular region of the lungs. The regions may correspond to
anatomical regions of the lungs, or may be determined independently of the lung
anatomy. For each group of locations, a regional assessment of the underlying lung
region is obtained based upon the values of the parameter in the group. The
regional assessment may be, for example, the sum of the values of the parameter at
the locations in the group, the maximum value, the minimum value or an average
value. Alternatively, the regional assessment may be the sum of the values of the
parameter at the locations in the group divided by the sum of the values of the
parameter in all of the groups. In one embodiment, each lung is divided into three
regions (top, middle and bottom), and a regional assessment is obtained as
explained above for each of the six regions. In another embodiment, the lungs are
divided into regions so that each region has the same number of overlying
microphones. The regional assessment may be presented in the form of a table.
Alternatively, a diagram showing the contours of the lungs and the lung regions is
generated, with the value of the regional assessment of each region appearing in
that region of the diagram.

In one embodiment, the plurality of locations is locations at which a
microphone was placed. Since the locations where the microphones were placed is
known, it is known for each microphone over which lung it is located and where
over the lung it is located. The microphones over each lung can be divided into
groups. For example, the set of microphones over each lung could be divided into
top, middle and bottom groups corresponding to the top, middle or bottom regions
of the lungs. A regional assessment of each of the six lung regions can then be
obtained.
In another embodiment, values of the parameter are calculated at a plurality of locations including one or more locations at which a microphone was not located. Values of the parameter at locations at which a microphone was not placed can be determined, for example, by interpolation of values calculated at the positions of the microphones. It is preferable to determine, for each location at which a value of the parameter was calculated, whether the location overlies the left lung or the right lung. The invention provides a method for locating the boundary between the locations overlying the left and right lungs, and for locating the top and bottom of the lungs.

In one embodiment of the invention, a breathing cycle is divided into two or more time intervals, and a regional assessment of the lungs, is obtained in accordance with the invention for each time interval.

The system of the invention includes a plurality of N transducers (microphones) configured to be attached to an essentially planar region R of the individual’s back or chest over the individual’s thorax. The transducers are typically embedded in a matrix that permits to affix them easily on the individual’s skin. Such a matrix may typically be in the form of a vest or garment for easily placing over the individual’s thorax. As may be appreciated, different matrices may be used for differently sized individuals; for different ages, sexes, etc.

Positions in the region R are indicated by two-dimensional position vectors \( x=(x^1,x^2) \) in a two-dimensional coordinate system defined in the planar region R. The \( i \)th transducer, for \( i=1 \) to \( N \), is fixed at a position \( x_i \) in the region R and generates a signal, denoted herein by \( P(x_i,t) \), indicative of pressure waves in the body arriving at \( x_i \).

In a preferred embodiment, the parameter calculated at each of the plurality locations is an average acoustical energy. The term “acoustic energy” at a location is used herein to refer to a parameter indicative of or approximating the product of the pressure and the mass propagation velocity at that location. US Patent No. 6,887,208 to Kushnir et al. discloses a system and method for calculating an average acoustic energy at plurality of locations over the lungs from acoustic
signals of lung sounds. As disclosed in that patent, an average acoustic energy, denoted herein by $\bar{P}(x, t_1, t_2)$, at a plurality of positions $x$ in the region $R$ over a time interval from $t_1$ to $t_2$ may be generated from the $N$ signals and used to generate an image of the lungs.

In one embodiment of the invention, an average acoustic energy over a time interval from $t_1$ to $t_2$ is obtained at a position of one or more of the microphones using the algebraic expression

$$\bar{P}(x_i, t_1, t_2) = \int_{t_1}^{t_2} P^2(x, t) dt \quad (1)$$

where $x_i$ is the position of the microphone.

In a more preferred embodiment, an average acoustic energy $\bar{P}(x_i, t_1, t_2)$ over a time interval from $t_1$ to $t_2$ is obtained at a plurality of positions $x_i$ of the microphones, for example using Equation (1), and then calculating $\bar{P}(x, t_1, t_2)$ at other locations $x$ by interpolation of the $\bar{P}(x_i, t_1, t_2)$ using any known interpolation method.

