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(54) **STRAIN RATE ANALYSIS IN ULTRASONIC DIAGNOSTIC IMAGES**

DEHNUNGSRATENANALYSE IN DIAGNOSTISCHEN ULTRASCHALLBILDERN

ANALYSE DE LA VITESSE DE DILATATION DANS DES IMAGES DIAGNOSTIQUES
ULTRASONORES

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- **COHEN L D ET AL: "Cardiac wall tracking using Doppler tissue imaging (DTI)" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON IMAGE PROCESSING (ICIP) LAUSANNE, SEPT. 16 - 19, 1996, NEW YORK, IEEE, US, vol. 1, 16 September 1996 (1996-09-16), pages 295-298, XP010202389 ISBN: 0-7803-3259-8**

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Description

[0001] This invention relates to ultrasonic diagnostic imaging systems and, in particular, to ultrasonic diagnostic imaging systems which automatically perform strain rate analysis within an ultrasonic image.

[0002] Many ultrasonic diagnostic procedures in which bodily functions and structures are quantified rely upon clear delineation and definition of the body structures and organs which are being measured. When the quantification or measurement procedure uses static images or a small set of measurements, the delineation of the bodily structure being measured can be done manually. An example of such a procedure is the obstetrical measurements of a developing fetus. Static images of the developing fetus can be acquired during periods when fetal activity is low. Once an image is acquired, only a few circumference or length measurements are usually required to compute development characteristics such as gestational age and anticipated delivery date. These measurements can readily be made manually on the fetal images. Other diagnostic procedures, particularly those involving measurements of the heart and its functioning, present a further set of difficulties. The heart is always beating and hence is always in motion. As it moves, the contours of the heart constantly move and change as the organ contracts and expands. To fully assess many characteristics of cardiac function it is necessary to evaluate many and at times all of the images acquired during the heart cycle (one heartbeat), which can amount to thirty to one hundred and fifty or more images. The structure of interest such as the endocardium, epicardium or valves must then be delineated in each of these images, a painstaking, time-consuming task. Since these structures are constantly in motion, they appear slightly different in each image acquired during the cardiac cycle, and can also vary significantly from one patient to another. While applications such as obstetrical procedures would benefit from a processor which automatically delineates specific anatomy in an ultrasonic image, cardiac diagnosis would benefit even more so.

[0003] An ultrasonic cardiac diagnostic technique which has been in development for several years is a parametric imaging method known as strain rate analysis. In strain rate analysis the velocities at consecutive points along an ultrasonic beam line are differentiated to produce a measure of velocity change at points in the image. However, parameters of strain computed in this manner can be arbitrary, as the correspondence of the beam line directions and the anatomy in the image are essentially unrelated, being determined in many instances by the position in which the clinician desires to hold and orient the scanhead. Accordingly it is desirable to be able to compute strain rate parameters in a way that is related to the characteristics of the anatomy under diagnosis.

[0004] Reference is made to patent US 5,615,680 that discloses a diagnostic ultrasound system comprising an

element for detecting a velocity of motion of a tissue contained in an object at every sampling point in a section of the object and an element for creating two-dimensionally mapped data of the velocity in the section. The system further comprises an element for analysing a motion state of the tissue on the basis of local velocities falling into a plurality of local regions set on the two-dimensionally mapped data of the velocity and an element for displaying analysis results of the motion state.

[0005] Reference is also made to Document entitled "Real-time strain velocity imaging (SVI)" Ultrasonics symposium 1997. Proceedings. 1997 IEEE Toronto, ONT, CANADA 1997, NY, NY, USA, IEEE 5 October 1997, pages 1423-1426, by Heimdel A et al.

[0006] In accordance with the principles of the present invention, strain rate analysis is performed for ultrasonic images in which the spatial gradient of velocity is calculated in the direction of tissue motion as defined in claim 1. Preferably Strain rate is calculated for cardiac ultrasound images in the direction of motion which, for myocardial images, may be either in the plane of the myocardium or across the myocardium. Preferably the spatial gradient values are first determined in the direction of motion of the myocardium that is approximately parallel to the endocardial wall of the heart. Strain rate information is calculated for a sequence of images of a heart cycle and displayed for an automatically drawn border such as the endocardial border over the full heart cycle.

[0007] In the drawings:

FIGURE 1 is a four chamber ultrasound image of the heart;

FIGURE 2 illustrates an ultrasound display of both end diastole and end systole cardiac images;

FIGURES 3a and 3b illustrate the step of locating the medial mitral annulus (MMA) and the lateral mitral annulus (LMA) in an ultrasound image of the left ventricle (LV);

FIGURE 4 illustrates the step of locating the apex of the LV;

FIGURES 5a-5c illustrate standard border shapes for the LV;

FIGURES 6a-6b illustrate geometric templates used to locate the MMA and LMA;

FIGURES 7a-7c illustrate a technique for fitting a standard border shape to the endocardial boundary of the LV;

FIGURE 8 illustrates an end diastole and end systole display with endocardial borders drawn automatically in accordance with the principles of the present invention;

FIGURE 9 illustrates the rubber-banding technique for adjusting an automatically drawn border;

FIGURE 10 illustrates the selection of a cardiac cycle by viewing automatically drawn borders;

FIGURE 11 illustrates a tissue Doppler map of endocardial motion over a plurality of cardiac cycles;

Fig. 12 illustrates the use of automated border de-

tection to segment an image of the heart wall;
 Figs. 13a and 13b illustrate scorecards for scoring
 segments of the heart wall;
 Figs. 14a and 14b illustrate techniques for making
 strain rate measurements as a function of tissue mo-
 tion;
 Figs. 15a-15c illustrate 3D techniques for evaluating
 cardiac performance;
 Fig. 15d illustrates a scorecard for scoring a three
 dimensional image of the heart; and
 Fig. 16 illustrates in block diagram form an ultrasonic
 diagnostic imaging system constructed in accord-
 ance with the principles of the present invention.

[0008] Referring first to Fig. 1, an ultrasound system
 display is shown during the acquisition of cardiac images.
 The ultrasound image 10 is a four-chamber view of the
 heart which is acquired by a phased array transducer
 probe to produce the illustrated sector-shaped image.
 The image shown is one of a sequence of real-time im-
 ages acquired by placement of the probe for an apical 4-
 chamber view of the heart, in which the probe is oriented
 to view the heart from the proximity of its apex 11. The
 largest chamber in the image, in the central and upper
 right portion of the image, is the left ventricle (LV). As the
 real-time ultrasound image sequence is acquired an ECG
 trace 12 of the heart cycle is simultaneously acquired
 and displayed at the bottom of the display, with a trian-
 gular marker 14 denoting the point or phase of the cardiac
 cycle at which the currently-displayed image was ac-
 quired. A typical duration of the heart cycle when the
 body is at rest is about one second, during which time
 approximately 30-90 image frames of the heart are ac-
 quired and displayed in rapid succession. A sequence of
 image frames for a heart cycle is referred to herein as a
 "loop" of images, as a clinician will often acquire and save
 the sequence of images of a heart cycle and then replay
 them in a continuous "loop" which repetitively displays
 the selected cardiac cycle. As the clinician views the dis-
 play of Fig. 1, the heart is seen beating in real time in the
 ultrasound display as the ECG waveform 12 scrolls be-
 neath the ultrasound images 10, with the instantaneously
 displayed heart phase indicated by the marker 14.

[0009] In one mode of acquisition the clinician ob-
 serves the beating heart in real time while manipulating
 the transducer probe so that the LV is being viewed dis-
 tinctly in maximal cross-section. When the four chamber
 view is being acquired continuously and clearly, the cli-
 nician depresses the "freeze" button to retain the images
 of the current heart cycle in the image frame or Cineloop®
 memory of the ultrasound system. The Cineloop memory
 will retain all of the images in the memory at the time the
 freeze button is depressed which, depending upon the
 size of the memory, may include the loop being viewed
 at the time the button was depressed as well as images
 of a previous or subsequent loop. A typical Cineloop
 memory may hold 400 image frames, or images from
 about eight to ten heart cycles. The clinician can then

scan through the stored images with a trackball, arrow
 key, or similar control to select the loop with the images
 best suited for analysis. When the clinician settles on a
 particular loop, the "ABD" protocol is actuated to start the
 border drawing process.

[0010] When the ABD protocol is actuated the display
 changes to a dual display of the end diastole image 16
 and the end systole image 18 displayed side-by-side as
 shown in Fig. 2. The ultrasound system identifies all of
 the images comprising the selected loop by the duration
 of the ECG waveform associated with the selected loop.
 The ultrasound system also recognizes the end diastole
 and end systole points of the cardiac cycle in relation to
 the R-wave of the ECG waveform 12 and thus uses the
 ECG waveform R-wave to identify and display the ultra-
 sound images at these two phases of the heart cycle.
 The dual display of Fig. 2 shows the ECG waveform 12
 for the selected heart cycle beneath each ultrasound im-
 age, with the marker 14 indicating the end diastole and
 end systole phases at which the two displayed images
 were acquired.

[0011] Since the Cineloop memory retains all of the
 images of the cardiac cycle, the user has the option to
 review all of the images in the loop, including those pre-
 ceding and succeeding those shown in the dual display.
 For instance, the clinician can "click" on either of the im-
 ages to select it, then can manipulate the trackball or
 other control to sequentially review the images which pre-
 cede or succeed the one selected by the ultrasound sys-
 tem. Thus, the clinician can select an earlier or later end
 diastole or end systole image from those selected by the
 ultrasound system. When the clinician is satisfied with
 the displayed images 16 and 18, the ABD processor is
 actuated to automatically delineate the LV borders on
 the two displayed images as well as the intervening un-
 displayed images between end diastole and end systole.

[0012] In this example the ABD processor begins by
 drawing the endocardial border of the LV in the end sys-
 tole image 18. The first step in drawing the border of the
 LV is to locate three key landmarks in the image, the
 medial mitral annulus (MMA), the lateral mitral annulus
 (LMA), and the endocardial apex. This process begins
 by defining a search area for the MMA as shown in Fig.
 3 a, in which the ultrasound image grayscale is reversed
 from white to black for ease of illustration. Since the ABD
 processor is preconditioned in this example to analyze
 four-chamber views of the heart with the transducer 20
 viewing the heart from its apex, the processor expects
 the brightest vertical nearfield structure in the center of
 the image to be the septum which separates the left and
 right ventricles. This means that the column of pixels in
 the image with the greatest total brightness value should
 define the septum. With these cues the ABD processor
 locates the septum 22, and then defines an area in which
 the MMA should be identified. This area is defined from
 empirical knowledge of the approximate depth of the mi-
 tral valve from the transducer in an apical view of the
 heart. A search area such as that enclosed by the box

24 in Fig. 3a is defined in this manner.

[0013] A filter template defining the anticipated shape of the MMA is then cross correlated to the pixels in the MMA search area. While this template may be created from expert knowledge of the appearance of the MMA in other four-chamber images as used by Wilson et al. in their paper "Automated analysis of echocardiographic apical 4-chamber images," *Proc. of SPIE*, August, 2000, the present inventors prefer to use a geometric corner template. While a right-angle corner template may be employed, in a constructed embodiment the present inventors use an octagon corner template 28 (the lower left corner of an octagon) as their search template for the MMA, as shown at the right side of Fig. 6a. In practice, the octagon template is represented by the binary matrix shown at the left side of Fig. 6a. The ABD processor performs template matching by cross correlating different sizes of this template with the pixel data in different translations and rotations until a maximum correlation coefficient above a predetermined threshold is found. To speed up the correlation process, the template matching may initially be performed on a reduced resolution form of the image, which highlights major structures and may be produced by decimating the original image resolution. When an initial match of the template is found, the res-

olution may be progressively restored to its original quality and the location of the MMA progressively refined by template matching at each resolution level.

