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(54) ULTRASONOGRAPH

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(57) ABSTRACT

An ultrasonograph comprises a probe **5** provided with a transmitting/receiving ultrasonic transducer **7** at the center thereof, and the probe **5** is comprised of a transmitting ultrasonic transducer **8** and a receiving ultrasonic transducer **9** which are symmetrically movable with respect to the transmitting/receiving ultrasonic transducer **7**. Contacting the probe **5** with the skin of a diagnosis area, a direction of the probe **5** is adjusted to be perpendicular to the diagnosis object using echo signals of the transducer **7**. Then the echo signals of the transmitting ultrasonic transducer **8** and the transmitting/receiving ultrasonic transducer **7**, and a distance between the ultrasonic transducers **8**, **9** are processed to obtain a signal intensity. Results are displayed on a display **14** to indicate thickness, hardness of an articular cartilage, and a surface condition thereof visually so that it is possible to diagnose the articular cartilage without inserting a probe into the cavitas articulare.

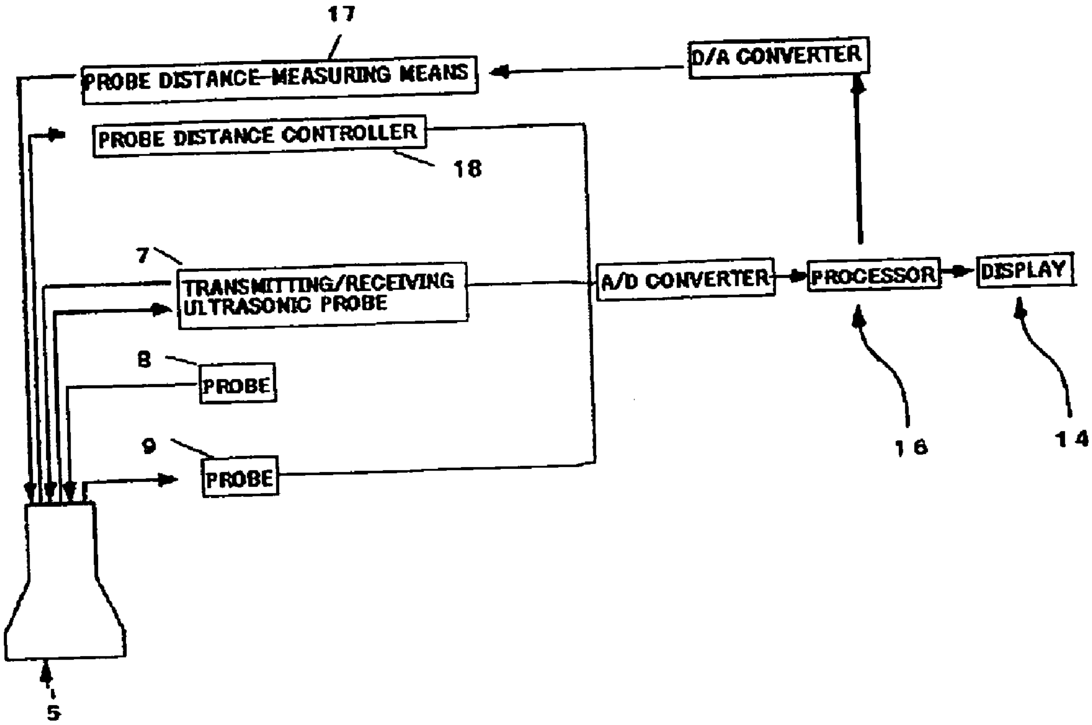


Fig.1

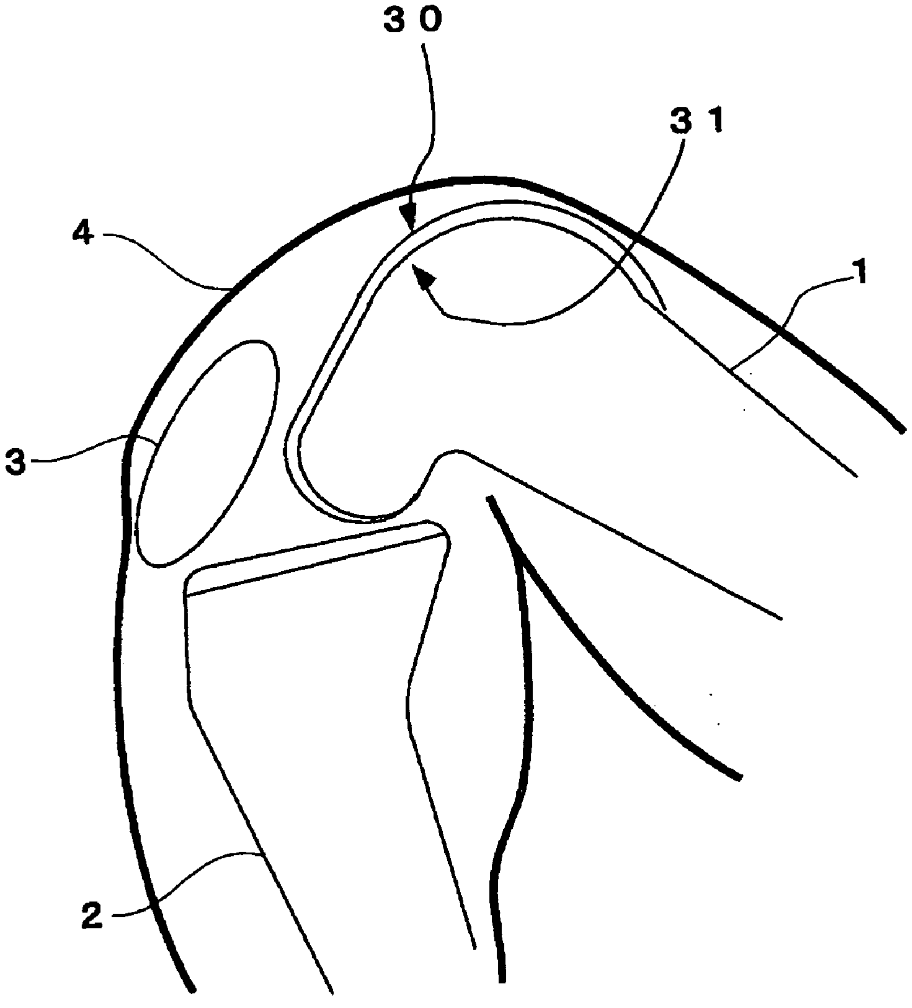
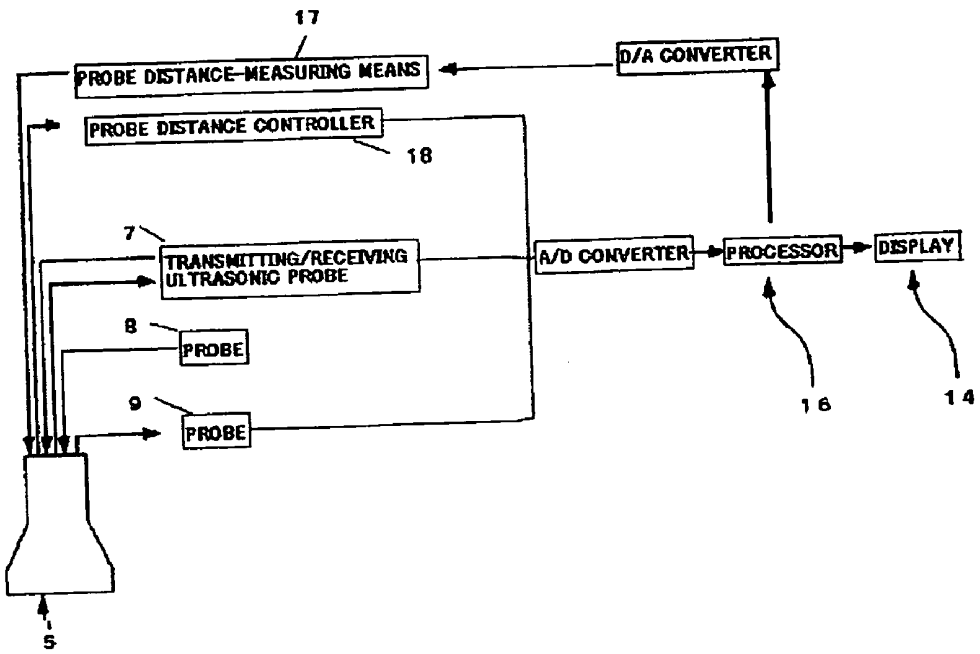


Fig. 2



17
PROBE DISTANCE-MEASURING MEANS
D/A CONVERTER
PROBE DISTANCE CONTROLLER
18
7
TRANSMITTING/RECEIVING ULTRASONIC PROBE
A/D CONVERTER
PROCESSOR
DISPLAY
8
PROBE
9
PROBE
16
14
5