In a most preferred embodiment, the interpolation is performed to obtain an average acoustic energy $\bar{P}(x, t_1, t_2)$ at a position $x = (x^1, x^2)$ in the surface $R$ using the algebraic expression:

$$\bar{P}(x, t_1, t_2) = \sum_{i=1}^{N} \bar{P}(x_i, t_1, t_2) g(x, x_i, \sigma) \quad (2)$$

where $g(x, x_i, \sigma)$ is a kernel satisfying

$$\nabla^2 g = \frac{\partial g}{\partial \sigma} \quad (3)$$

$$\sum_{i=1}^{N} g(x, x_i, \sigma) \text{ is approximately equal to } 1 \quad (4)$$

and where $x_i = (x_i^1, x_i^2)$ is the position of the $i$th microphone and $\sigma$ is a selectable parameter.

For example, the kernel
\[ g(x, x_i, \sigma) = \exp \left( - \frac{(x_i - x_1^{\sqrt{\sigma}})^2}{2\sigma} \right) \cdot \exp \left( - \frac{(x_i - x_2^{\sqrt{\sigma}})^2}{2\sigma} \right) \] (5)

may be used.

US Patent No. 6,887,208 to Kushnir et al. discloses generating an image of the lungs from average acoustic energies calculated over a time interval. In a most preferred embodiment of the invention, an image of the lungs is generated from the calculated average acoustic energies. The image is displayed on a display device with the lungs in the image being divided into the lung regions. The regional assessment of the lung regions is displayed together with the image of the lungs.

Thus, in its first aspect, the invention provides a system for regional assessment in two or more regions of an individual's lungs comprising:

(a) a plurality of N transducers, each transducer configured to be fixed on a surface of the individual over the thorax, the ith transducer being fixed at a location \( x_i \) and generating a signal \( P(x_i, t) \) indicative of pressure waves at the location \( x_i \); for \( i = 1 \) to \( N \); and

(b) a processor configured to receive the signals \( P(x_i, t) \) and determine a value of a parameter in each of the regions in a calculation involving one or more of the signals \( P(x_i, t) \)

In its second aspect, the invention provides a method for regional assessment in two or more regions of an individual's lungs comprising:

(a) obtaining \( N \) signals \( P(x_i, t) \) indicative of pressure waves at the location \( x_i \); for \( i = 1 \) to \( N \); and

(a) determining a value of a parameter in each of the regions in a calculation involving one or more of the signals \( P(x_i, t) \)

In its third aspect, the invention provides a computer program product comprising a computer useable medium having computer readable program code
embodied therein for regional assessment in two or more regions of an individual's lungs the computer program product comprising:

computer readable program code for causing the computer to determine a value of a parameter in each of the regions in a calculation involving one or more signals $R(x_i,t)$ indicative of pressure waves at locations $x_i$ for $i = 1$ to $N$.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 shows a system for carrying out regional assessment in accordance with one embodiment of the invention;

Fig. 2 shows a flow chart for a method of regional assessment in accordance with one embodiment of the invention;

Fig. 3 shows the locations of microphone placement on the back of a subject for regional assessment in accordance with the invention;

Fig. 4 shows regional assessment of a first subject by the method of the invention (Fig. 4a) and by VQ scan (Fig. 4b);

Fig. 5 shows a method for dividing an image of the lungs into regions; and

Fig. 6 shows regional assessment of a second subject by the method of the invention (Fig. 6a) and by VQ scan (Fig. 6b).

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a system generally indicated by 100 for performing regional assessment of the lungs in accordance with one embodiment of the invention. A plurality of $N$ sound transducers 105, of which four are shown, are applied to a planar region of the chest or back skin of individual 110. The transducers 105 may be applied to the subject by any means known in the art, for example using an
adhesive, suction, or fastening straps. Each transducer 105 produces an analog voltage signal 115 indicative of pressure waves arriving to the transducer. The analog signals 115 are digitized by a multichannel analog to digital converter 120. The digital data signals $P(x_i,t)$ 125, represent the pressure wave at the location $x_i$ of the $i$th transducer ($i=1$ to $N$) at time $t$. The data signals 125 are input to a memory 130. Data input to the memory 130 are accessed by a processor 135 configured to process the data signals 125. The signals 125 may be denoised by filtering components such as components having frequencies outside of the range of lung sounds, for example, vibrations due to movement of the individual. Each signal 125 may also be subject to band pass filtering so that only components in the signal within a range of interest are analyzed.