[0014] Once the MMA has been located a similar search is made for the location of the LMA, as shown in Fig. 3b. The small box 26 marks the location established for the MMA in the image 18, and a search area to the right of the MMA is defined as indicated by the box 34. A right corner geometric template, preferably a right octagon corner template 38 as shown in Fig. 6b, is matched by cross-correlation to the pixel values in the search area of box 34. Again, the image resolution may be decimated to speed the computational process and different template sizes may be used. The maximal correlation coefficient exceeding a predetermined threshold defines the location of the LMA.

[0015] With the MMA 26 and the LMA 36 found, the next step in the process is to determine the position of the endocardial apex, which may be determined as shown in Fig. 4. The pixel values of the upper half of the septum 22 are analyzed to identify the nominal angle of the upper half of the septum, as indicated by the broken line 43. The pixel values of the lateral wall 42 of the LV are analyzed to identify the nominal angle of the upper half of the lateral wall 42, as shown by the broken line 45. If the lateral wall angle cannot be found with confidence, the angle of the scanlines on the right side of the sector is used. The angle between the broken lines 43,45 is bisected by a line 48, and the apex is initially assumed to be located at some point on this line. With the horizontal coordinate of the apex defined by line 48, a search is made of the slope of pixel intensity changes along the line 48 to determine the vertical coordinate of the apex.

This search is made over a portion of line 48 which is at least a minimum depth and not greater than a maximum depth from the transducer probe, approximately the upper one-quarter of the length of line 48 above the mitral valve plane between the MMA 26 and the LMA 36. Lines of pixels along the line 48 and parallel thereto are examined to find the maximum positive brightness gradient from the LV chamber (where there are substantially no specular reflectors) to the heart wall (where many reflectors are located). A preferred technique for finding this gradient is illustrated in Fig. 7. Fig. 7a shows a portion of an ultrasound image including a section of the heart wall 50 represented by the brighter pixels in the image. Drawn normal to the heart wall 50 is a line 48 which, from right to left, extends from the chamber of the LV into and through the heart wall 50. If the pixel values along line 48 are plotted graphically, they would appear as shown by curve 52 in Fig. 7b, in which brighter pixels have greater pixel values. The location of the endocardium is not the peak of the curve 52, which is in the vicinity of the center of the heart wall, but relates to the sense of the slope of the curve. The slope of the curve 52 is therefore analyzed by computing the differential of the curve 52 as shown by the curve 58 in Fig. 7c. This differential curve has a peak 56 which is the maximal negative slope at the outside of the heart wall (the epicardium). The peak 54, which is the first major peak encountered when proceeding from right to left along curve 58, is the maximal positive slope which is the approximate location of the endocardium. The pixels along and parallel to line 48 in Fig. 4 are analyzed in this manner to find the endocardial wall and hence the location of the endocardial apex, marked by the small box 46 in Fig. 4.

[0016] Once these three major landmarks of the LV have been located, one of a number of predetermined standard shapes for the LV is fitted to the three landmarks and the endocardial wall. Three such standard shapes are shown in Figs. 5a, 5b, and 5c. The first shape, border 62, is seen to be relatively tall and curved to the left. The second shape, border 64, is seen to be relatively short and rounded. The third shape, border 66, is more triangular. Each of these standard shapes is scaled appropriately to fit the three landmarks 26,36,46. After an appropriately scaled standard shape is fit to the three landmarks, an analysis is made of the degree to which the shape fits the border in the echo data. This may be done, for example, by measuring the distances between the shape and the heart wall at points along the shape. Such measurements are made along paths orthogonal to the shape and extending from points along the shape. The heart wall may be detected using the operation discussed in FIGS. 7a-7c, for instance. The shape which is assessed as having the closest fit to the border to be traced, by an average of the distance measurements, for instance, is chosen as the shape used in the continuation of the protocol.

[0017] The chosen shape is then fitted to the border to be traced by "stretching" the shape, in this example,

to the endocardial wall. The stretching is done by analyzing 48 lines of pixels evenly spaced around the border and approximately normal to heart wall. The pixels along each of the 48 lines are analyzed as shown in FIGS. 7a-7c to find the adjacent endocardial wall and the chosen shape is stretched to fit the endocardial wall. The baseline between points 26 and 36 is not fit to the shape but is left as a straight line, as this is the nominal plane of the mitral valve. When the shape has been fit to points along the heart wall, the border tracing is smoothed and displayed over the end systole image as shown in the image 78 on the right side of the dual display of Fig. 8. The display includes five control points shown as X's along the border between the MMA landmark and the apex, and five control points also shown as X's along the border between the apex landmark and the LMA landmark. In this example the portion of line 48 between the apex and the mitral valve plane is also shown, as adjusted by the stretching operation.

[0018] With the end systole border drawn in this manner the ABD processor now proceeds to determine the end diastole border. It does so, not by repeating this operation on the end diastole image 16, but by finding a border on each intervening image in sequence between end systole and end diastole. In a given image sequence this may comprise 20-30 image frames. Since this is the reverse of the sequence in which the images were acquired, there will only be incremental changes in the endocardial border location from one image to the next. It is therefore to be expected that there will be a relatively high correlation between successive images. Hence, the end systole border is used as the starting location to find the border for the previous image, the border thus found for the previous image is used as the starting location to find the border for the next previous image, and so forth. In a constructed embodiment this is done by saving a small portion of the end systole image around the MMA and the LMA and using this image portion as a template to correlate and match with the immediately previous image to find the MMA and the LMA locations in the immediately previous image. The apex is located as before, by bisecting the angle between the upper portions of the septum and lateral LV wall, then locating the endocardium by the maximum slope of the brightness gradient. Since the LV is expanding when proceeding from systole to diastole, confidence measures include the displacement of the landmark points in an outward direction from frame to frame. When the three landmark points are found in a frame, the appropriately scaled standard shape is fit to the three points. Another confidence measure is distention of the standard shapes; if a drawn LV border departs too far from a standard shape, the process is aborted.

[0019] Border delineation continues in this manner until the end diastole image is processed and its endocardial border defined. The dual display then appears as shown in Fig. 8, with endocardial borders drawn on both the end diastole and end systole images 76,78.

[0020] As Fig. 8 shows, the endocardial borders of both the end diastole and end systole images have small boxes denoting the three major landmarks and control points marked by X's on the septal and lateral borders. The clinician chooses the default number of control point which will be displayed initially; on the border 80 shown in Fig. 9 there are three control points shown on the septal wall and four control points shown on the lateral wall. The clinician can review the end diastole and systole images, as well as all of the intervening images of the loop if desired, and manually adjust the positions of the landmark boxes and control point X's if it is seen that the automated process placed a border in an incorrect position. The clinician can slide a box or X along the border to a new position, and can add more control points or delete control points from the border. The process by which the clinician relocates a box or X laterally is known as rubberbanding. Suppose that the ABD processor had initially located the control point and border at the position shown by circle 82 and dashed line 84, which the clinician observes is incorrect. The clinician can relocate the control point laterally by dragging the X with a screen pointing device to the new location as shown by 86. As the X is dragged, the border moves or stretches along with the X, thereby defining a new border as shown by the solid line border 88. In this manner the clinician can manually correct and adjust the borders drawn by the ABD processor. As the clinician laterally relocates a control point X, the ABD processor responds by automatically recalculating the positions of the adjoining border and adjacent control points if necessary so that the border remains smoothly continuous. The recalculation will not adjust the position of a control point or landmark box which has been previously manually repositioned by the clinician, thereby preserving this expert input into the border drawing process. If the clinician relocates a landmark box, the ABD processor recalculates and refits the entire border to the landmarks and heart wall. Since the adjustment of one border in the image sequence can affect the borders of temporally adjacent images in the sequence, the ABD processor will also respond to a manual adjustment by correlating the adjusted border with temporally adjacent borders so that the manual adjustment is properly continuously represented in some or all of the images in the loop.

[0021] Another way to interactively adjust the drawn borders is to assemble only the border tracings in a "stack" in time sequence from ED to ES or later to form a surface defined by the borders which is viewed in three dimensions such as in a kinetic parallax display. The continuous surface formed by the borders can be assessed and adjusted as desired by a rubberbanding technique known as active surface adjustment. If the clinician sees a point on the surface formed by the borders which is out of alignment with temporally adjacent tracings or the desired border, the clinician can pull or push on the surface with a pointing device. The active surface adjustment then conforms the adjacent borders and the surface de-

fined thereby to the adjustment made by the clinician, much as a balloon conforms when depressed at a point on its surface. The clinician can thus observe the effect of an adjustment made to one border on the temporally surrounding borders of the cardiac cycle.

[0022] In a preferred embodiment the control points are not simply distributed at uniform intervals around the drawn border, but their positions correspond to constant anatomical locations from frame to frame over the heart cycle. This may be done by referencing the control points of the image to those of a reference image through speckle tracking, feature tracking, or any kind of vector velocity or displacement processing. Since points in anatomy shown in an ultrasound image will exhibit a substantially constant pattern of speckle from frame to frame, the control points in other images can be located at points on their respective drawn borders which correspond to their characteristic speckle locations on the reference image. When the control points are located at constant anatomical positions they will appear to move closer together and then further apart through the heart cycle as the heart wall contracts and expands. When a control point X is relocated on a border by the clinician, the corresponding control point X's on the other images are correspondingly relocated automatically to the new speckle-tracked locations on each image. Such constant anatomical locations for the control points are important when assessing local heart wall motion as discussed below.

[0023] Since each of the images shown in Fig. 8 is one image in the cardiac loop of images, the clinician can further verify the accuracy of the borders of the end diastole and end systole images 76,78 by playing the cardiac loop of images behind the borders drawn on the display of Fig. 8. This is done by selecting one of the images of Fig. 8, then selecting "Play" from the system menu to repetitively play the cardiac loop in real time or at a selected frame rate of display behind the border. In the end diastole image 76 the endocardium is at its maximum expansion; hence, the endocardium in the loop should appear to move inward from and then back to the endocardial border drawn on the end diastole image. In the end systole image 78 the endocardium is fully contracted; hence, the endocardium in the loop should appear to move outward and then back to the border in this image. If the endocardium does not move in this manner and, for example, is seen to pass through the border, a different image may need to be chosen for end diastole or end systole, or manual adjustment of a drawn border may be necessary. Of course, the loop and its drawn borders over the complete cardiac cycle can be replayed, enabling the clinician to view to endocardial tracing as it changes with the heart motion in real time.

[0024] As the ABD processor is identifying the key landmarks and fitting borders to the sequence of images, it is periodically making confidence measurements to gauge the likelihood that the image borders are being accurately located and traced. For instance, if the septum is not clearly contrasted from the blood pool in the LV

chamber, the automated process will stop. If the various correlation coefficients do not exceed predetermined thresholds the process will stop. Both spatial and temporal confidence measurements are employed. For instance, if the computed border of an image varies too much from a standard shape in either size or shape, the process will abort. This can arise if the landmarks are located in unusual positions in relation to each other, for example. If the change in the computed border from one image in the sequence to another is too great, the process will likewise abort. When the process stops, a message is displayed notifying the clinician of the reason for stopping the process, and gives the clinician the option to continue the automated process, to continue the automated process with or after clinician input, or for the clinician to acquire a new loop of images or manually trace the current images.

[0025] In the illustrated example of Fig. 8 the automatically drawn borders of the end diastole and end systole images are used to compute the heart's ejection fraction. This is done by an automatic modified Simpson's rule process which divides the delineated heart chamber at each phase into a stack of virtual disks. The diameter of each disk is used with the disk height to compute an effective volume of each disk, and these volumes are summed to compute the heart chamber volume at both end diastole and end systole. The difference between the two yields the ejection fraction, the volume or percentage of the heart volume which is expelled as pumped blood during each heart cycle. The ejection fraction calculation is shown in the measurement box at the lower left hand corner of Fig. 8 and is constantly updated. Thus, if the clinician should adjust a drawn border by the rubberbanding technique, the computed volume of the heart during that phase will change, affecting the ejection fraction calculation, and the new calculation immediately appears in the measurement box. As the clinician adjusts the drawn borders he instantaneously sees the effects of these changes on the calculation of the ejection fraction.