Fig. 3

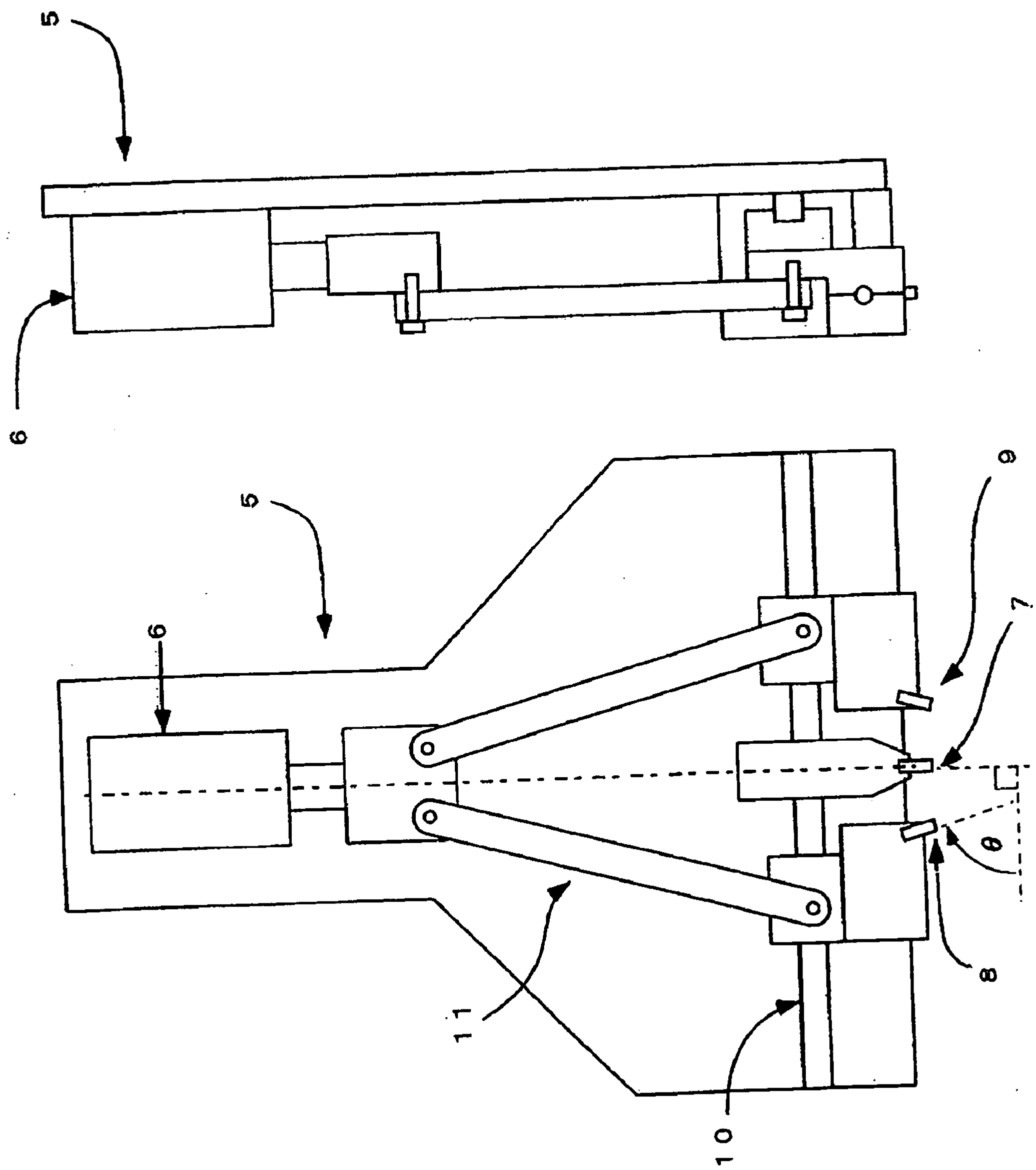


Fig. 4

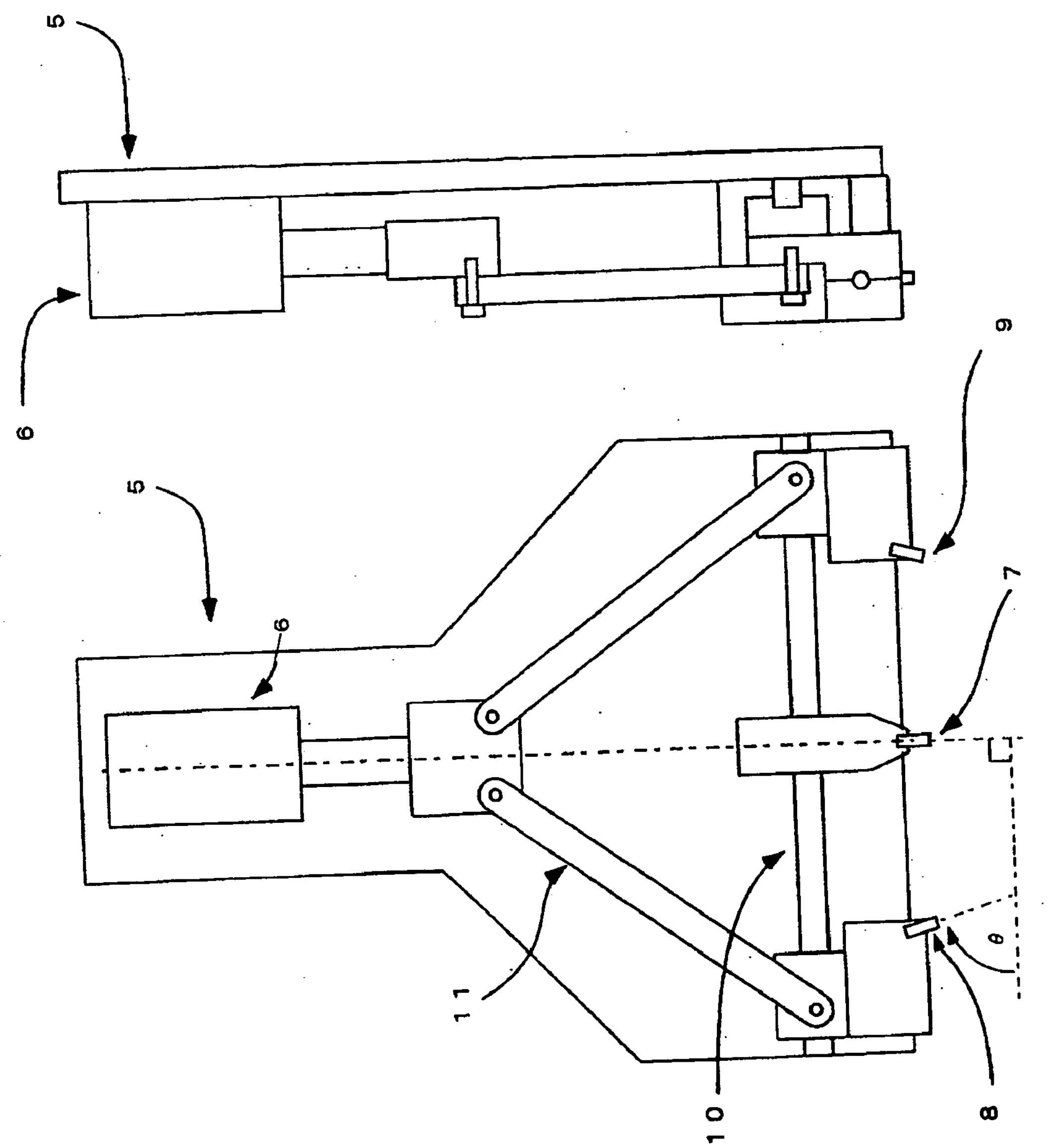


Fig. 5

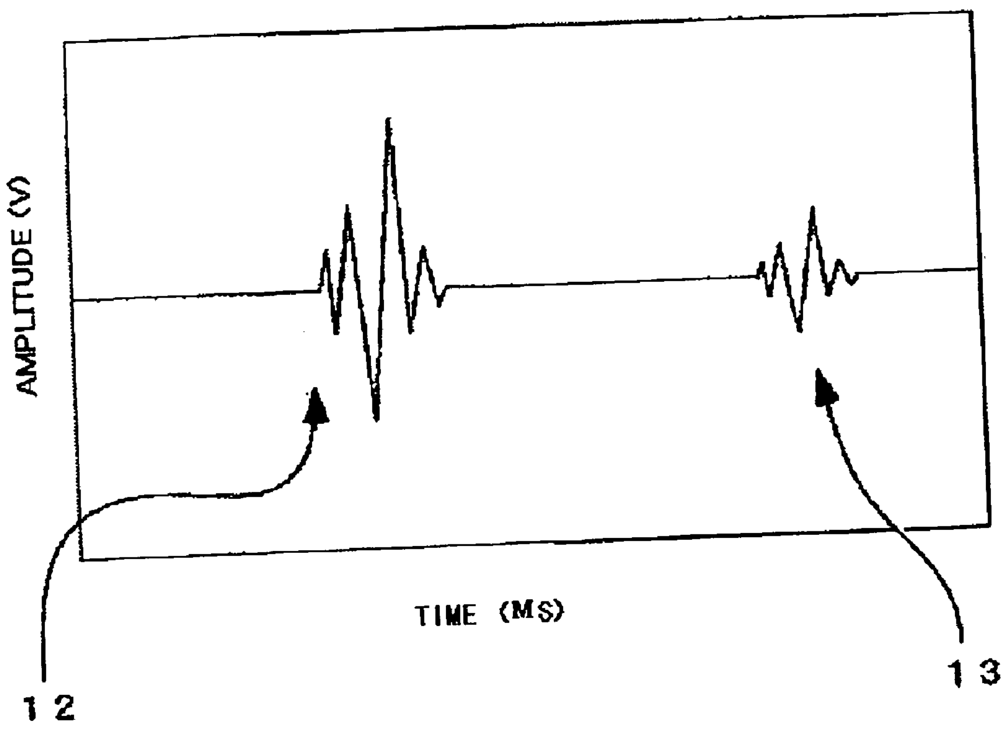
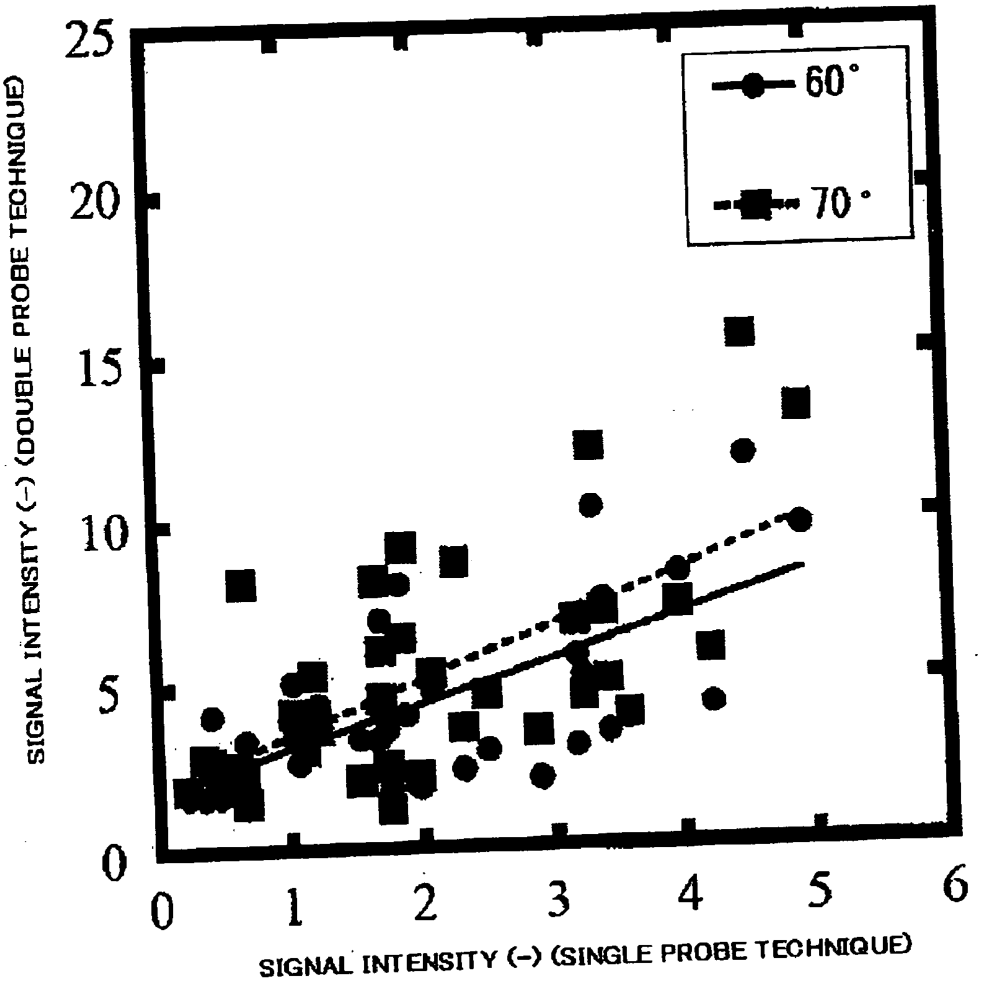
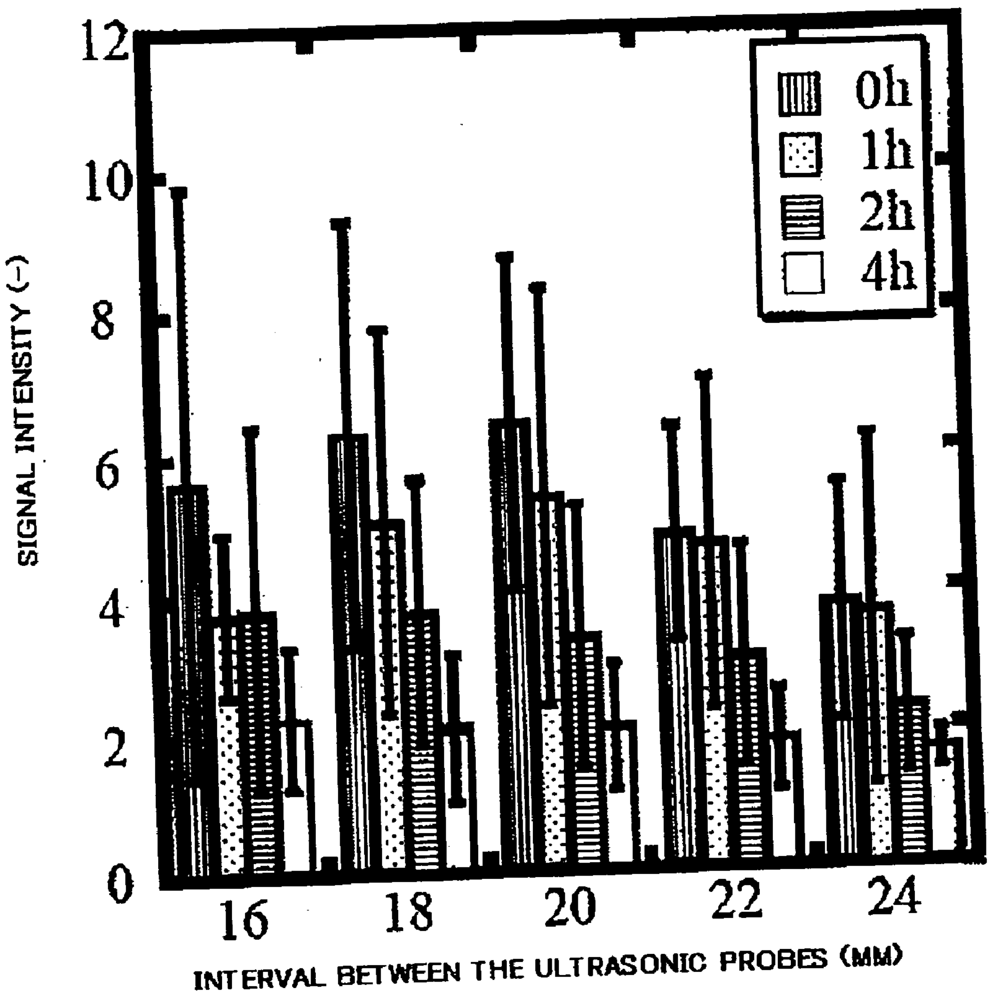


Fig. 6



60°
70°
25
20
15
10
5
0
0
1
2
3
4
5
6
SIGNAL INTENSITY (-) (DOUBLE PROBE TECHNIQUE)
SIGNAL INTENSITY (-) (SINGLE PROBE TECHNIQUE)

Fig. 7



12
10
8
6
4
2
0
SIGNAL INTENSITY (-)
0h
1h
2h
4h
16
18
20
22
24
INTERVAL BETWEEN THE ULTRASONIC PROBES (MM)