An input device, such as a computer keyboard 140 or mouse 145, is used to input relevant information relating to the examination such as personal details of the individual 110. The input device 140 may also be used to input values of one or more times $t_1$ and $t_2$ that specify times at which the signals $P(x_i,t)$ are to be analyzed or that specify one or more time intervals over which no signals $P(x_i,t)$ are to be analyzed. The processor 135 calculates the value of a parameter at a plurality of locations over the lungs at the specified times or over the specified time intervals. In a preferred embodiment, the processor 135 is configured to calculate an average acoustic energy $\bar{P}(x,t_1,t_2)$ over a time interval from $t_1$ to $t_2$ at a plurality of locations $x$ in the region $R$ in a calculation involving at least one of the signals $P(x_i,t)$.

The locations at which the parameter was calculated are divided into groups, where each group overlies a region of the lungs. The processor 135 is further configured to perform a regional assessment of the lungs. The regional assessment comprises for each of the groups determining the value of one or more regional parameters where each regional parameter is obtained in a calculation involving the parameter values calculated at the location in the region. For example, a regional parameter may be the sum of the parameters in the region, the maximum of the
parameter value, the minimum or the average. The regional parameter values may be normalized by dividing the regional parameter by the sum of the regional parameter values.

Fig. 2 shows a flow chart diagram for carrying out the method of the invention in accordance with a preferred embodiment. In step 200 the signals $P(x_i, t)$ are obtained from N transducers placed at predetermined locations $x_i$ for i from 1 to N overlying the lungs. In step 205 values of one or more times are either input to the processor 135 using the input devices 140 or 145, or are determined by the processor. In step 210, a value of a parameter is determined at a plurality of locations $x$ at the one or more input times or over one or more intervals. In step 220 a regional parameter is calculated in each of two or more predetermined lung regions. In step 225, the total of the regional parameters is calculated. In step 230, for each region, the regional parameters are normalized by dividing them by the calculated total to generate the regional assessment of the region. In step 240, an image of the lungs is displayed on the display 150 in which the lungs are divided into the predetermined lung regions, and the normalized or non-normalized regional parameter for each region is displayed in the region in the image. The regional assessment is the total average acoustic energy in the region over the time interval or the total acoustic energy of the region divided by the total acoustic energy of the lungs.

In a most preferred embodiment of the invention, an image of the lungs is generated from the average acoustic energies obtained over a time interval. US Patent No. 6,887,208 to Kushnir et al. discloses generating an image of the lungs from average acoustic energies calculated at a plurality of locations over the lungs. The image of the lungs is displayed on a display monitor with the lungs in the image being divided into the lung regions.

It will also be understood that the system according to the invention may be a suitably programmed computer. Likewise, the invention contemplates a computer program being readable by a computer for executing the method of the invention. The invention further contemplates a machine-readable memory tangibly
embodying a program of instructions executable by the machine for executing the
method of the invention.

Examples

Two subjects were subjected to regional assessment of lung function by VQ
scan and by the method of the invention. The first subject was a 35 year old male
having a BMI (body weight to height squared) of 26 who never smoked. The
second subject was a 71 year old male having a BMI of 30 who quite smoking five
years prior to undergoing regional assessment of lung function. The second subject
had a PIY (packs of cigarettes smoked per day times the number of years of
smoking) of 150

For the regional assessment carried out by the method of the invention, a
two-dimensional coordinate system was defined on the subject’s back. As shown in
Fig. 3a, 48 transducers were placed on the individual’s back over the lungs at the
locations indicated by the circles 300. The curves 305 show the presumed contours
of the lungs. As can be seen, the transducers were arranged in a regular orthogonal
lattice with a spacing between the transducers in the horizontal and vertical
directions of 5 cm. The signals $P(x, t)$ were then recorded. Each signal was filtered
using a low-pass filter having a cut-off of 150Hz. The average value of each
filtered function $P(x, t)$ over the respiratory cycle is indicated in Fig. 3a by means
of gray level shading of each circle 300 with reference to the gray level scale 310.
$\bar{P}(x, t_1, t_2)$ was obtained using Equations (1) and (2) above with the kernel $g$ of
Equation (5) with $\sigma=36$ pixels.

Fig. 4a shows an image 500 of the lungs obtained by the method of US
Patent No. 6,887,208 on the first subject. The image is a two-dimensional array of
pixels $x(i, j)$, where $x(i, j)$ is the gray value or other intensity value at the pixel $(i, j)$,
where $i$ and $j$ are the column number and row number respectively of the pixel. The
image 500 was divided into six regions using the algorithm shown in the flow chart
diagram depicted in Fig. 5. In step 400 the intensity values in each column $i$ are
summed to yield column sums $A_i = \sum_j x(i, j)$. The graph 501 of the function $A_i$ is
shown in Fig. 4a. The function $A_i$ has a local minimum $502$ that identifies the boundary between the left lung $504$ and the right lung $506$ in the image $500$. In step $402$ a vertical line $508$ is introduced into the image at the boundary between the left and right lungs $504$ and $506$, respectively.