[0026] In the previous example the clinician began by acquiring a cardiac loop on which to automatically trace borders. Fig. 10 shows an ultrasound image display in which a loop is acquired based upon the ability of the ABD processor to automatically draw borders on the images. In the illustrated display the real time ultrasound image 10 is continuously viewed as in Fig. 1 as the clinician manipulates the transducer probe to acquire the desired four chamber view of the heart. As the clinician manipulates the probe the ABD processor is operative to attempt to draw borders on at least one of the images of each cardiac cycle. Using the R-wave timing of the ECG trace 12, the ultrasound system automatically selects the image or images to be traced from each loop. The selected image could be the first image of a cardiac cycle, the end diastole image, or the end systole image, for instance. As the ABD processor attempts to draw borders on the fly on the selected images of the real time

loops, the results of the ABD process for an image of each loop is shown as a small "thumbnail" image 92-98 below the real time image 10. In the illustrated example four thumbnail images are shown for four consecutive loops. Each time a new thumbnail is processed by the ABD processor it appears at the right side of the row of thumbnail images, the oldest thumbnail image disappears, and the row slides to the left. Initially the clinician may not be acquiring the heart in an orientation which is acceptable for the ABD process, at which time the progression of thumbnail images will show no borders as the ABD processor is unable to successfully draw borders on the images. But as the clinician manipulates the probe to acquire the necessary viewing plane for successful ABD performance and the images are acquired with better clarity and definition, borders will appear on the progression of thumbnail images as shown in the drawing Fig.. When the clinician is holding the probe at the necessary angulation relative to the heart so that the ABD process is continuously successful, the progression of thumbnail images will continuously show successfully drawn borders. The clinician will then freeze the acquisition to capture one or more of the successfully traced loops in the Cineloop memory, and will then select one of the loops for full ABD processing and display as described above. Thus, the ABD processor is used to assist the clinician in manipulating the probe for successful image acquisition and in acquiring loops which can be successfully processed for border definition by the ABD processor.

[0027] Another way to indicate to the clinician that acceptable images for ABD processing are being acquired is by means of a graphical ABD success indicator. Such an indicator may be qualitative, quantitative, or both, as is the example shown in Fig. 10. At the right of the display of Fig. 10 is a gauge 110 which is quantified from zero to 100%. When the clinician is acquiring images which are unsuitable for ABD processing, the gauge 110 is empty. But as suitable images begin to be acquired, a color bar 112 begins to rise from the bottom of the gauge. The quantization of the gauge indicates either the percentage of borders which were attempted and successfully drawn, or the changes in overall confidence measures as discussed above. In the drawing a green bar is at the 80% level, indicating that the ABD processor was able to successfully process 80% of the images attempted over a recent interval such as the last few heart cycles, or that the borders drawn achieved an 80% confidence level of accuracy.

[0028] A third way to indicate ABD success to the clinician is to present drawn borders in real time on the real time images 10. The ABD processor can attempt to draw a border on a single image for each heart cycle, such as the end systole image, and the successfully drawn border is displayed over the real time image for the duration of that heart cycle until the time of the next end systole image. Alternatively, if sufficient processing speed is available, borders are calculated and displayed for every im-

age in the heart cycle. In either case, the drawn border will not appear or will flicker on and off when unsuitable or marginal cardiac images are being acquired, but will constantly appear when a succession of suitable images is being acquired, at which time the clinician knows that the probe is oriented to acquire good four chamber views for ABD processing.

[0029] In addition to the LV of four chamber views, the ABD processor of the present invention can also define borders in other types of ultrasound images. Short axis views can be processed for automatic border definition, in which case the landmarks used can be the annulus or the outflow track. Alternatively, the center of the heart chamber can be found from its contrast with the surrounding heart wall, then the desired border located by radial extension and fitting of a circular standard shape. The walls of blood vessels such as the carotid artery can similarly be traced by identifying the center line of the vessel, then extending straight line shapes out from opposite sides of the center line to fit small line segments to the endothelial wall. Fetal anatomy such as the fetal cranium can also be automatically traced by use of an elliptical shape.

[0030] With the ability to automatically draw borders of structures of the heart such as the endocardium on a complete loop of images, a number of diagnostic techniques become practical. For instance, Fig. 11 illustrates a technique for assessing regional wall motion using automated border detection. The drawing of Fig. 11 represents an ultrasound display in which the continuous motion of the endocardium or myocardium is shown over several complete heart cycles. The ABD processor is operated as described above to draw a trace along the endocardial border or continuously through the myocardium of the images of one or more loops. The latter is performed by tracing the endocardial border as described above, then drawing a curve parallel to and slightly larger than the endocardial border curve. Such a curve will reliably pass continuously through the heart muscle. The border 100 for one such image is shown at the left side of the drawing, with the landmark points and control points numbered from one to eight in sequence around the border. For analysis of wall motion the image points beneath the border are Doppler processed to determine the velocity, Doppler power or variance along the defined border. Thus, a tissue Doppler image line is computed along the endocardium or myocardium at locations defined by the automatically drawn border. This Doppler processing is performed for the defined border of each image in the loop or loops. The Doppler processed information from the moving tissue may be fundamental frequency signals or harmonic frequency signals which can be processed as described in U.S. patent 6,036,643. The lines of Doppler values for all of the images are displayed in straight vertical lines as shown at the right side of Fig. 11 as indicated by the vertical sequence of numbers 1-8. The lines are arrayed sequentially adjacent to each other in the time sequence of the images. The Doppler values

are preferably displayed in color, thus forming a color M-mode display area 102. The display in area 102 may be referred to as an ABD-TDI (ABD with tissue Doppler imaging) display. In the illustrated display the color Doppler lines for the first loop are arrayed across the area indicated by bracket L1, the color Doppler lines for the next loop are arrayed across the area indicated by bracket L2, and the color Doppler lines for the third loop are arrayed across the area indicated by bracket L3, and so on. As the arrow at the bottom of the display area 102 indicates, the Doppler lines progress in time in the horizontal direction. This display 102 thus shows in a continuum over the heart cycle the motion of the LV myocardium. This display enables the clinician to follow the motion of one point or region of the heart wall over a full cardiac cycle by observing a horizontal row of the display. For instance, the heart wall at the apex of the heart is marked by 5 at the left of the area 102, corresponding to the apex landmark 5 on the border 100. By viewing the Doppler data (colors) to the right of 5 in area 102 the clinician is able to see the velocity or change in velocity or intensity of motion of the heart wall at the apex of the heart as it varies over the complete heart cycle or cycles. If a region of the wall is not moving due to infarction or some other defect, it can be spotted by a change or difference in color at a particular horizontal elevation in the ABD-TDI display.

[0031] It will be appreciated that, since the LV heart wall is constantly expanding and contracting as the heart beats, the length of the line 100 from the MMA, around the apex, and back to the LMA is constantly changing in correspondence. If the control points are simply delineated in even spacings around the line 100, they may not continuously correspond to the same points of the heart wall through the full heart cycle. This is overcome by tracking the anatomy from a baseline of control points over the heart cycle, as by speckle tracking each local point of the heart wall along the ABD trace from frame to frame, as described above. The different length lines are rescaled or normalized to a common length so that a horizontal line extended to the right from each number at the left of the display 102 will relate to the same point or region of the heart wall over the continuum of tissue Doppler lines.

[0032] An ABD-TDI display may also be formed from short axis images of the heart. In short axis views the heart wall exhibits a ring shape. As described previously, the endocardium can be traced automatically for each frame of the cardiac cycle and a parallel, slightly larger circle than the tracing can be drawn through the myocardial muscle in the images. Doppler values are acquired around each of these circles, which are displayed in a continuum of lines in the format shown in area 102 of Fig. 11. Thus, the display format 102 may be used for either short or long axis views of the heart.

[0033] Another application for automatically drawn cardiac borders is shown in Fig. 12. In this illustration the border 300 represents the endocardial border defined by

automated border detection as described above, with a line 306 for the mitral valve plane at the bottom. A second, slightly larger border 302 is drawn around the first border 300. This second border may be an ABD-produced border of the epicardium, or it may be a trace spaced by a predetermined lateral distance d normal to the endocardial border 300. In this latter case, the trace 302 can pass continuously through the myocardium. Thus, Doppler values along the trace 302 would yield motional measures taken in a central portion of the heart muscle. The space between the two traces can be divided into small areas 304 and the Doppler values within each area integrated to produce a measure of regional wall motion at a particular location on the LV wall. These measures are made using ABD processing of many or all of the images of the cardiac loop to quickly and accurately provide quantified measures of cardiac performance over most or all of the cardiac cycle.

[0034] The measurements made from the areas 304 can be used to automatically fill out an anatomically corresponding scorecard for cardiac performance. For example, Fig. 13a shows a graphical representation 310 of the LV in a 4-chamber view, with the myocardium divided into numbered areas. The region numbered 6 on the anatomical scorecard 310 corresponds to the small areas 304a-304d which were defined by automatically drawn borders. The measurements taken in these areas 304a-304d can be aggregated and used to automatically place a score on the scorecard 310 for region 6, which may be numerical or qualitative, for example, a coded color. The score can be a peak or average value measured for one phase of the heart cycle or taken over all the frames of the full heart cycle. Fig. 13b illustrates a similar anatomical scorecard 312 for a short axis view of the heart, which may be used to score images with automatically drawn borders acquired from that view. A scorecard may be filled in for just a single image frame, for a group of image frames taken together, or a scorecard may be completed for each frame of a cardiac sequence. In the latter case, color coded scorecards can be played in rapid succession in a real time (or slower or faster) loop of images of the scorecards, enabling the clinician to view the time variation of a region of the heart in a segment of the scorecard which is stationary on the display screen from frame to frame.

[0035] Automatically drawn cardiac borders may also be used to define the myocardial area in contrast-enhanced images or loops. The addition of a contrast agent to the cardiac imaging exam allows the physician to assess how well the heart muscle is being perfused with blood. Automatically computed borders may be used as input into a variety of perfusion quantification algorithms. Automatically drawn cardiac borders and perfusion information presented simultaneously in an image or loop is a powerful combination since the clinician can assess wall motion, thickening, and perfusion simultaneously. Given that the borders are known, the thickness of the myocardial walls between the endocardial and epicardial

edges can be determined on a segment-by-segment basis as shown in Fig. 12. Perfusion information quantified by an independent algorithm may also be displayed side-by-side with the quantitative wall thickening information. Quantitative perfusion information and wall thickening may also be parametrically combined and presented on a segment-by-segment basis in a color coded display for Doppler and wall motion integration.

[0036] Another diagnostic technique made practical by automatic border detection is strain rate analysis of cardiac performance. The strain rate is a measurement computed as the axial derivative of the velocity of the tissue, and can lead to a representation of the relative deformation of the tissue during contraction or expansion. The conventional way to compute strain rate in an ultrasound image is to find Doppler velocity values along the ultrasound beams, then to compute the spatial gradient as a derivative using successive velocity values along the beam. This spatial gradient of velocity is thus strongly dependent upon the variable relationship between the beam directions and the anatomy in the image, which means that the strain rate values can change as the probe is moved. The present inventors prefer to use a strain rate calculation which is dependent upon the direction of tissue motion rather than an arbitrary beam direction. Accordingly the present inventors calculate strain rate in the direction of the velocity vector of tissue motion. In order to do this it is necessary to have not only velocity values for the tissue pixels in an image but also the direction or vectorial component of the motion, which can be obtained by known vector Doppler techniques. The differential between adjacent pixels in the direction of motion is then computed as the strain rate. The strain rate can be computed from fundamental frequency echo information, or from harmonic frequency signals which can be more clutter-free than the fundamental frequency signals.