Fig. 8

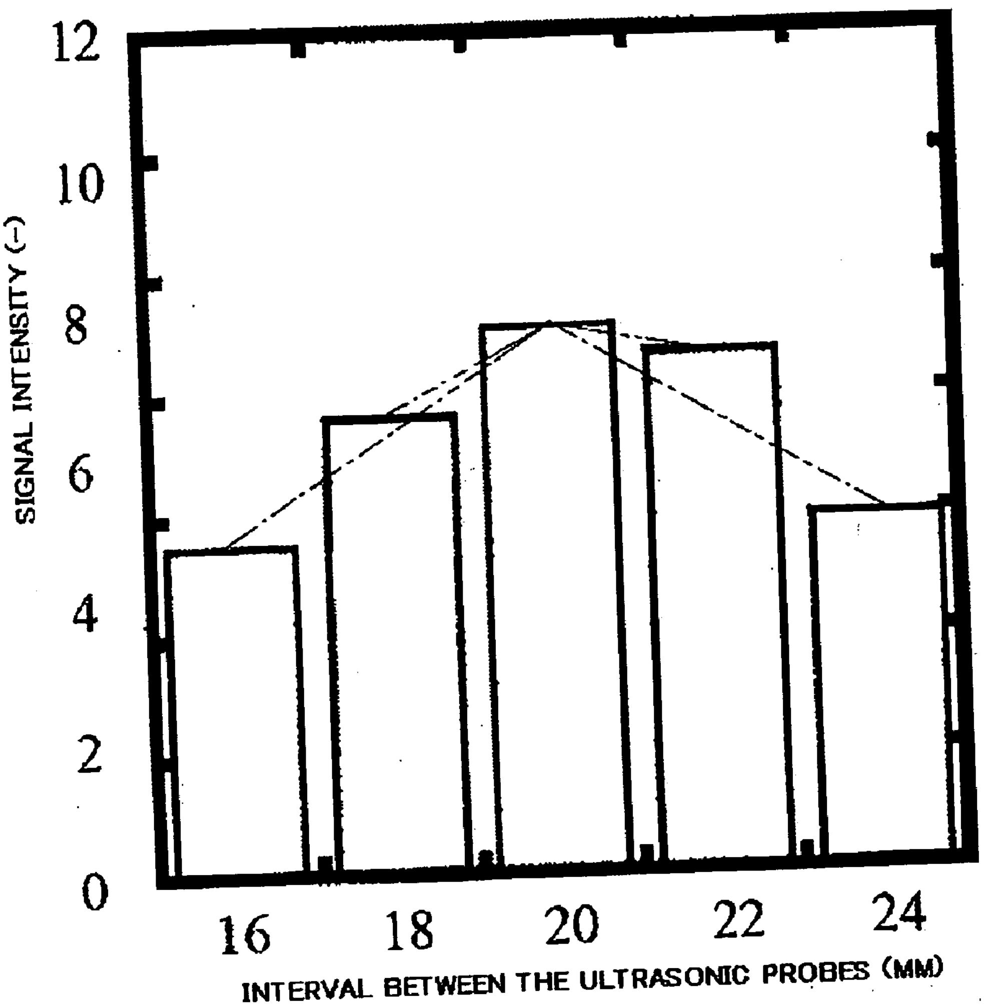

12
10
8
6
4
2
0
SIGNAL INTENSITY (-)
16
18
20
22
24
INTERVAL BETWEEN THE ULTRASONIC PROBES (MM)

Fig.9

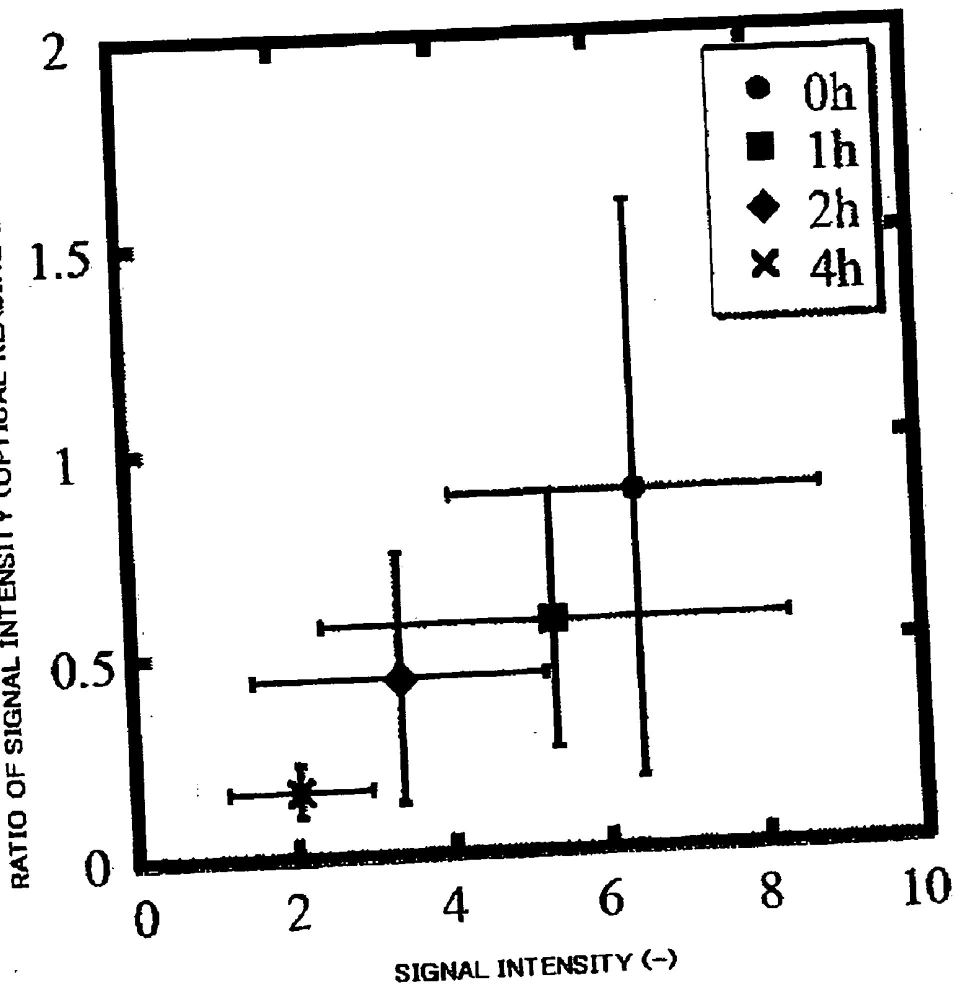

RATIO OF SIGNAL INTENSITY (OPTICAL READING DEVICE 1/MM)
2
1.5
1
0.5
0
0
2
4
6
8
10
SIGNAL INTENSITY (–)
0h
1h
2h
4h

Fig.10

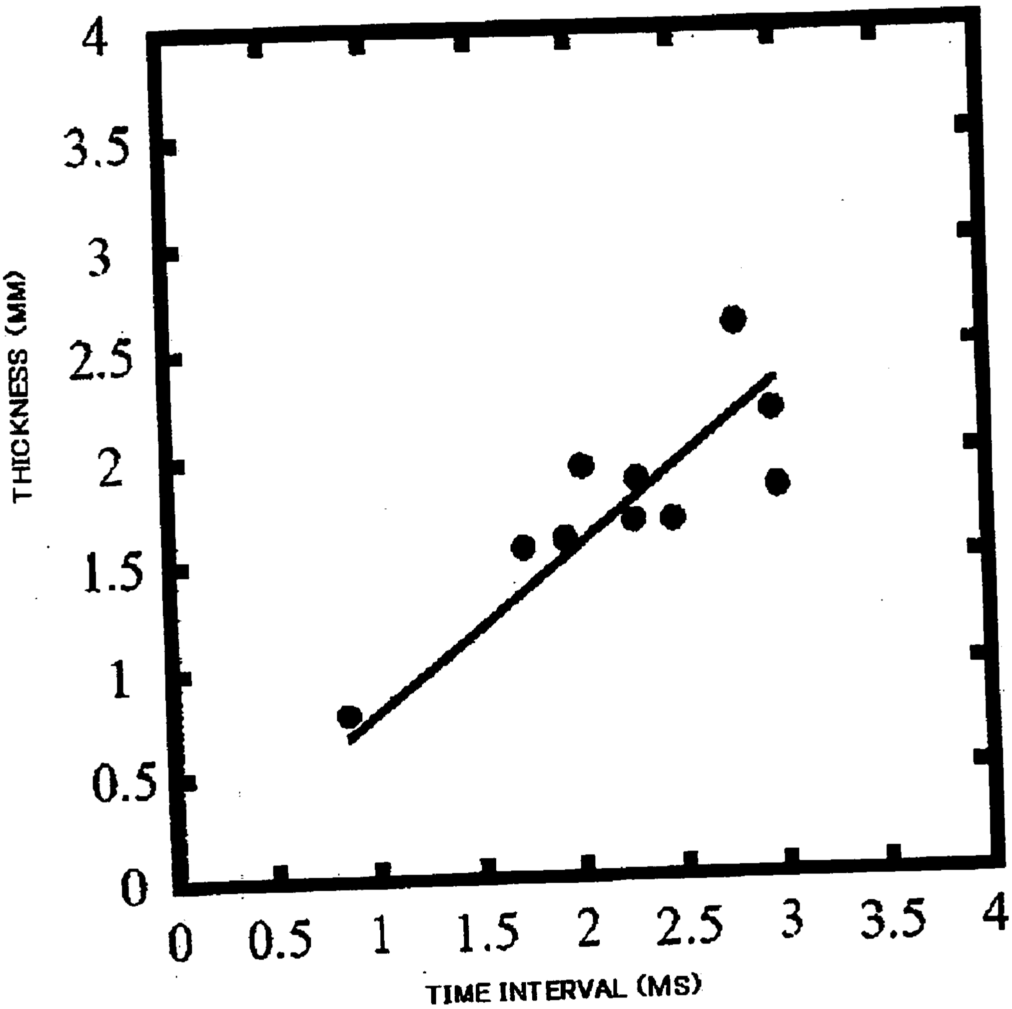

4
3.5
3
2.5
2
1.5
1
0.5
0
THICKNESS (MM)
0 0.5 1 1.5 2 2.5 3 3.5 4
TIME INTERVAL (MS)