In step $404$ the rows of the image in the right lung are summed to yield row sums $B_j = \sum_{i \in \text{right lung}} x(i, j)$. The graph $511$ of the function $B_j$ is shown in the image $500$ adjacent to the right lung $506$. The top of the right lung is identified in step $406$ as the highest row $j$ for which $B_j$ exceeds a predetermined threshold value. A horizontal line $510$ is then introduced into the image $500$ at the top of the right lung in step $408$. The bottom of the right lung is identified in step $410$ at the lowest row $j$ for which $B_j$ exceeds a predetermined threshold value. A horizontal line $512$ is then introduced into the image at the bottom of the right lung in step $410$.

In step $412$, the rows of the image in the left lung are summed to yield row sums $C_j = \sum_{i \in \text{left lung}} x(i, j)$. The graph $513$ of the function $C_j$ is shown in the image $500$ adjacent to the left lung $504$. The top of the left lung is identified in step $414$ at the highest row $j$ for which $C_j$ exceeds a predetermined threshold value. A horizontal line $514$ is then introduced into the image at the top of the left lung in step $416$. The bottom of the left lung is identified in step $418$ at the lowest row $j$ for which $C_j$ exceeds a predetermined threshold value. A horizontal line $516$ is then introduced into the image at the bottom of the left lung in step $420$.

In step $422$ the height of the right lung is calculated as the number of pixel rows in the image between the top and bottom of the right lung. In step $424$, the height of the right lung is divided by 3 and in step $426$, horizontal lines $520$ and $522$ are introduced into the image $500$ so as to divide the right lung in the image into three regions, the right top $\text{RT}$, right middle $\text{RM}$ and right bottom $\text{RB}$ of equal height.
In step 428, the height of the left lung is calculated as the number of pixel rows in the image between the top and bottom in the left lung. In step 430, the height of the left lung is divided by 3, and in step 432, horizontal lines 524 and 526 are introduced into the image so as to divide the left lung in the image into three regions the left top LT, left middle LM, and left bottom LB of equal height.

Now that the lungs in the image 500 have been divided into the six regions RT, RM, RB, LT, LM, and LB, the intensities of the pixels in each region are summed in step 434. The sum for each region is a value of a regional assessment parameter for the region. In the case that the pixel intensities are calculated as disclosed in US Patent No. 6,887,208, the regional assessment that is obtained is indicative of the airflow in each region of the lungs.

Fig. 4b shows the regional assessment of the same individual determined by VQ scan. The image was divided into 6 regions and the fraction of radioactivity in each region was calculated, as is known in the art. The regional assessment of each region is shown in the region.

Fig. 6a shows the regional assessment obtained on the second subject by the method of the invention, and Fig. 6b shows the regional assessment obtained on the second subject by VQ scan.
CLAIMS:
1. A system for regional assessment in two or more regions of an individual's lungs comprising:
   (a) a plurality of \( N \) transducers, each transducer configured to be fixed on a surface of the individual over the thorax, the \( i \)th transducer being fixed at a location \( x_i \) and generating a signal \( P(x_i, t) \) indicative of pressure waves at the location \( x_i \); for \( i=1 \) to \( N \); and
   (b) a processor configured to receive the signals \( P(x_i, t) \) and determine a value of a parameter in each of the regions in a calculation involving one or more of the signals \( P(x_i, t) \)
2. The system according to Claim 1 wherein the parameter is a total average acoustic energy of the region over a time interval from a first time \( t_1 \) to a second time \( t_2 \).
3. The system according to Claim 1 wherein the parameter is a total acoustic energy of the region over a time interval from a first time \( t_1 \) to a second time \( t \) divided by a total average acoustic energy of the lungs over the same time interval.
4. The system according to Claim 3 further comprising a two-dimensional display device.
5. The system according to Claim 3 wherein the processor is further configured to display an image of the lungs divided into the regions and the regional assessments of the regions.
6. The system according to Claim 5 wherein the image is obtained in a calculation involving the signals \( P(x_i, t) \).
7. The system according to Claim 6 wherein the image is obtained in a calculation involving the average acoustic energies \( \bar{P}(x_i, t_1, t_2) \) obtained at locations \( x \) over the lungs over a time interval from a first time \( t_1 \) to a second time \( t_2 \).
8. The system according to Claim 2 wherein the average acoustic energy \( \bar{P} \) over a time interval from \( t_1 \) to \( t_2 \) is determined at a location \( x_i \) of a transducer using the algebraic expression:

\[
\bar{P}(x_i, t_1, t_2) = \int_{t_1}^{t_2} P^2(x_i, t) \, dt.
\]