[0037] Fig. 14a shows two traces which have been automatically drawn over the borders of a 4-chamber view of the LV. The border 250 is drawn to define the endocardium and the border 252 has been drawn to define the epicardium of the LV. A third trace 260 is automatically drawn between the endocardial and epicardial borders. This third trace 260 will reliably pass continuously through the myocardium. These traces enable the strain rate to be computed for the two major components of motion of the LV. One of these components is the contraction and expansion of adjoining cells in the heart muscle. This motion is generally along the direction of the trace 260. A strain rate representation of this cellular motion can be found by differentiating the velocity values of successive points A-A' along trace 260 as shown in the drawing. The overall motion of the heart chamber as the muscle cells contract and expand is toward and away from the center of the heart chamber. A strain rate representation of this second motional component is computed by differentiating velocities in a direction normal to the drawn borders such as at points B-B' across the heart

muscle. The strain rate so calculated along the myocardium is preferably displayed in a color-coded representation. A similar set of strain rate measurements can be made using borders 270 (endocardium) 272 (epicardium) and trace 280 (myocardium) drawn on short axis views of the heart such as that shown in Fig. 14b. In that drawing muscle cell contraction and expansion is used to compute strain rate in the circumferential direction such as would be computed from the velocities at points A-A' in the image. Radial components of expansion and contraction are represented in a strain rate display by differentiating in the radial direction such as by using the velocities at points B-B', C-C', and D-D'. The strain rate over the full cardiac cycle can be displayed by computing the strain rate around the entire border for each frame in the cardiac cycle, then displaying the strain for each frame as a vertical line in a time sequence of lines as shown by display 102 in Fig. 11.

[0038] Figs. 15a and 15b illustrate the use of automated border detection in three dimensional imaging. The previous examples have shown how borders can be automatically drawn on two dimensional cardiac images. The technique described above is effective for defining the borders of three dimensional cardiac images also. If a three dimensional cardiac image is produced by acquiring a series of spatially adjacent 2D image planes of the heart, the ABD process described above can be performed on each component frame to define a series of boundaries which together define a surface of the heart such as the endocardial surface. If the three dimensional cardiac image is produced from ultrasonic beams steered in three dimensions to scan the heart three dimensionally in real time as described in U.S. patent US 6, 468, 216 entitled "ULTRASONIC DIAGNOSTIC IMAGING OF THE CORONARY ARTERIES," the resulting three dimensional data set can be divided into a series of parallel planes which are processed as described above to define a series of planar borders which can be assembled to provide a boundary such as the heart wall. Preferably the three dimensional data set is processed three dimensionally, in which case advantage is taken of the contiguous nature of the heart wall in three dimensions in the data set to more reliably define the three dimensional border. In either case, the resultant three dimensional border of the LV endocardium may appear as shown in Fig. 15a, a somewhat elongated pouch-like surface which is closed at the apex end A and open at the mitral valve plane A'. Fig. 15a represents the three dimensional endocardial surface traced at one phase of the heart cycle. In each 3D image of a 3D cardiac loop the endocardial surface will be slightly different as the LV continuously contracts and expands during the heart cycle. Thus a different border surface 200 can be computed for each three dimensional image in the loop. Since the speed of sound may not enable the ultrasonic data for a full 3D image to be acquired at the desired 3D frame rate, the 3D images may be built up over time by using a heart gate triggered from the ECG waveform to acquire the

data for a portion of a 3D image at specific phases of the heart over numerous cardiac cycles until the full data set necessary to produce 3D images of the desired temporal spacing over the entire heart cycle is acquired.

[0039] The 3D image of the endocardium in Fig. 15a can be produced by Doppler processing, thereby revealing the velocity, variance, or Doppler power at each point on the LV wall by rotating and examining the endocardial tissue Doppler surface 200. Another way to view the Doppler information for the entire endocardium is to "unwrap" the tissue Doppler surface 200 to a two dimensional form as shown in Fig. 15b. In this illustration the apex is located at A and the mitral valve plane extends along the bottom edge between A' and A'. In this display the clinician can examine the motion of the entire endocardium in one view. Such a display shows motion at only one phase of the heart cycle, the phase indicated by cursor 14 below the ECG waveform 12 of the display, and thus it is desirable to unwrap all of the endocardial surfaces from all of the 3D images of the heart cycle and arrange them in a "stack" so that the clinician can view them sequentially in any order. If the clinician spots a motional abnormality on one of the unwrapped images, such as in the area denoted by box 202, she can focus in on this cardiac wall location where the abnormality is seen. She can then scan through the stack of images in the box 202 in either temporal order to examine the abnormality in greater detail over the full heart cycle. Alternately, the clinician can draw a line through the abnormality in box 202, then display the tissue Doppler values along that line from all the images in the sequence in an ABD-TDI display 102 as described above.

[0040] If real time 3D imaAng capability is not available, a 3D diagnosis can still be performed by acquiring multiple image planes of a chamber of the heart at different orientations, which are then processed by automatic border detection. An ultrasound system which acquires ultrasound information from only selected planes of an organ of the body is which acquires ultrasound information from only selected planes of an organ of the body is described in U.S. Patent U.S. 6, 443, 896, entitled "METHOD OF CREATING MULTIPLANAR ULTRASONIC IMAGES OF A THREE DIMENSIONAL OBJECT." Fig. 15c is an illustration of the endocardial border 200 viewed from the apex A in the center of the drawing, which is how the heart may be viewed by a transducer probe placed for an apical view as described above. With the probe so located, ultrasound information is acquired from three planes which pass through the heart chamber, labeled 204, 206 and 208 in the drawing. In this drawing the planes are viewed edge-on, and in this example the three planes intersect in the vicinity of the apex of the LV. The ultrasound information from the three planes may be acquired at a particular phase of the heart cycle chosen by and ECG heart gate, or over the full cardiac cycle which may also be assisted by ECG gated acquisition over a number of cardiac cycles. The LV endocardial borders in the images of the three planes are auto-

matically drawn as described above and analyzed.

[0041] A quick method for identifying a region of the heart where more detailed study is required is to score cardiac performance on a symbolic representation of the heart. One such symbolic representation is the bullet scorecard 210 shown in Fig. 15d. The scorecard 210 represents the heart muscle of a chamber of the heart as if the myocardium were spread out in a single plane with the apex at the center of the scorecard and the juncture of the myocardium and the mitral valve plane located around the perimeter of the scorecard. Each sector of the scorecard 210 extending from the center to the perimeter represents a different section of the heart muscle extending from the apex to the mitral valve plane. The areas in the scorecard are numbered to refer to specific areas of the heart wall. For instance the image plane 204 of Fig. 15c would intersect areas 1, 7, the center of the scorecard, and areas 10 and 4. The image plane 206 of Fig. 15c would intersect areas 6, 12, 16, 14, 9 and 3 of the scorecard, and the image plane 208 of Fig. 15c would intersect areas 5, 11, 15, 13, 8 and 2 of the scorecard. The Doppler-detected motion on an automatically drawn border in one or more image frames in the image planes is used to enter data in the scorecard 210. The scorecard is filled in automatically using the motion information from the automatically drawn borders to indicate areas of the heart where detailed diagnosis is warranted. For instance, if cardiac behavior in the plane 204 of the LV is normal, areas 1,7,10, and 4 can be displayed in green on the ultrasound system display. If an unusual characteristic such as abnormal motion is sensed in the vicinity of the juncture of the myocardium and the mitral valve plane, area 1 may be displayed in yellow (for mild irregularity) or red (for a serious irregularity), to caution the clinician to look more closely at this area. Numerical scores may be used in addition to or alternatively to color-coding. A preferred four-tiered scoring system for cardiac performance is to score regions of the heart muscle as being either normal, hypokinetic, dyskinetic, or akinetic. Thus the displayed bullet scorecard with its color-coded or numerically scored areas will point the clinician to regions of the heart where more detailed diagnosis should be performed.

[0042] It is preferable, of course, to use a complete 3D data set to fill in the scorecard 210. For instance, the defined heart wall 200 of Fig. 15a can be "flattened," and spread in a circle about the apex so that each area of the myocardium in the data set corresponds to an area of the scorecard. The motional data over a section of the flattened heart wall 200 can be averaged to fill in a corresponding section of the bullet scorecard 210. For example, the motional data over section 212 of the endocardial data 200 can be averaged to automatically compute a score (either quantitative or qualitative) for corresponding area 5 of the scorecard 210. The scores for section 212 from a plurality of endocardial data sets taken over the full heart cycle can also be averaged or outlying values detected to produce a scorecard of averages of

cardiac performance or greatest degrees of abnormal performance.

[0043] Fig. 16 illustrates an ultrasound system constructed in accordance with the present invention. A probe or scanhead 410 which includes a 1D or 2D array transducer 412 transmits ultrasonic waves and received ultrasonic echo signals. This transmission and reception is performed under control of a beamformer 420 which processes in received echo signals to form coherent beams of echo signals from the anatomy being scanned. The echo information is Doppler processed by a Doppler processor 430 when ABD-TDI information or strain rate information is to be presented, and the processed Doppler information is coupled to an image processor 440 which forms 2D or 3D grayscale or Doppler images. The images pass through a Cineloop memory 460 from which they may be coupled directly to a video processor 470 for display on an image display 480. The images may also be applied to an ABD processor which operates on the 2D or 3D images as described above to define the anatomical borders and boundaries in the images. The defined borders are overlaid on the images which are coupled to the video processor 470 for display. The system may operate to define and display borders on loops of images saved in the Cineloop memory 460, or to display borders drawn on real time images produced during live scanning of a patient.

Claims

1. A method for determining strain rate using ultrasonic signal information of a heart comprising:
 - acquiring velocity information by Doppler processing at points in an ultrasonic field;
 - determining a direction of motion at the points;
 - computing spatial gradient values for points in the field using velocity information related by the direction of motion; and
 - displaying an ultrasonic image utilizing the spatial gradient values,

characterized in that the spatial gradient values are derived by computing derivatives of successive values of velocities in the local direction of motion.
2. The method of Claim 1, wherein acquiring further comprises acquiring ultrasonic velocity information.
3. The method of Claim 1, wherein acquiring comprises acquiring motion information by a vector velocity technique.
4. The method of Claim 1, wherein acquiring comprises acquiring tissue motion information.
5. The method of Claim 1, wherein computing spatial gradients values comprises computing the differential velocity between adjacent points in the field in the direction of motion.
6. The method of Claim 1, wherein acquiring comprises acquiring velocity information using harmonic signals received from points in an ultrasonic image field.
7. The method of Claim 1, further comprising automatically tracing the endocardial or epicardial border of the heart; and
 - wherein computing spatial gradient values comprises computing spatial gradient values utilizing points delineated by a border tracing.
8. The method of Claim 7, wherein automatically tracing comprises:
 - tracing both the endocardial and epicardial borders of the heart;
 - defining a path intermediate the endocardial and epicardial borders which extends through the myocardium; and
 - wherein computing spatial gradient values comprises computing spatial gradient values utilizing points delineated by the intermediate path.
9. The method of Claim 7, wherein automatically tracing comprises
 - tracing either the endocardial or epicardial border of the heart;
 - defining a path offset from the tracing in the direction of the center of the myocardium; and
 - wherein computing spatial gradient values comprises computing spatial gradient values utilizing points delineated by the offset path.
10. The method of one of Claim 1, **characterized in that** it further comprises:
 - computing additional spatial gradient values for points of the myocardium using velocity information related by a second direction of motion of myocardium being approximately normal to the endocardial wall of the heart;
 - displaying the ultrasonic image utilizing the additional spatial gradient values.
11. The method of Claim 10, further comprising automatically tracing the endocardial and epicardial border of the heart; and
 - wherein computing the additional spatial gradient values comprises computing spatial gradient values utilizing points delineated by the two border tracings.
12. The method of Claim 10, further comprising automatically tracing either the endocardial or epicardial border of the heart;

defining a path offset from the tracing in the direction of the center of the myocardium; and
wherein computing the additional spatial gradient values comprises computing spatial gradient values utilizing points delineated by the tracing and the off-set path.