Fig.11

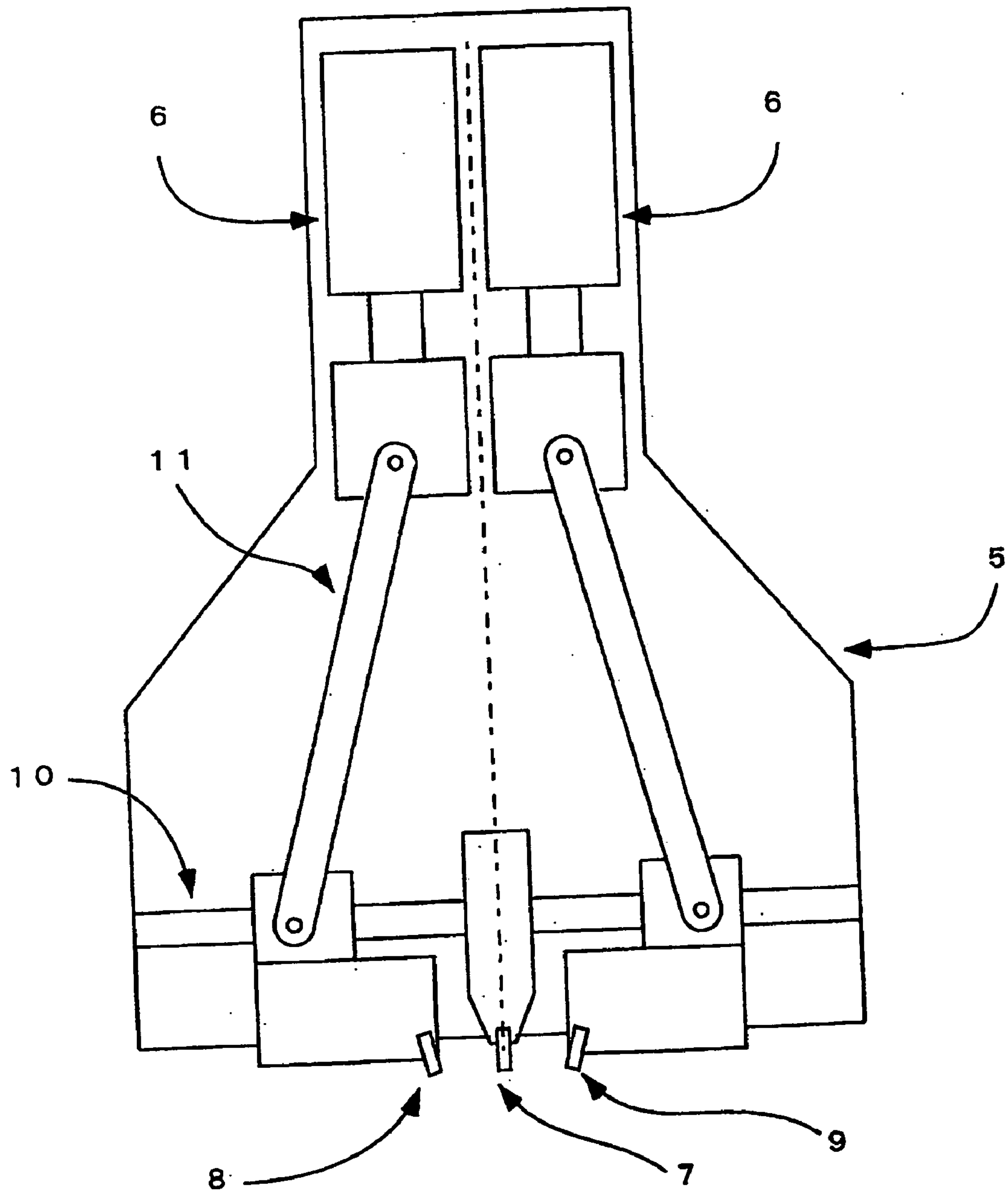


Fig.12

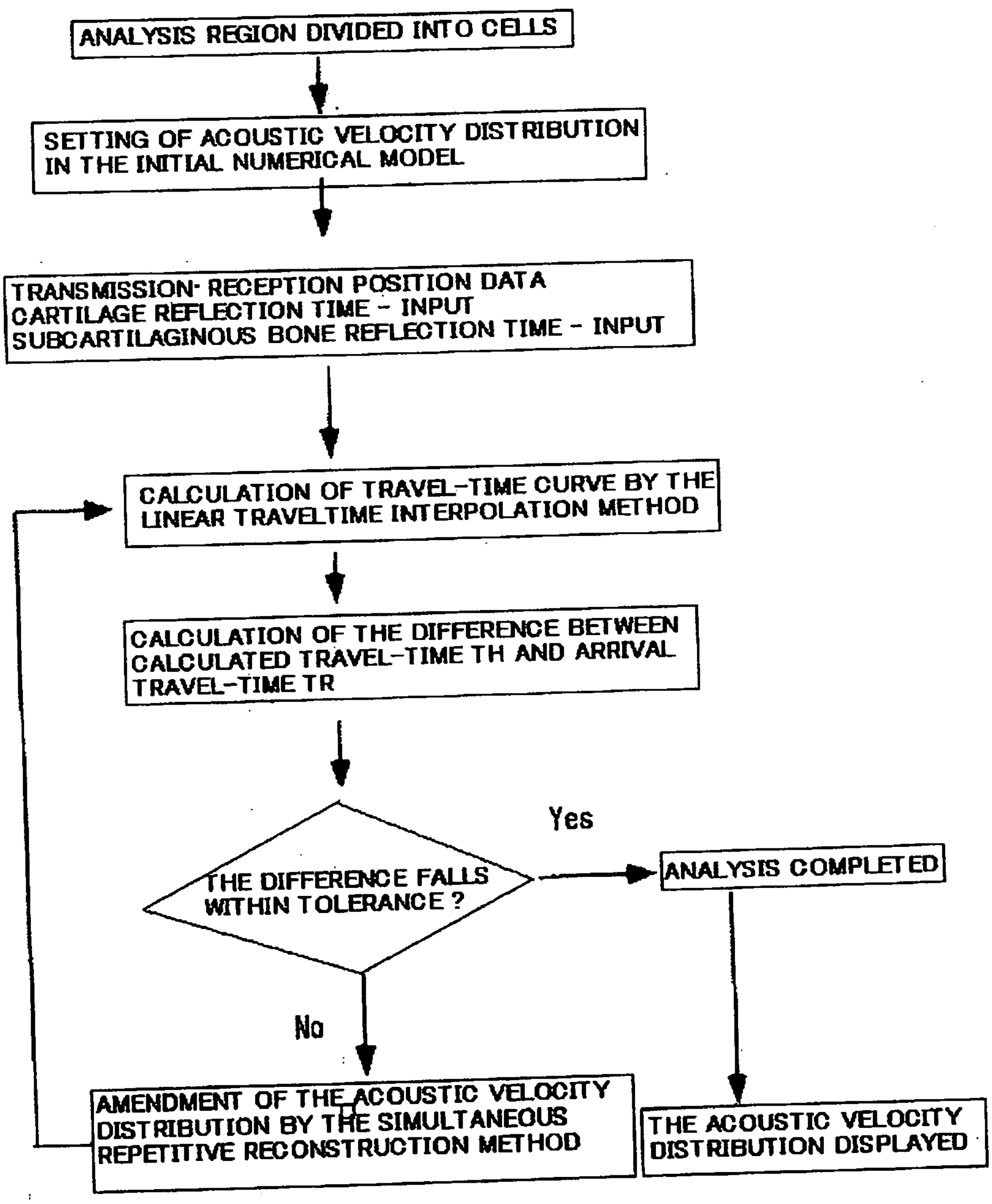
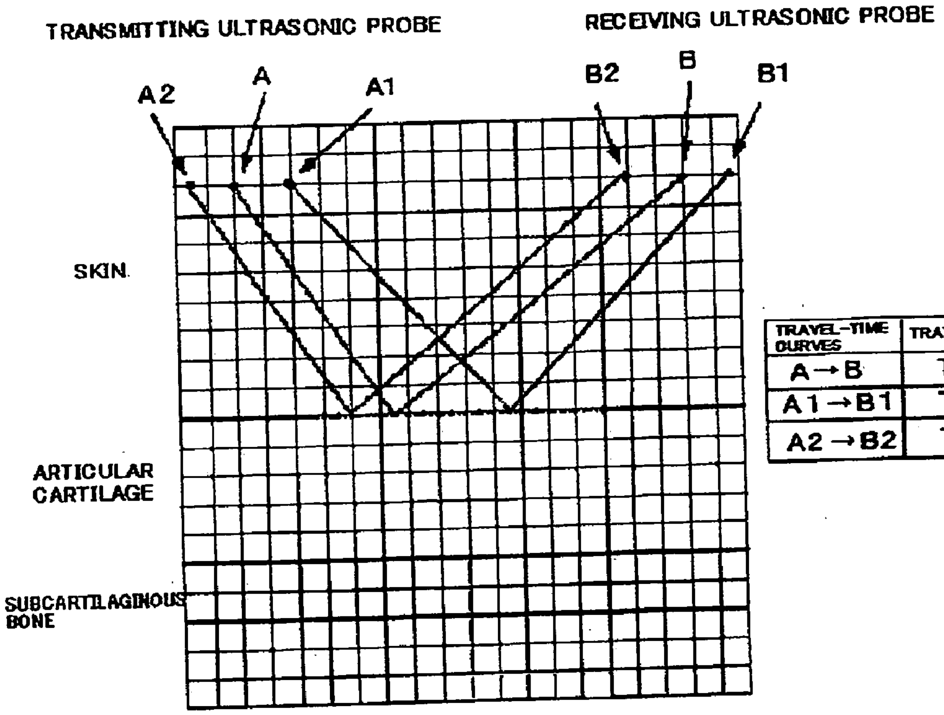
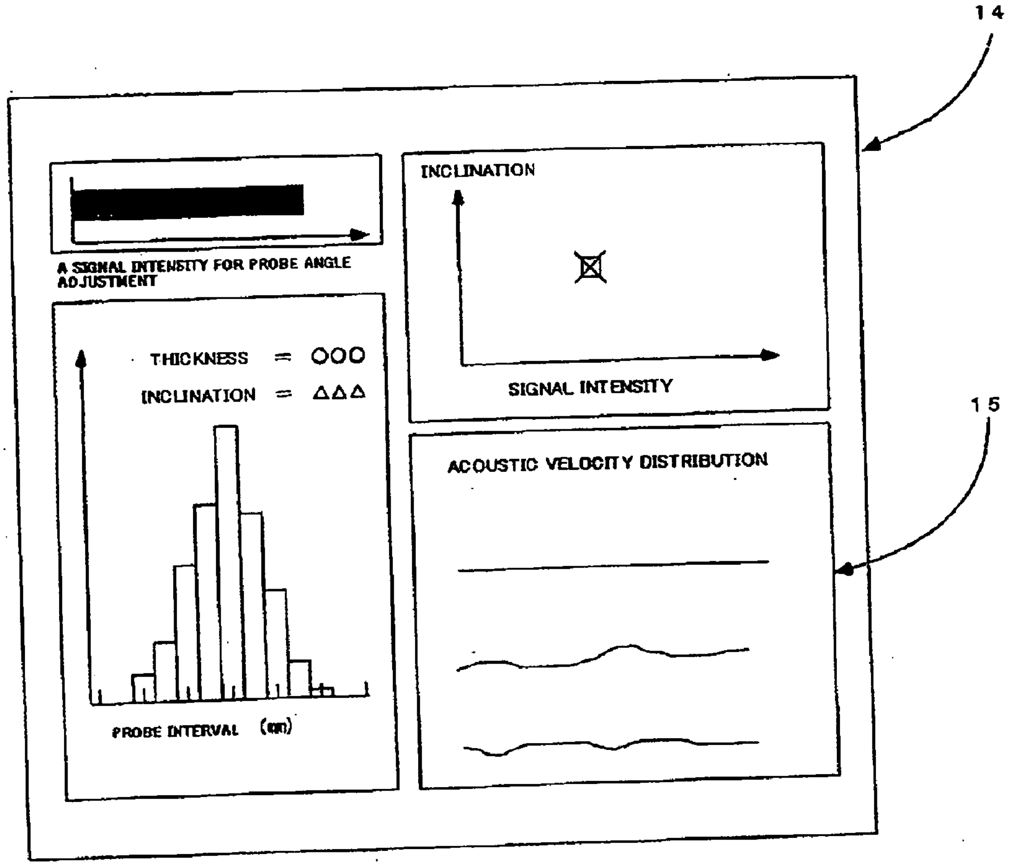