9. The system according to Claim 2 wherein the average acoustic energy \( \bar{P} \) is determined at one or more locations \( x \) in an algorithm comprising:
   
   (a) determining an average acoustic energy \( \bar{P}(x_i, t_1, t_2) \) over a time interval from \( t_1 \) to \( t_2 \) at a plurality of locations \( x_i \) of transducers; and
   
   (b) determining an average acoustic energy \( \bar{P}(x_i, t_1, t_2) \) at at least one location \( x \) by interpolation of the determined \( \bar{P}(x_i, t_1, t_2) \).

10. The system according to Claim 8 wherein an average acoustic energy \( \bar{P}(x_i, t_1, t_2) \) is determined over a time interval from \( t_1 \) to \( t_2 \) at a plurality of locations \( x_i \) of transducers using the algebraic expression:

\[
\bar{P}(x_i, t_1, t_2) = \int_{t_1}^{t_2} P^2(x_i, t) \, dt.
\]

11. The system according to Claim 8 wherein an average acoustic energy is determined at at least one location \( x \) by interpolation of the determined \( \bar{P}(x_i, t_1, t_2) \) using the algebraic expression:

\[
\bar{P}(x, t_1, t_2) = \sum_{i=1}^{N} \bar{P}(x_i, t_1, t_2) g(x, x_i, \sigma)
\]

where \( g(x, x_i, \sigma) \) is a kernel satisfying

\[
\nabla^2 g = \frac{\partial g}{\partial \sigma}
\]

\[
\sum_{i=1}^{N} g(x, x_i, \sigma) \text{ is approximately equal to } 1.
\]
12. The system according to Claim 10 wherein \( g(x, y, \sigma) \) is the kernel
\[
g(x, x', \sigma) = \exp - \left( \frac{(x' - x)^2}{2\sigma} \right) \cdot \exp - \left( \frac{(x^2 - x'^2)^2}{2\sigma} \right).
\] (5)

13. The system according to Claim 2 wherein the processor is configured to perform a regional assessment of the lungs over a plurality of time intervals, each regional assessment being determined using an algorithm involving at least one of the signals \( P(x_i, t) \).

14. A method for regional assessment in two or more regions of an individual's lungs comprising:
   
   (a) obtaining \( N \) signals \( P(x_i, t) \) indicative of pressure waves at the location \( x_i \) for \( i=1 \) to \( N \); and
   
   (b) determining a value of a parameter in each of the regions in a calculation involving one or more of the signals \( P(x_i, t) \).

15. The method according to Claim 13 wherein the parameter is a total average acoustic energy of the region over a time interval from a first time \( t_1 \) to a second time \( t_2 \).

16. The method according to Claim 13 wherein the parameter is a total acoustic energy of the region over a time interval from a first time \( t_1 \) to a second time \( t_2 \) divided by a total average acoustic energy of the lungs over the same time interval.

17. The method according to Claim 15 further comprising a two-dimensional display device.

18. The method according to Claim 15 wherein the processor is further configured to display an image of the lungs divided into the regions and the regional assessments of the regions.

19. The method according to Claim 17 wherein the image is obtained in a calculation involving the signals \( P(x_i, t) \).
20. The method according to Claim 18 wherein the image is obtained in a calculation involving the average acoustic energies $\bar{P}(x_i,t_1,t_2)$ obtained at locations $x$ over the lungs over a time interval from a first time $t_1$ to a second time $t_2$.

21. The method according to Claim 14 wherein the average acoustic energy $\bar{P}$ over a time interval from $t_1$ to $t_2$ is determined at a location $x_i$ of a transducer using the algebraic expression:

$$\bar{P}(x_i,t_1,t_2) = \int_{t_1}^{t_2} \int P^2(x_i,t)dt.$$

22. The method according to Claim 14 wherein the average acoustic energy $\bar{P}$ is determined at one or more locations $x$ in an algorithm comprising:

(a) determining an average acoustic energy $\bar{P}(x_i,t_1,t_2)$ over a time interval from $t_1$ to $t_2$ at a plurality of locations $x_i$ of transducers; and

(b) determining an average acoustic energy $\bar{P}(x_i,t_1,t_2)$ at at least one location $x$ by interpolation of the determined $\bar{P}(x_i,t_1,t_2)$.