13. The method of claim 1, further comprising:

acquiring a sequence of ultrasonic cardiac images;
displaying a succession of spatial gradient values for the sequence of cardiac images.

14. The method of Claim 13, wherein displaying comprises displaying strain rate information of the heart in a display having a spatial coordinate and a temporal coordinate corresponding to a portion of a heart cycle.

15. The method of Claim 14, wherein the spatial coordinate comprises the path delineated by the border tracings, and wherein the temporal coordinate comprises corresponding points from one border tracing to another.

16. A ultrasonic diagnostic images apparatus comprising means for carrying out the steps of the ultrasonic method of Claim 1.

Patentansprüche

1. Verfahren zum Ermitteln der Dehnungsrate unter Verwendung von Ultraschallsignalinformationen eines Herzens, das Folgendes umfasst:

Erfassen von Geschwindigkeitsinformationen durch Dopplerverarbeitung an Punkten in einem Ultraschallfeld,
Bestimmen einer Bewegungsrichtung an den Punkten,
Berechnen räumlicher Gradientenwerte für Punkte in dem Feld anhand von Geschwindigkeitsinformationen, die durch die Bewegungsrichtung in Beziehung gesetzt sind, und
Anzeigen eines Ultraschallbildes unter Verwendung der räumlichen Gradientenwerte,

dadurch gekennzeichnet, dass die räumlichen Gradientenwerte durch Berechnen von Ableitungen von aufeinander folgenden Werten von Geschwindigkeiten in der lokalen Bewegungsrichtung abgeleitet werden.

2. Verfahren nach Anspruch 1, wobei das Erfassen ferner das Erfassen von Ultraschallgeschwindigkeitsinformationen umfasst.

3. Verfahren nach Anspruch 1, wobei das Erfassen das Erfassen von Bewegungsinformationen durch ein Vektorgeschwindigkeitsverfahren umfasst.

4. Verfahren nach Anspruch 1, wobei das Erfassen das Erfassen von Gewebewegungsinformationen umfasst.

5. Verfahren nach Anspruch 1, wobei das Berechnen von räumlichen Gradientenwerten das Berechnen der Differenzgeschwindigkeit zwischen benachbarten Punkten in dem Feld in der Bewegungsrichtung umfasst.

6. Verfahren nach Anspruch 1, wobei das Erfassen das Erfassen von Geschwindigkeitsinformationen unter Verwendung von Oberwellensignalen umfasst, die von Punkten in einem Ultraschallbildfeld empfangen werden.

7. Verfahren nach Anspruch 1, das ferner das automatische Abgrenzen der Endokard- oder Epikardgrenze des Herzens umfasst, und
wobei das Berechnen räumlicher Gradientenwerte das Berechnen räumlicher Gradientenwerte unter Verwendung von Punkten umfasst, die durch eine Grenzzeichnung abgegrenzt werden.

8. Verfahren nach Anspruch 7, wobei das automatische Abgrenzen Folgendes umfasst:

Zeichnen sowohl der Endokard- als auch der Epikardgrenze des Herzens,
Definieren eines Pfades zwischen der Endokard- und der Epikardgrenze, die durch das Myokard verläuft, und
wobei das Berechnen räumlicher Gradientenwerte das Berechnen räumlicher Gradientenwerte unter Verwendung von Punkten umfasst, die durch den Zwischenpfad abgegrenzt werden.

9. Verfahren nach Anspruch 7, wobei das automatische Abgrenzen Folgendes umfasst:

Zeichnen sowohl der Endokard- als auch der Epikardgrenze des Herzens,
Definieren eines Pfadversatzes von der Abgrenzung in der Richtung zur Mitte des Myokards, und
wobei das Berechnen räumlicher Gradientenwerte das Berechnen räumlicher Gradientenwert unter Verwendung von Punkten umfasst, die durch den Versatzpfad abgegrenzt werden.

10. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** es ferner Folgendes umfasst:

- Berechnen zusätzlicher räumlicher Gradientenwerte für Punkte des Myokards unter Verwendung von Geschwindigkeitsinformationen, die durch eine zweite Bewegungsrichtung des Myokards in Beziehung gesetzt werden, die ungefähr senkrecht zum Endokard des Herzens steht,
Anzeigen des Ultraschallbildes unter Verwendung der zusätzlichen räumlichen Gradientenwerte.
11. Verfahren nach Anspruch 10, das ferner das automatische Zeichnen der Endokard- und der Epikardgrenze des Herzens umfasst, und wobei das Berechnen der zusätzlichen räumlichen Gradientenwerte das Berechnen räumlicher Gradientenwerte unter Verwendung von Punkten umfasst, die durch die beiden Grenzzzeichnungen dargestellt werden.
12. Verfahren nach Anspruch 10, das ferner Folgendes umfasst:
- automatisches Zeichnen der Endokard- oder der Epikardgrenze des Herzens,
Definieren eines Pfadversatzes aus der Abgrenzung in der Richtung der Mitte des Myokards, und
wobei das Berechnen der zusätzlichen räumlichen Gradientenwerte das Berechnen räumlicher Gradientenwerte unter Verwendung von Punkten umfasst, die durch die Zeichnung und den Versatzpfad abgegrenzt werden.
13. Verfahren nach Anspruch 1, das ferner Folgendes umfasst:
- Erfassen einer Folge von Ultraschallbildern des Herzens,
Anzeigen einer Folge von räumlichen Gradientenwerten für die Folge von Bildern des Herzens.
14. Verfahren nach Anspruch 13, wobei das Anzeigen das Anzeigen von Dehnungsrateninformationen des Herzens in einer Anzeige umfasst, die eine räumliche Koordinate und eine zeitliche Koordinate aufweist, die einem Teil des Herzzyklus entspricht.
15. Verfahren nach Anspruch 14, wobei die räumliche Koordinate den Pfad umfasst, der durch die Grenzzzeichnungen abgegrenzt wird, und wobei die zeitliche Koordinate entsprechende Punkte von einer Grenzzzeichnung zur nächsten umfasst.
16. Diagnostisches Ultraschall-Bildgebungsgerät, das Mittel zum Durchführen der Schritte des Ultraschallverfahrens nach Anspruch 1 umfasst.
- Revendications**
1. Procédé de détermination de la vitesse de dilatation en utilisant une information de signal ultrasonore d'un coeur comprenant:
- l'acquisition d'une information de vitesse par traitement Doppler sur des points dans un champ ultrasonore;
 - détermination d'une direction de mouvement sur des points;
 - calcul de valeurs de gradients spatiaux pour des points dans le champ en utilisant une information de vitesse en rapport avec la direction du mouvement; et
 - affichage d'une image ultrasonore utilisant les valeurs de gradients spatiaux; **caractérisé en ce que** les valeurs de gradients spatiaux sont dérivées par calcul de dérivées de valeurs successives de vitesses dans la direction locale du mouvement.
2. Procédé selon la revendication 1, dans lequel l'acquisition comprend par ailleurs l'acquisition d'une information de vitesse ultrasonore.
3. Procédé selon la revendication 1, dans lequel l'acquisition comprend l'acquisition d'une information de mouvement par une technique de vitesse vectorielle.
4. Procédé selon la revendication 1, dans lequel l'acquisition comprend l'acquisition d'une information sur le mouvement du tissu.
5. Procédé selon la revendication 1, dans lequel le calcul des valeurs de gradients spatiaux comprend le calcul de la vitesse différentielle entre points adjacents dans la zone dans la direction de mouvement.
6. Procédé selon la revendication 1, dans lequel l'acquisition comprend l'acquisition d'informations de vitesse en utilisant des signaux harmoniques reçus à partir de points dans une zone d'image ultrasonore.
7. Procédé selon la revendication 1, comprenant par ailleurs le tracé automatique de la frontière endocardique ou épicaudique du coeur, et dans lequel le calcul des valeurs de gradients spatiaux comprend le calcul des valeurs de gradients spatiaux utilisant des points délimités par un tracé de frontière.
8. Procédé selon la revendication 7, dans lequel le tracé automatique comprend:
- le tracé des frontières endocardique et épicaudique du coeur;
 - la définition d'une voie intermédiaire entre les frontières endocardique et épicaudique qui

- s'étend au travers du myocarde; et dans lequel le calcul des valeurs de gradients spatiaux comprend le calcul des valeurs de gradients spatiaux utilisant des points délimités par la voie intermédiaire. 5
9. Procédé selon la revendication 7, dans lequel le tracé automatique comprend:
- le tracé de la frontière endocardique ou épica- 10
rdique du coeur;
la définition d'un décalage de la voie à partir du tracé dans la direction du centre du myocarde; et dans lequel le calcul des valeurs de gradients spatiaux comprend le calcul des valeurs de gra- 15
dients spatiaux en utilisant des points délimités par la voie de décalage.
10. Procédé selon la revendication 1, **caractérisé en ce qu'il** comprend par ailleurs: 20
- le calcul de valeurs supplémentaires de gra-
dients spatiaux pour des points dans le myocar-
de utilisant l'information de vitesse en rapport
avec une deuxième direction de mouvement du 25
myocarde approximativement perpendiculaire à la paroi endocardique du coeur;
l'affichage de l'image ultrasonore en utilisant les
valeurs supplémentaires de gradients spatiaux. 30
11. Procédé selon la revendication 10, comprenant par ailleurs le tracé automatique des frontières endocar-
dique et épica- 35
rdique du coeur; et dans lequel le calcul des valeurs supplémentaires de gradients spatiaux comprend le calcul des valeurs de gradients spatiaux en utilisant des points délimi-
tés par les deux tracés de frontière.
12. Procédé selon la revendication 10, comprenant par ailleurs le tracé automatique des frontières endocar- 40
dique ou épica-
rdique du coeur;
la définition d'un décalage de voie à partir du tracé dans la direction du centre du myocarde; et dans lequel le calcul des valeurs supplémentaires 45
de gradients spatiaux comprend le calcul des valeurs de gradients spatiaux utilisant des points délimités par le tracé et la voie de décalage.
13. Procédé selon la revendication 1, comprenant par ailleurs: 50
- l'acquisition d'une séquence d'images cardia-
ques ultrasonores;
l'affichage d'une succession de valeurs de gra- 55
dients spatiaux pour la séquence d'images car-
diaques.
14. Procédé selon la revendication 13, dans lequel l'af-
fichage comprend l'affichage d'une information de la vitesse de dilatation du coeur dans un affichage possédant une coordonnée spatiale et une coordon-
née temporelle correspondant à une partie d'un cy-
cle cardiaque.
15. Procédé selon la revendication 14, dans lequel la coordonnée spatiale comprend la voie délimitée par les tracés des frontières et dans lequel la coordon-
née temporelle comprend des points correspon-
dants d'un tracé de frontière vers un autre.
16. Dispositif d'imagerie de diagnostic ultrasonore com-
prenant des moyens pour exécuter les étapes du
procédé ultrasonore de la revendication 1.