ANALYSIS REGION DIVIDED INTO CELLS
SETTING OF ACOUSTIC VELOCITY DISTRIBUTION IN THE INITIAL NUMERICAL MODEL
TRANSMISSION· RECEPTION POSITION DATA
CARTILAGE REFLECTION TIME - INPUT
SUBCARTILAGINOUS BONE REFLECTION TIME - INPUT
CALCULATION OF TRAVEL-TIME CURVE BY THE LINEAR TRAVELTIME INTERPOLATION METHOD
CALCULATION OF THE DIFFERENCE BETWEEN CALCULATED TRAVEL-TIME TH AND ARRIVAL TRAVEL-TIME TR
THE DIFFERENCE FALLS WITHIN TOLERANCE ?
Yes
ANALYSIS COMPLETED
No
AMENDMENT OF THE ACOUSTIC VELOCITY DISTRIBUTION BY THE SIMULTANEOUS REPETITIVE RECONSTRUCTION METHOD
THE ACOUSTIC VELOCITY DISTRIBUTION DISPLAYED

Fig.13



TRAVEL-TIME CURVES	TRAVEL TIME
A→B	Tr
A1→B1	Tr1
A2→B2	Tr2

Fig.14


14
15
A SIGNAL INTENSITY FOR PROBE ANGLE ADJUSTMENT
THICKNESS = OOO
INCLINATION = ΔΔΔ
PROBE INTERVAL (cm)
INCLINATION
SIGNAL INTENSITY
ACOUSTIC VELOCITY DISTRIBUTION

ULTRASONOGRAPH

FIELD OF THE INVENTION

[0001] The invention relates to a ultrasonograph for diagnosing a condition of soft tissues such as, an articular cartilage and a blood vessel in the vicinity of the skin of a body, by utilizing ultrasonic.

BACKGROUND OF THE INVENTION

[0002] It is well known that a method for directly observing the surface of a joint by inserting an arthroscope into the cavitas articulare, a method of intuitively diagnosing a degree of injury, and hardness of the surface of a cartilage by contacting a probe with a damaged area of an articulara, a method for observing images picked up by the MRI, and so forth. With direct-vision observation by use of the arthroscope or the probe, however, none other than a surface state can be discriminated and it has been impossible to discriminate a crack present inside an articular cartilage. Similarly, it has been impossible to quantitatively determine mechanics•structural characteristics of a subchondral bone area. Meanwhile, with the MRI method, it is impossible to observe a slight changes occurring in the cartilage. Further, it is difficult to make a diagnosis at a spotted area.

[0003] It is difficult to evaluate numerically the mechanics•structural characteristics of an articular cartilage by the conventional diagnostic methods, because the diagnosis criteria are not clear and the results are different depending on observers. Further, in the numerical evaluation, the results are expressed as numbers, however, there might be a possibility that numbers on a display is miss-read by the operator, since several jobs are going on simultaneously during the surgery operation.

[0004] Bones and articular cartilages have important roles for a motion of the body, and for supporting a body weight, therefore it is preferable that the bones are hard (high Young's modulus), and in case of the articular cartilages, it is preferable that the hardness falls within a certain range because the articular cartilages contributes not only to supporting the body weight, but also to absorbing shock.

[0005] Similarly, blood vessels should have adequate hardness in order to fulfill its function for flowing pulsating blood because the blood vessels are susceptible to damage if excessively hard, and are unable to withstand blood pressure if excessively soft on the contrary.

[0006] An ultrasonic reflects at a boundary of tissues differ in acoustic impedances, and it is possible to display a respective image of internal organs and tissues in the body by utilizing the echo signals from the boundary. An acoustic velocity correlates with Young's modulus, which is an index of hardness, and when in measurement of a substantially constant density objects, the echo signals contain mechanical characteristics of the objects (See Non-patent document 1, and Non-patent document 2).

[0007] As shown in FIG. **1**, a load-bearing part of a knee joint cartilage, which is likely susceptible to articular diseases, is moved to an area in the vicinity of the body surface when the knee is bent. The tissues of this area constitute a substantial laminar structure consisting of skin **4**, articular cartilage **30** (several mm in thickness), and subchondral bone **31**.

[0008] The skin **4**, and the articular cartilage **30**, among these tissues, containing rather much water, and have almost the same densities and relatively the same acoustic impedance although they have slightly different acoustic velocities. The subchondral bone **31** has a larger value in both acoustic velocity and density compared with the skin **4** and the articular cartilage **30**, and has a significantly different acoustic impedance from both the skin **4**, and the articular cartilage **30**.

[0009] [Patent document 1] JP 10-118062 A

[0010] [Patent document 2] JP 2002-136520 A

[0011] [Patent document 3] JP 11-316215 A

[0012] [Patent document 4] JP S61 (1986)-290942 A

[0013] [Patent document 5] JP 2002-345821 A

[0014] [Non-patent document 1] Ultrasonic Handbook by Ultrasonic Handbook Compilation Committee, published by Maruzen

[0015] [Non-patent document 2] "Ultrasonic Waves and Material" by Japan Material Science Society, published by Shokabo

[0016] [Non-patent document 3] "Review on Ultrasonic Evaluation by the Double Probe Technique (Ultrasonic Evaluation from Outside the body)" by Okamoto, Mori, et al., Japan Machinery Society, Proceedings, 2006 annual general meeting, Vol. 15, pp. 153-154, 2006

DISCLOSURE OF THE INVENTION

[0017] In Patent document 1, it is an object of the invention to obtain ultrasonic tomography images along with hardness. The hardness is determined on the basis of variation in resonance frequency of a probe, and the probe should be placed close to an object.

[0018] In Patent document 2, it is an object of the invention to evaluate hardness of a living tissue. A bone is a measurement object, and the hardness is estimated on the basis of variation in resonance frequency of a probe and the probe must be contact with the bone. In this method, it is difficult to make a probe contact with the bone, and it is not clear to which extent the results are dependant.

[0019] Patent document 3 discloses an ultrasonic reflectscope for acquiring information on the position of defects such as a crack of an object by use of TOFD method, however, this method is predicated on an assumption that an acoustic velocity within the object is uniform. Therefore it is difficult to apply this invention to the living tissue comprising skin, an articular cartilage and a subchondral bone.

[0020] In Patent document 4, there is disclosed an apparatus displaying tomography images of living tissue, and concurrently measuring an acoustic velocity and nonlinear acoustic parameters. However, since ultrasonic refraction is not taken into consideration for determining acoustic velocity distribution, a positional accuracy in the acoustic velocity distribution is not accurate, therefore it is difficult to extract surface roughness of the articular cartilage and minute cracks thereof.