23. The method according to Claim 20 wherein an average acoustic energy $\bar{P}(x_i,t_1,t_2)$ is determined over a time interval from $t_1$ to $t_2$ at a plurality of locations $x_i$ of transducers using the algebraic expression:

$$\bar{P}(x_i,t_1,t_2) = \int_{t_1}^{t_2} \int P^2(x_i,t)dt.$$

24. The method according to Claim 20 wherein an average acoustic energy is determined at at least one location $x$ by interpolation of the determined $\bar{P}(x_i,t_1,t_2)$ using the algebraic expression:

$$\bar{P}(x,t_1,t_2) = \sum_{i=1}^{N} \bar{P}(x_i,t_1,t_2)g(x,x_i,\sigma)$$

(2)

where $g(x,x_i,\sigma)$ is a kernel satisfying
\[ \nabla^2 g = \frac{\partial g}{\partial \sigma} \]  \hspace{1cm} (3)

\[ \sum_{i=1}^{n} g(x, x_i, \sigma) \] is approximately equal to 1.  \hspace{1cm} (4)

25. The method according to Claim 22 wherein \( g(x, y, \sigma) \) is the kernel

\[ g(x, x_i, \sigma) = \text{Exp} \left( - \frac{(x^2 - x_i^2)^2}{2\sigma^2} \right) \cdot \text{Exp} \left( - \frac{(x^1 - x_i^1)^2}{2\sigma^2} \right) \]  \hspace{1cm} (5)

26. The method according to Claim 14 wherein the processor is configured to perform a regional assessment of the lungs over a plurality of time intervals, each regional assessment being determined using an algorithm involving at least one of the signals \( P(x_i, t) \).

27. A computer program product comprising a computer useable medium having computer readable program code embodied therein for regional assessment in two or more regions of an individual's lungs the computer program product comprising:

- computer readable program code for causing the computer to determine a value of a parameter in each of the regions in a calculation involving one or more signals \( P(x, t) \) indicative of pressure waves at locations \( x_i \) for \( i=1 \) to \( N \).
START

1. Obtain signals $P(x_i,t)$

2. Input or determine times

3. Calculate value of parameter at locations $x$

4. Calculate regional parameter in each region

5. Normalize regional parameter

6. Display image of lungs

END

FIG. 2
LUNGS PERF.

L1 = 21.7%
L2 = 55.8%
L3 = 22.5%
R1 = 22.1%
R2 = 55.4%
R3 = 22.5%

TOTAL COUNT:
POST VIEW: LEFT 264879 RIGHT 97777.0
ANT. VIEW: LEFT 109668 RIGHT 236383

GEOMETRIC AVERAGE COUNT:
LEFT 260596 RIGHT 103552

FUNCTION:
LEFT 71.6% RIGHT 28.4%

FIG. 4b

START

SUM COLUMNS IN IMAGE 400

INTRODUCE VERTICAL LINE 508 402

SUM ROWS IN RIGHT LUNG 404

IDENTIFY TOP OF RIGHT LUNG 406

INTRODUCE HORIZONTAL LINE 510 408

a

TO FIG.5 (END)

FIG. 5 (BEGINNING)
FROM FIG. 5 (BEGINING)

a

IDENTIFY TOP OF RIGHT LUNG 410

INTRODUCE HORIZONTAL LINE 512 412

SUM ROWS IN LEFT LUNG 414

IDENTIFY TOP OF LEFT LUNG 416

INTRODUCE HORIZONTAL LINE 514 418

IDENTIFY BOTTOM OF LEFT LUNG 420

INTRODUCE HORIZONTAL LINE 516 422

CALCULATE HEIGHT OF RIGHT LUNG 424

DIVIDE HEIGHT OF RIGHT LUNG BY 3 426

INTRODUCE HORIZONTAL LINES 520 AND 522 428

CALCULATE HEIGHT OF LEFT LUNG 430

DIVIDE HEIGHT OF LEFT LUNG BY 3 432

INTRODUCE HORIZONTAL LINES 524 AND 526 434

SUM PIXELS IN EACH REGION 436

INTRODUCE REGIONAL ASSESSMENTS INTO IMAGE 438

END

FIG. 5 (END)
FIG. 6a

FIG. 6b