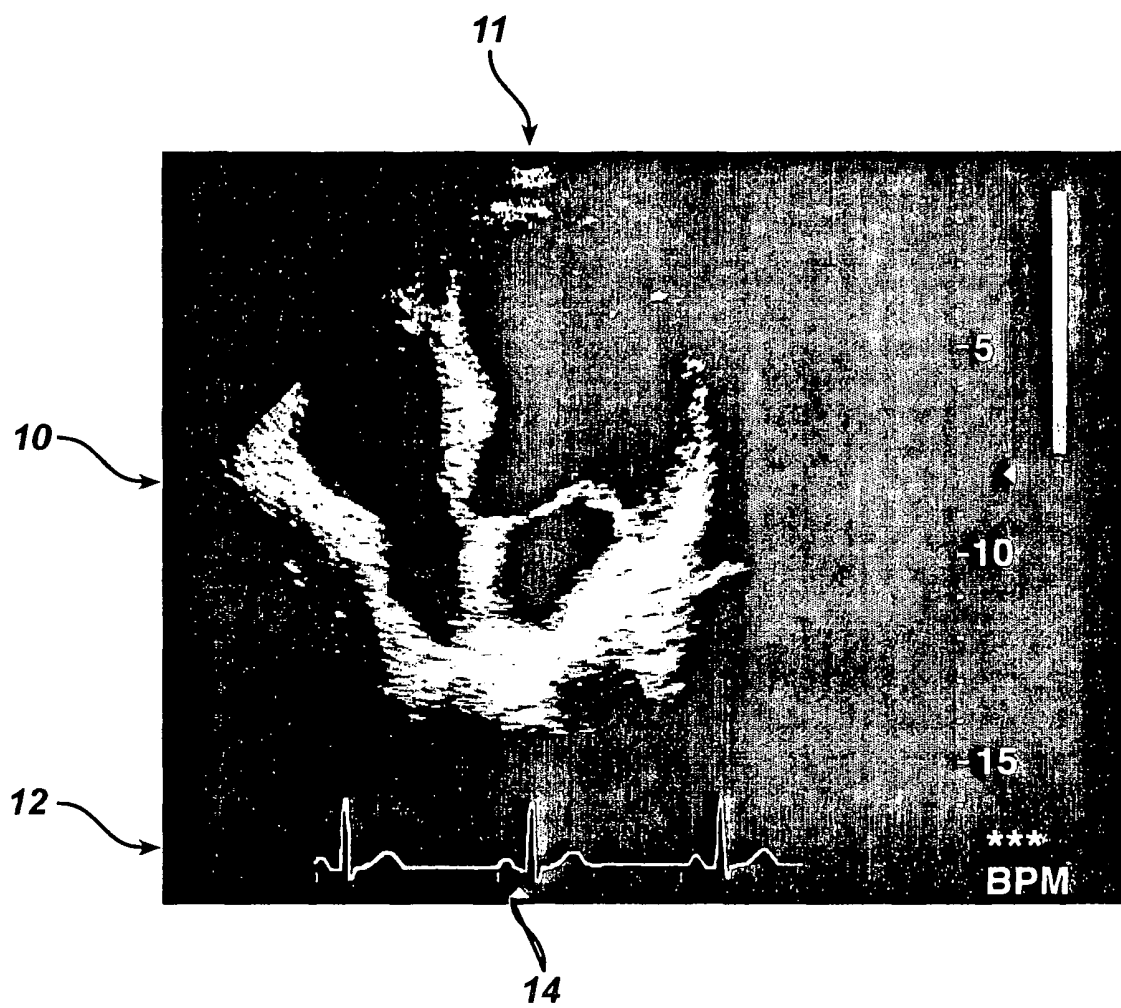


FIG. 1



FIG. 2



FIG. 3b

FIG. 3a

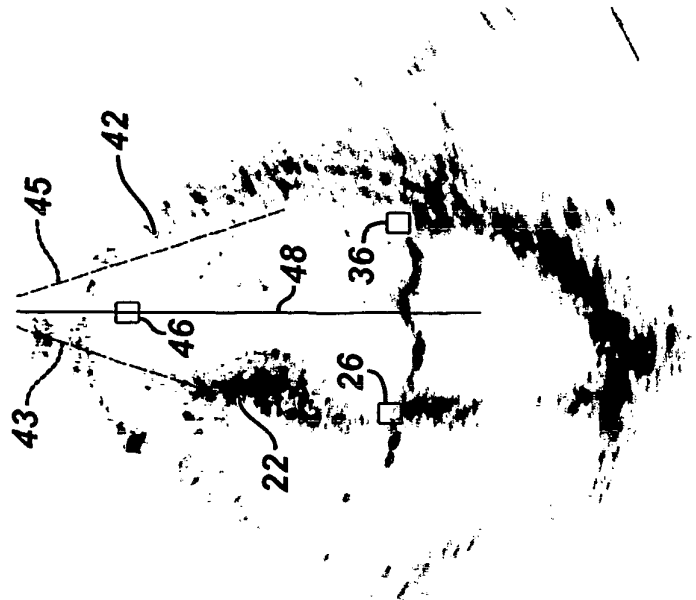


FIG. 4

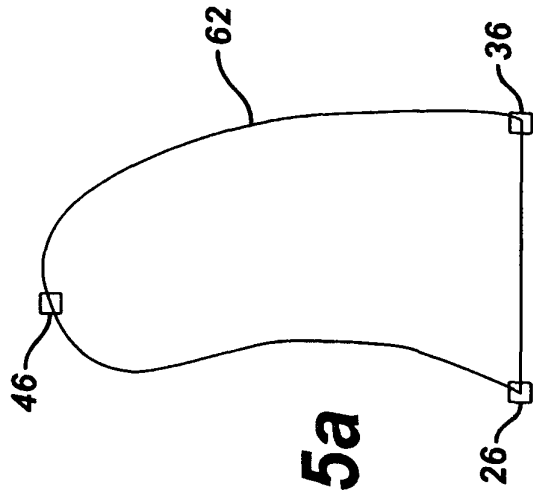


FIG. 5a

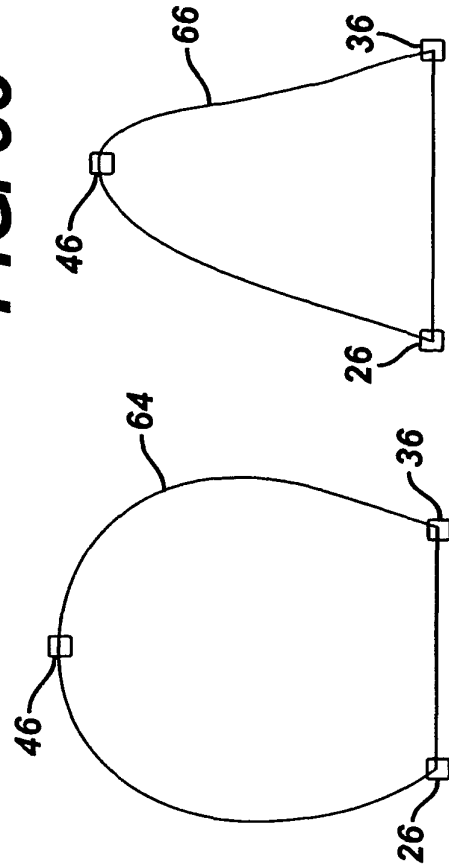


FIG. 5b

FIG. 5c

FIG. 6a

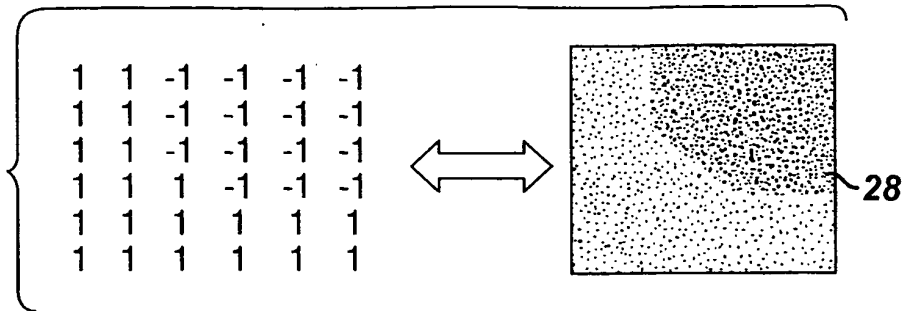


FIG. 6b

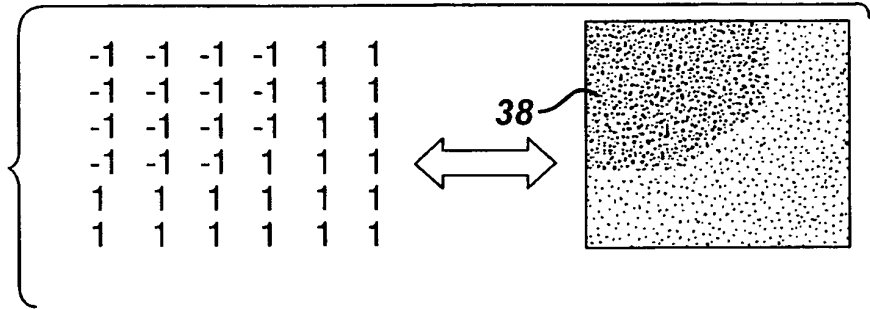


FIG. 7a

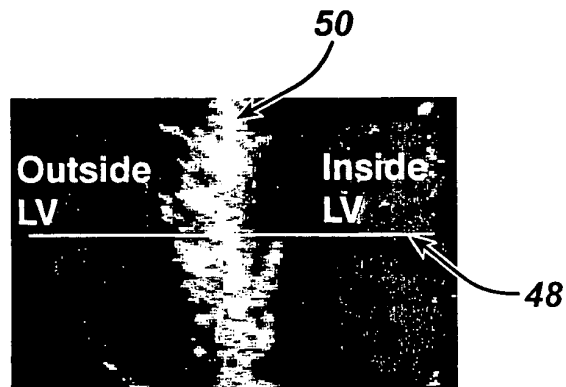


FIG. 7b

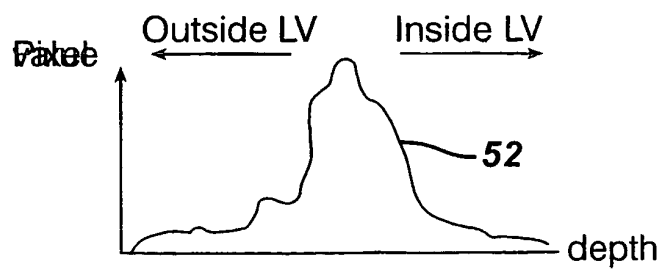
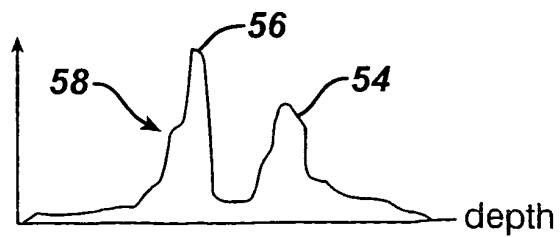