[0021] In Patent document 5, there is disclosed a method for evaluating hardness of an articular cartilage by utilizing intensity of echo signals. With this method, thickness of the articular cartilage can be concurrently evaluated, however, since the ultrasonic is directly emitted to the object, a probe must be inserted into the cavitas articulare, consequently it is impossible to observe the object through the skin.

[0022] Non-patent document 3 disclose the best location of a receiving ultrasonic transducer where the maximum echo signal from the evaluation target of the articular cartilage is received, while a transmitting ultrasonic transducer remains at fixed position. However, no solution is disclosed how the apparatus is placed in relation to the area for the evaluation to obtain the maximum echo signal. Furthermore, characteristics of the articular cartilage correlated to the maximum echo signal, and data necessary for evaluation of a degree of degeneration of the articular cartilage remain unclear.

[0023] The thickness and the hardness are considered to be important indexes for evaluation of the articular cartilage. Further, as the smoothness of the surface of the articular cartilage decreases (formation of swells, from several tens to several hundreds of micrometers in length) due to deterioration in articular disorder, and small cracks occur to the surface of the articular cartilage. Therefore detection of such features is also useful for early diagnosis. Accordingly, it is important to acquire information on a shape such as the thickness, the surface roughness, along with the hardness.

[0024] It is therefore an object of the present invention to evaluate thickness as well as hardness of articular cartilage, nonuniformity of a surface of the articular cartilage, to detect cracks on the surface by emitting ultrasonic to a soft tissue inside the body from the surface of the body, and to display a state thereof so that one can recognize the state by intuition.

SUMMARY OF THE INVENTION

[0025] In accordance with one aspect of the invention, there is provided an ultrasonograph comprising a probe comprised of a transmitting/receiving ultrasonic transducer provided at the central part thereof, and a transmitting ultrasonic transducer, and a receiving ultrasonic transducer, bilaterally provided so as to be movable in bilateral symmetry with respect to the transmitting/receiving ultrasonic transducer, a processor for calculating signal intensity received from the receiving ultrasonic transducer, at an interval between the ultrasonic transducers, on the basis of respective reflected signals received by the receiving ultrasonic transducer, and the transmitting/receiving ultrasonic transducer, and position data on the respective ultrasonic transducers, bilaterally disposed, and a display device for displaying a relation between signal intensity and the interval between the ultrasonic transducers, and a signal from the transmitting/receiving ultrasonic transducer, and the ultrasonograph can display the thickness as well as hardness of an articular cartilage, and the surface state thereof.

[0026] In accordance with another aspect of the invention, there is further provided an ultrasonograph comprising a probe comprised of a transmitting/receiving ultrasonic transducer provided at the central part thereof, a transmitting ultrasonic transducer, provided on one side of the transmitting/receiving ultrasonic transducer, and a receiving ultrasonic transducer, on the other side thereof, so as to be independently movable in the bilateral direction, respectively, a processor for finding acoustic velocity distribution across the cross section of a diagnosis target on the basis of a reflected signal received by the receiving ultrasonic transducer, a reflected signal received by the transmitting/receiving ultrasonic transducer, and position data on the bilaterally disposed ultrasonic transducers, and a display device for displaying the acoustic velocity distribution, and a signal from the transmitting/receiving ultrasonic transducer, and the ultrasonograph can display the thickness as well as hardness of an articular cartilage, and the surface state thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] FIG. **1** is a schematic illustration showing relative positions of bones in the case of a bent knee joint;

[0028] FIG. **2** is a block diagram of an embodiment of an ultrasonograph according to the invention;

[0029] FIG. **3** is a front view of a probe of the ultrasonograph according to the invention;

[0030] FIG. **4** is a front view of the probe of the ultrasonograph according to the invention when an interval between the ultrasonic transducers of the probe of the ultrasonograph is expanded;

[0031] FIG. **5** a schematic illustration showing a echo signal from an articular cartilage;

[0032] FIG. **6** is a graph showing a correlation between signal intensity for measurement by transmitting and receiving ultrasonic waves, and signal intensity of a echo signal from a transmitting ultrasonic transducer;

[0033] FIG. **7** is a graph showing a relation between the interval between the ultrasonic transducers, and signal intensity variation by the collagenase treatment time length;

[0034] FIG. **8** is a graph showing a relation between the interval between the ultrasonic transducers, and signal intensity, for every collagenase treatment time length;

[0035] FIG. **9** is a graph showing a relation between signal intensity, and (signal intensity variation)/(interval variation);

[0036] FIG. **10** is a graph showing a relation between a time interval between a echo signal from the surface of the articular cartilage, and a echo signal from the subchondral bone, and thickness of the articular cartilage;

[0037] FIG. **11** is a front view of a probe of an ultrasonograph according to Embodiment 2 of the invention, capable of independently moving a transmitting ultrasonic transducer, and a receiving ultrasonic transducer;

[0038] FIG. **12** is a flow chart showing an analysis procedure for acquiring acoustic velocity distribution;

[0039] FIG. **13** is a conceptual view showing travel-time curves in a numerical model of cells; and

[0040] FIG. **14** is a schematic illustration showing an example of a display screen.

[0041] **1** a thighbone

[0042] **2** a tibia

[0043] **3** a kneecap

[0044] **30** articular cartilage

[0045] **31** subchondral bone

[0046] **4** skin

[0047] **5** probe

[0048] **6** linear actuator

[0049] **7** a transmitting and receiving transducer

[0050] **8** a transmitting transducer

[0051] **9** a receiving transducer

[0052] **10** a linear slider

[0053] **11** a link

[0054] **12** reflecting wave from the articular cartilage

[0055] **13** reflecting wave from the subchondral bone

[0056] **14** display device

[0057] **15** speed distribution display

[0058] **16** processing unit

[0059] **17** transducer distance measurement device

[0060] **18** transducer distance controller

PREFERRED EMBODIMENT OF THE INVENTION

Embodiment 1

[0061] Embodiments of ultrasonograph according to the invention are described hereinafter with reference to Embodiment 1 wherein an articular cartilage is an object.

[0062] As shown FIGS. **2**, and **3**, a probe **5** of the ultrasonograph is provided with a transmitting/receiving ultrasonic transducer **7** at the central part thereof, being comprised of a transmitting ultrasonic transducer **8**, and a receiving ultrasonic transducer **9**, in pairs, disposed in bilateral symmetry with respect to the transmitting/receiving ultrasonic transducer **7**, the transmitting ultrasonic transducer **8**, and the receiving ultrasonic transducer **9** each being tilted so as to form an angle θ against a line orthogonal to the transmitting/receiving ultrasonic transducer **7**, and movable in bilateral symmetry thereto, and a linear actuator **11** for causing the transmitting ultrasonic transducer **8**, and the receiving ultrasonic transducer **9**, in pairs, to move in bilateral symmetry along a linear slider **10**, thereby moving the transmitting ultrasonic transducer **8**, and the receiving ultrasonic transducer **9**, in bilateral symmetry, with the use of a linear actuator **6** through the intermediary of a linking mechanism **11**, as shown FIGS. **3**, and **4**. Further, the ultrasonograph comprises an ultrasonic transducer distance-measuring instrument **17** for measuring respective positions of the ultrasonic transducers **8** and **9**, thereby finding an interval therebetween, an ultrasonic transducer distance controller **18** for controlling the interval to a predetermined value, a processor **16** for processing ultrasonic signals reflected at a diagnosis target, and a display device **14** for showing results of processing, and intensity of echo signals received by the transmitting/receiving ultrasonic transducer **7**, and so forth are displayed as shown in FIG. **14**.

[0063] The transmitting/receiving ultrasonic transducer **7**, and the transmitting ultrasonic transducer **8**, assembled in the probe **5**, are each in the shape of a cylinder 2 mm in diameter, and 2 mm in height and transmit a plane wave of 15 MHz as center frequency.

[0064] When an ultrasonic wave is emitted to the articular cartilage **30**, echo signals **12** from the surface of the articular cartilage, and echo signals **13** from the subchondral bone can be detected as shown in FIG. **5**, however, if respective angles of the transmitting/receiving ultrasonic transducer **7**, and the transmitting ultrasonic transducer **8**, against the surface of the articular cartilage **30**, are not appropriate, there are occasions when the echo signals from the surface of the articular cartilage **30**, and the echo signals from the subchondral bone **31** cannot be clearly deteced and it is therefore important to set the probe **5** at an appropriate angle.

[0065] The appropriate angle of the probe **5** against a diagnosis object such as the articular cartilage is determined by the following procedure.

[0066] First, the probe **5** is brought into contact with the body surface, the angle of the probe **5** against the diagnosis object is changed while the ultrasonic waves are emitted from the transmitting/receiving ultrasonic transducer **7**, thereby finding an angle at which echo signals from the articular cartilage **30** is at the maximum, whereupon the probe **5** is fixed at this angle.

[0067] Subsequently, the linear actuator **6** is actuated, thereby causing the transmitting ultrasonic transducer **8**, and the receiving ultrasonic transducer **9**, in pairs, to move in bilateral symmetry with respect to the transmitting/receiving ultrasonic transducer **7** at the center. As a result of such movement, a distance between the transmitting ultrasonic transducer **8**, and the receiving ultrasonic transducer **9** is chaneged, thereby causing a maximum value of the echo signals from the surface of the articular cartilage to change, whereupon the linear actuator **6** is stopped at a position where the echo signal from the surface of the articular cartilage **30** is at the maximum, fixing the interval at that point in time.