FIG. 7c



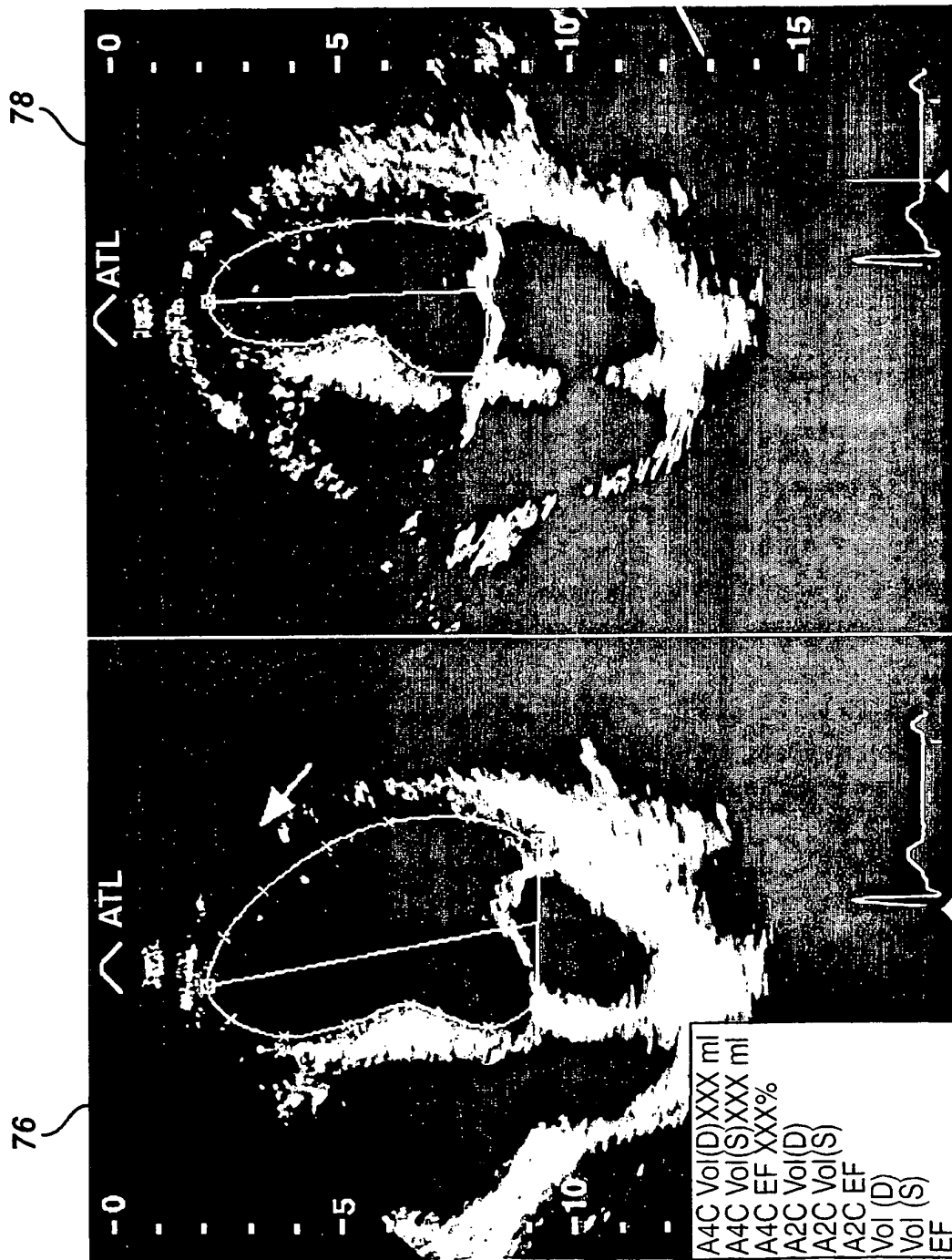


FIG. 8

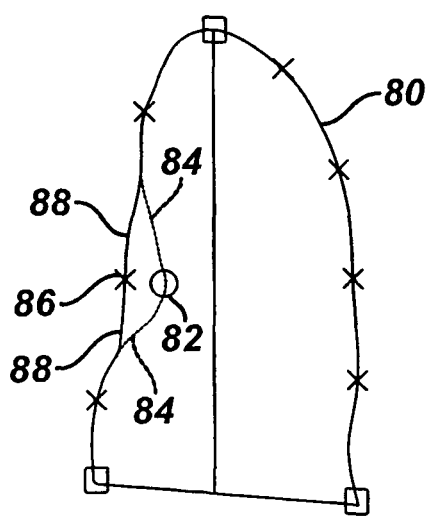
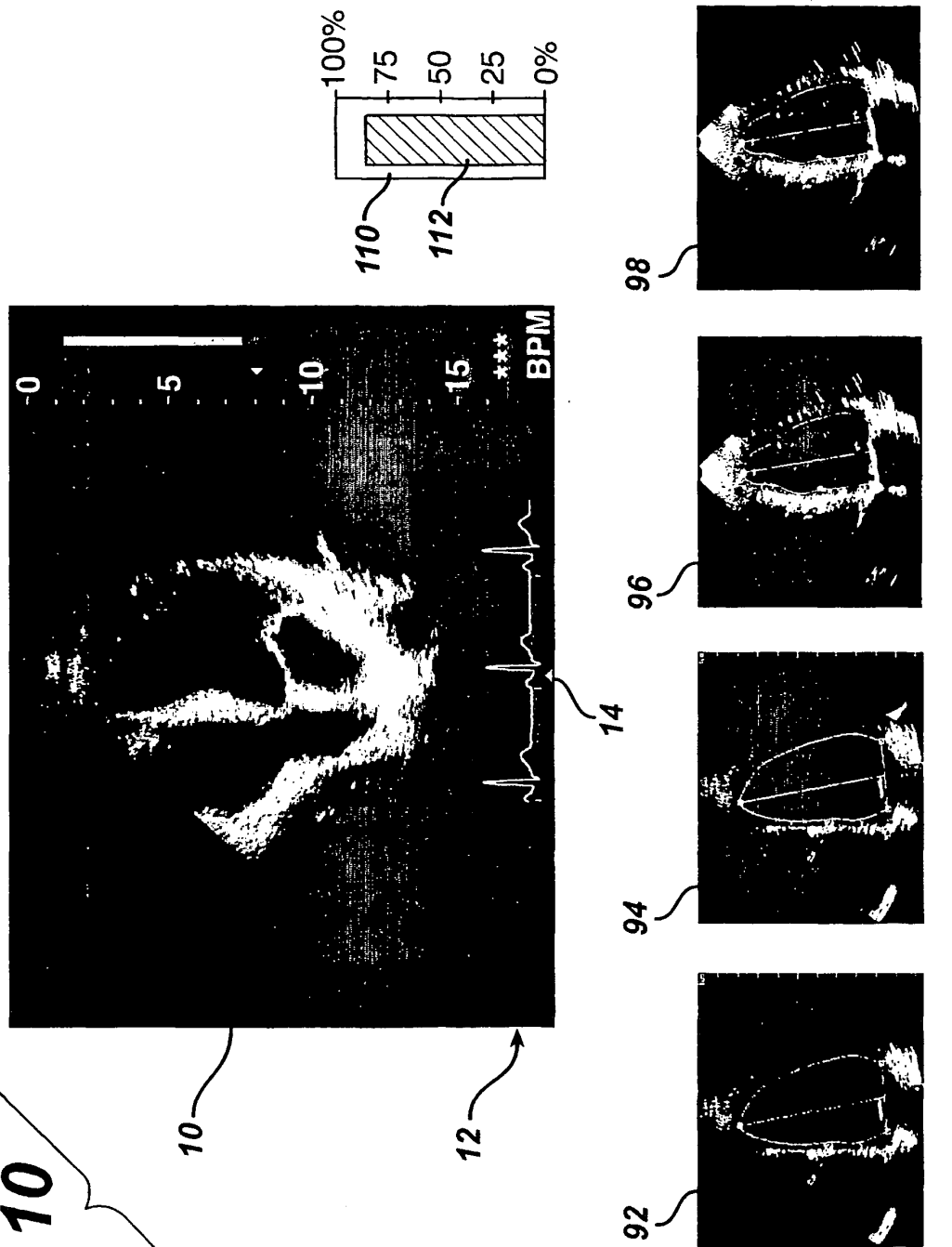


FIG. 9

FIG. 10



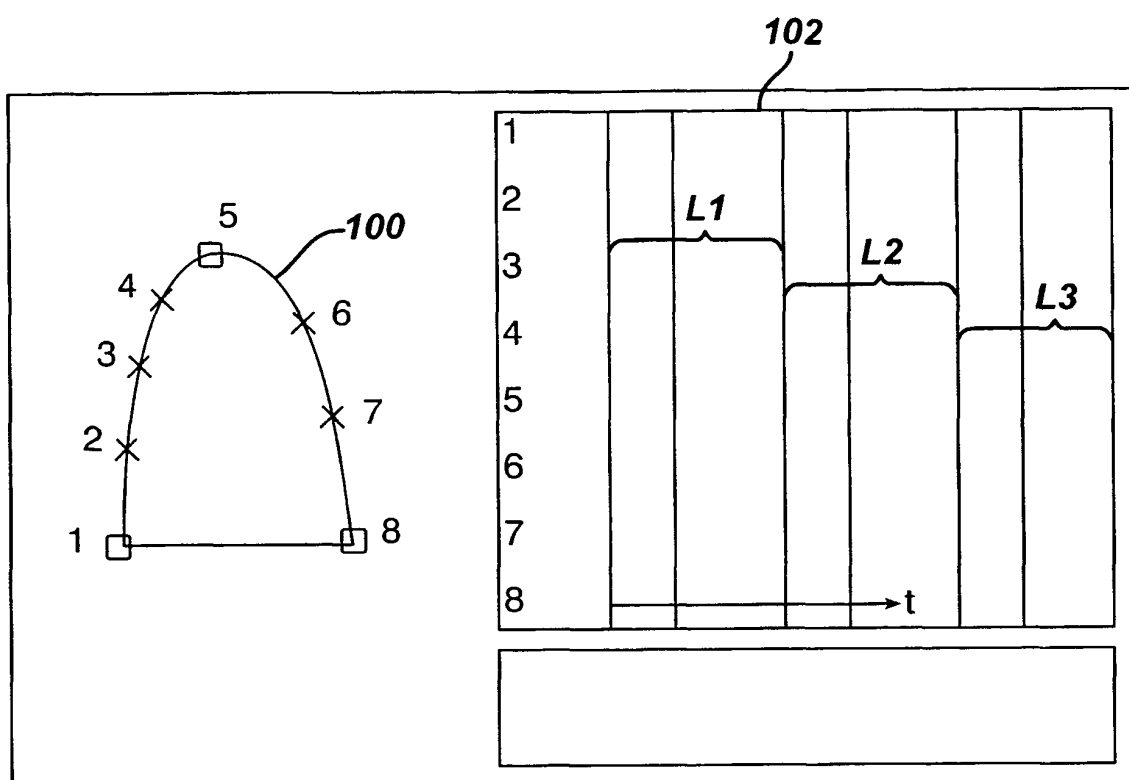


FIG. 11

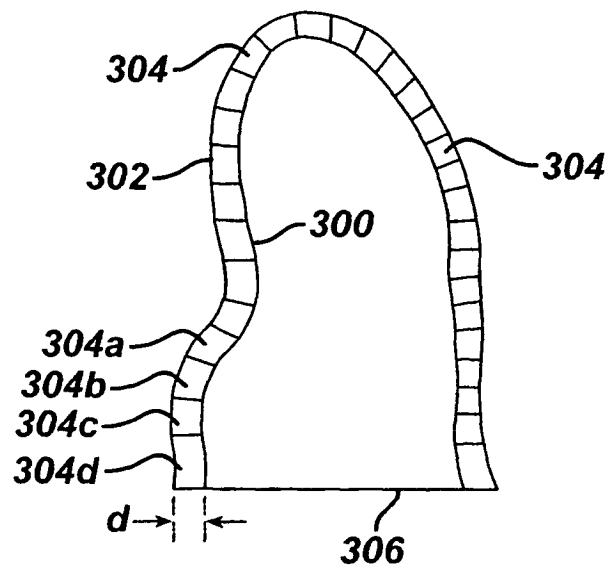


FIG. 12

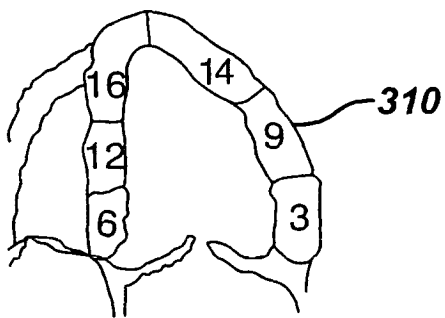


FIG. 13a

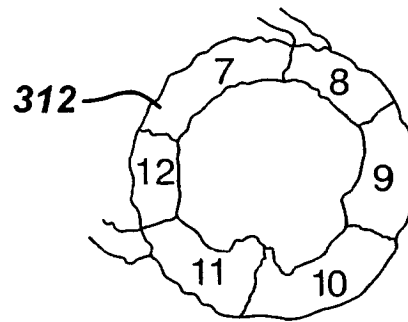


FIG. 13b

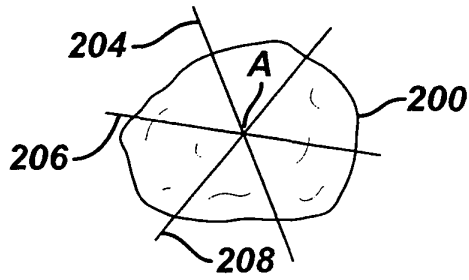


FIG. 15c

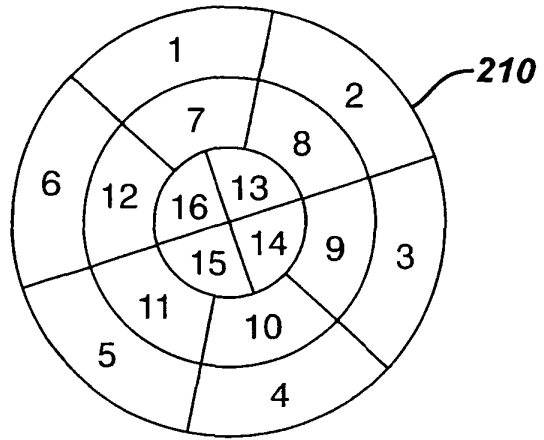


FIG. 15d

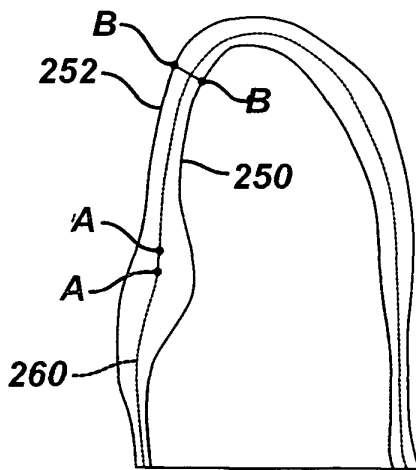


FIG. 14a

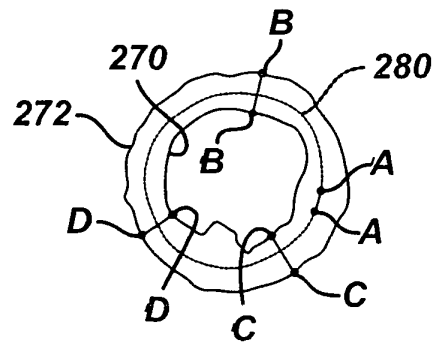


FIG. 14b

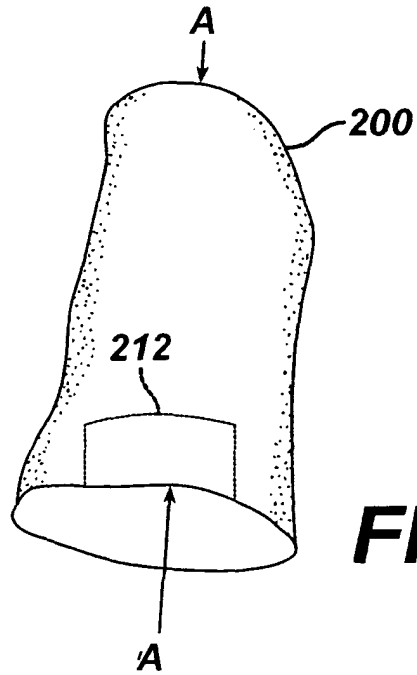
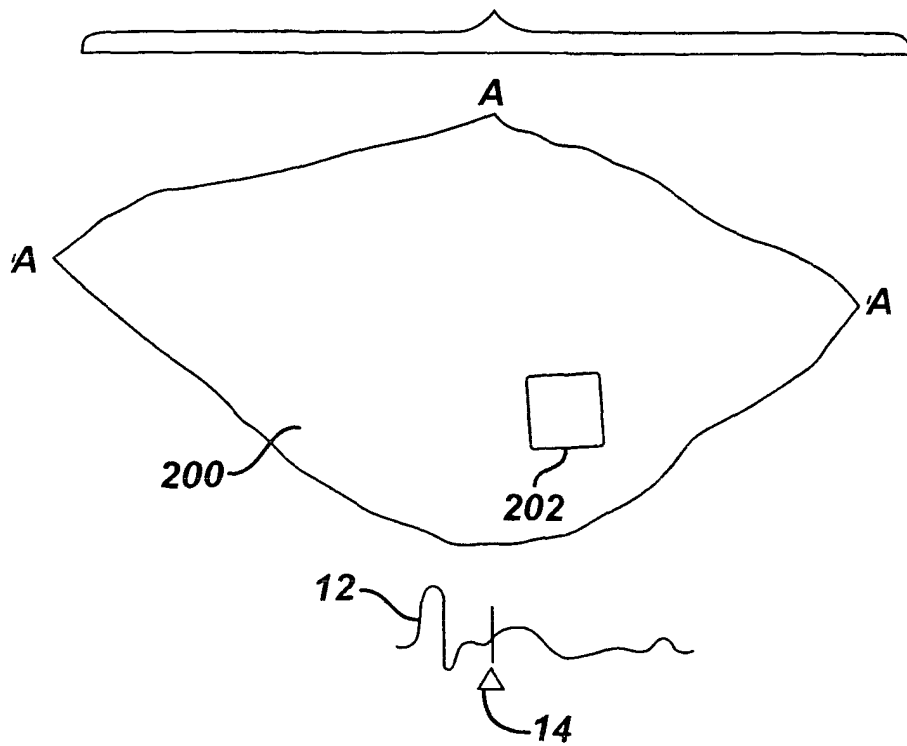


FIG. 15a

FIG. 15b



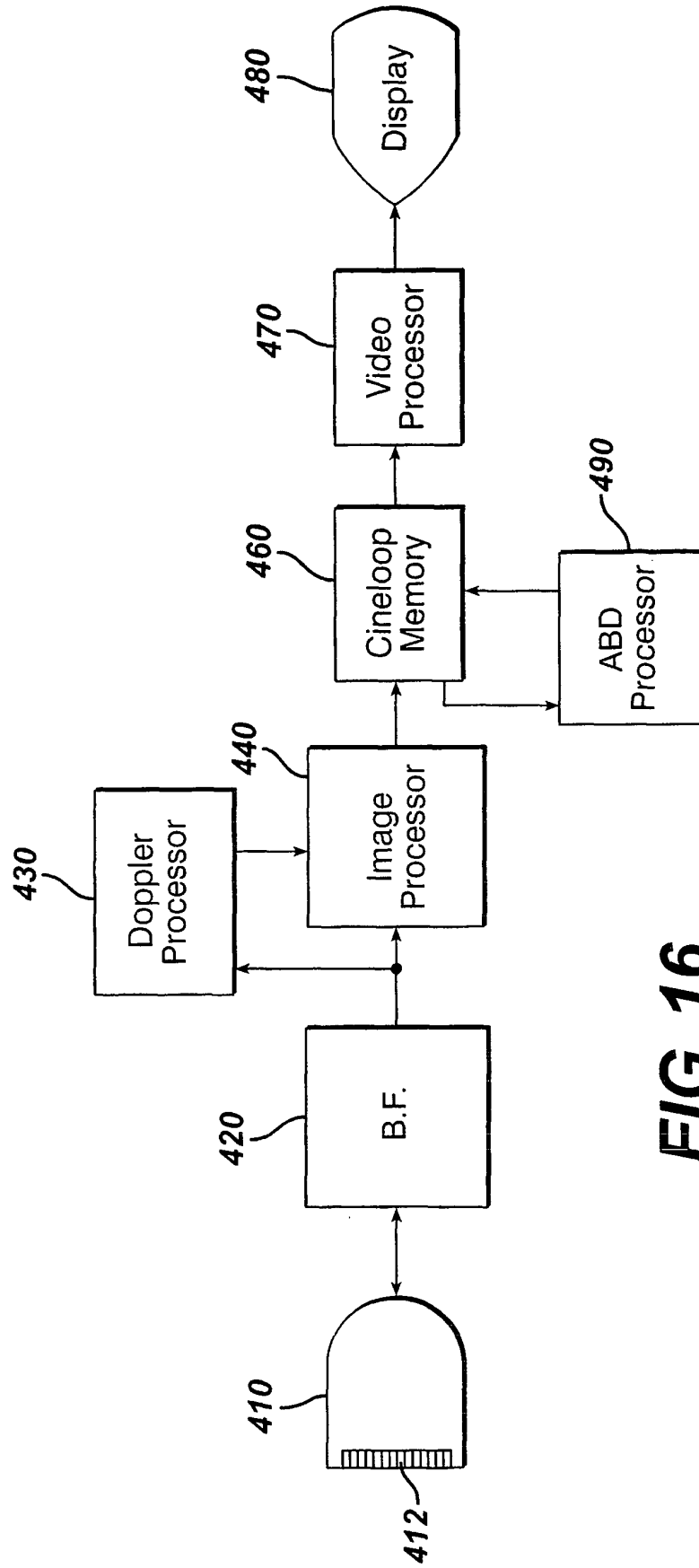


FIG. 16

专利名称(译)	超声诊断图像中的应变率分析		
公开(公告)号	EP1255489B1	公开(公告)日	2006-06-07
申请号	EP2001999319	申请日	2001-11-23
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V.		
当前申请(专利权)人(译)	皇家飞利浦电子N.V.		
[标]发明人	CRITON ALINE L CHENAL CEDRIC ROUNDHILL DAVID N		
发明人	CRITON, ALINE, L. CHENAL, CEDRIC ROUNDHILL, DAVID, N.		
IPC分类号	A61B8/08 G01S7/52 G01S15/89 G06T1/00 G06T7/20		
CPC分类号	G01S15/8979 A61B8/0883 A61B8/0891 A61B8/485 A61B8/486 A61B8/488 G01S7/52036 G01S7/52038 G01S7/52042 G01S15/8993 G06T7/251 G06T2207/30048		
优先权	09/732612 2000-12-07 US		
其他公开文献	EP1255489A1		
外部链接	Espacenet		

摘要(译)

对超声图像进行应变率分析，其中在组织运动方向上计算速度的空间梯度。针对心肌图像中的心脏超声图像计算应变率，对于心肌图像，可以在心肌平面中或穿过心肌。针对心动周期的一系列图像计算应变率信息，并针对自动绘制的边界（例如整个心脏周期上的心内膜边界）显示应变率信息。

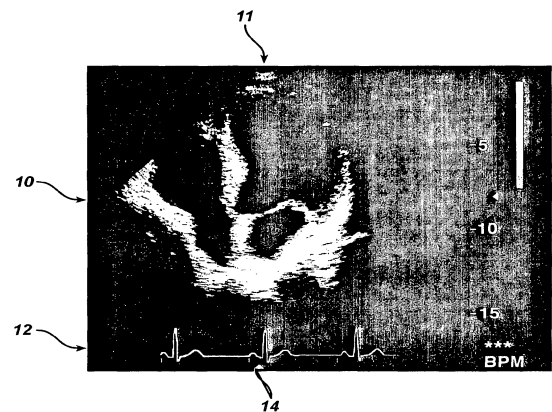


FIG. 1