[0068] It has been known that there is a correlation between signal intensity (the single transducer technique) of echo signal emitted to the articular cartilage from the vertical direction, having a correlation with Aggregate modulus corresponding to Young's modulus of the articular cartilage, and signal intensity by the double transducer technique using two ultrasonic transducers, for transmission, and receiving, as shown in FIG. **6** (refer to, for example, "Measurement on Mechanical Characteristics of Articular Cartilage by Utilizing Ultrasonic Waves" by Mori, et al., publication by Japan Clinical Biomechanics Society, 23, pp. 97-106, 2002).

[0069] Further, data shown in FIG. **6** were obtained ultrasonic transducer **8** and ultrasonic transducer **9** at an angle of 60°, and 70°, respectively.

[0070] It can be said that the signal intensity of an echo signal received by the receiving ultrasonic transducer **9** correlates to Aggregate modulus corresponding to Young's modulus of the articular cartilage. The signal intensity can be obtained by square value of the echo signal, and on the basis of the maximum value of the square of the echo signal, but if the echo signal is subjected to wavelet transformation, peripheral noises can be separated from the echo signal, whereupon the echo signal from the articular cartilage of the diagnosis object can be more clear, therefore, it is preferable to obatain the signal intensity after the wavelet transformation. And a program for excecuting the wavelet transformation is installed in the processor **16**.

[0071] The waveform of an ultrasonic wave generally consists of at least two sine waves, if a chirp wave is used as a transmitting wave and upon signal reception, noises are greatly reduced by determining an autocorrelation function between the receiving wave and the chirp wave.

[0072] Therefor it is preferable using the chirp wave as the transmitting wave.

[0073] For simulating a diagnosis of a state of an articular cartilage through a skin, a specimen of an articular cartilage coverd with a skin was placed at the bottom of a water tank and the specimen of the articular cartilage was immersed in a physiological salt solution and being subjected to testing.

[0074] Further, in order to artificially simulate damages inflicted on the articular cartilage, the articular cartilage was treated by a collagenase enzyme solution, and the damaged surface was artificially generated. The longer a collagenase treatment time, the greater the damaged surface.

[0075] FIG. **7** is a graph showing signal intensity versus the distance between the pair ultrasonic transducers **8**,**9** and the collagenase treatment time (a degree of damages of the cartilage) at an installation angle (an emitting angle of the ultrasonic wave) of 60 degrees.

[0076] The graph shows a tendency that as the collagenase treatment time increases, the maximum signal intensity decreases at any of the transducer distance, and the maximum signal intensity of the echo signal is obtained when the transducer distance is 20 mm. Further, as the transducer distance is away from the distance 20 mm, the signal intensity decreases. Except at the transducer distance of the maximum signal intensity, the signal intensity at each transducer distance, the signal intensity changes depending on the transducer distance. A degree of changes decreases as the transducer distance is away from 20 mm and the degree of damage (the collagenase treatment time).

[0077] Now, the transducer distance, where the maximum echo signal intensity of each damage degree of an articular cartilage which corresponds to collagenase treatment time, is adopted as a reference distance. A ratio of the echo signal deviation and the transducer distance deviation from the reference distance that is, for every collagenase treatment time, a ratio of signal intensity change due to the signal intensity being away from the center interval, that is, (signal intensity deviation)/(transducer distance deviation) is shown as an inclination of a dash and dotted line connecting the signal intensities of the maximum value and each value, as shown in FIG. **8**. In case of using a plurality of transducer distance, a mean value of ratios of signal intensity deviations at each distance is adopted as a ratio of signal intensity deviation of the specimen.

[0078] When obtained values are plotted on a graph expressing the ratio of signal intensity deviation along the vertical axis and the signal intensity along the horizontal axis as shown in FIG. **9**, the respective values are plotted on a line according to the collagenase treatment time, that is, the degree of damage of the articular cartilage. Accordingly, it is possible to evaluate the degree of damage quantitatively and visually by the location of the plot. More specifically, when the plot is located at right upper position, the specimen is considered to be normal condition, and on the other hand, at lower left position, the specimen is considered to be damaged.

[0079] In FIG. **10**, there is shown a correlation between thickness of the articular cartilage **30** and a time difference between the echo signal from the surface of the articular cartilage **30** and from the subchondral bone **31** at the transducer distance where the signal intensity of the echo signal is maximum.

[0080] Since the thickness of the articular cartilage **30** is proportional to a time difference between two peaks of echo signals received by the receiving ultrasonic transducer **9** at the transducer distance of the maximum signal intensity, the thickness of the articular cartilage **30** can be obtained from the time difference of the echo signal.

[0081] Thus, by securing the probe **5** at an angle where the echo signal from the articular cartilage **30** among the echo signals from the transmitting/receiving ultrasonic transducer **7** at the center, becomes the maximum, the Aggregate modulus corresponding to Young's modulus of the articular cartilage **30** is obtained, thereby evaluating the hardness of the articular cartilage **30**.

[0082] The preferable angle θ of the ultrasonic transducer **8**, **9** is between 45 to 85 degrees. If the angle θ is smaller, the echo signals can not be received under the influence of a curvature of the surface of the articular cartilage, or refraction when passing through the skin, so comparatively larger angle is preferable. On the other hand, if the angle θ is larger, the echo signals will be influenced by a slope of the articular cartilage, therefore more preferable angle θ ranges 60 to 75 degrees.

[0083] To determine the transducer distance for obtaining the maximum echo signal, transducer distance is varied with certain intervals. It is preferable with small distance interval for obtaining a accurate transducer distance. But it takes too much time to find a appropriate transducer distance, it is preferable varying the transducer distance at an interval of 0.10 mm to 0.50 mm.

[0084] The center frequency of the ultrasonic wave is preferably in a range of 1 to 20 MHz and if the high frequency is used, the space resolution becomes better, however, the ultrasonic wave will be influenced by the small property change of tissues when passing through living tissues. Further, the higher the ultrasonic frequency, the greater the attenuation of the ultrasonic wave, the echo signal will have much noises and the intensity of the echo signal decreases. Accordingly, considering the trade off between the spatial resolution and the echo signal intensity, the preferable center frequency of the ultrasonic wave is in a range of 3 to 10 MHz.

[0085] Either the transmitting ultrasonic transducer **8** or the receiving ultrasonic transducer **9** can be moved independently for changing the transducer distance and obtaining the transducer distance-echo signal intensity correlation, because an ideal position of the ultrasonic wave reflected on the surface of the articular cartilage will deviate from a position where the ultrasonic wave is actually emitted from the transmitting/receiving ultrasonic transducer **7**, it is impossible to confirm whether the probe **5** is perpendicular to the area of a daignosis object. For this reason, the transmitting ultrasonic transducer **8**, and the receiving ultrasonic transducer **9** should be moved symmetricaly with respect to the transmitting/receiving ultrasonic transducer **7** located at the center of the divice, so that the ideal position of the ultrasonic wave reflected on the surface of the articular cartilage will coincide with the position where the ultrasonic wave is emitted.

[0086] Detection of locations of the ultrasonic transducers **8**, **9** is executed by an appropriate location-detecting means, for example, by a laser displacement gauge, and calculating a distance between them. A stepping motor is used for the linear actuator **6**, for moving the linear actuator **6**, the distance can be calculated on the basis of a rotation angle of the motor.

[0087] A transducer array comprising of a plurality of transmitting ultrasonic transducers **8**, and the receiving ultrasonic transducers **9**, symmetrically arranged with respect to the transmitting/receiving ultrasonic transducer **7** locating at the center of the device, and switching transmission and reception sequentially for scanning the articular cartilage electronically therefor the mechanical scanning system is not necessary and the device rarely becomes out of order, and it is possible to change the transmission and reception position of the transducers rapidly (more than 10 to 30 time per second) compared with the mechanical scanning. However, electronic scanning requires a plurality of ultrasonic transducers, which brings a cost increasing problem.

[0088] In this invention, the transducer distance should be changed with the precision of from 0.10 mm to 0.50 mm, but the scanning speed is not necessarily high, either the mechanical scanning or the electronic scanning should be selected considering the cost of the device.

Embodiment 2

[0089] As shown in FIG. **11**, an ultrasonograph of Embodiment 2, essentially identical to the Embodiment 1, comprises a transmitting/receiving ultrasonic transducer **7** located at the center of the device, for checking whether a probe **5** is perpendicular to an articular cartilage which is a diagnosis object, a transmitting ultrasonic transducer **8** and a receiving ultrasonic transducer **9** disposed symmetrically with respect to the transducer **7**, and linear actuators **6** driving the transducers **8**, **9** symmetrically and laterally for scanning. Each transducer **8**, **9** have its own linear actuator **6** for independent driving along a linear slider **10**.

[0090] FIG. **12** indicates a process for determining an acoustic velocity distribution.

[0091] As shown in a schematic diagram of FIG. **13**, in which the transmitting ultrasonic transducer **8** is fixed at a certain position A, then the linear actuator **6** drive the receiving ultrasonic transducer **9** along the linear slider **10** for scanning the surface of the articular cartilage **30**, a position of the receiving ultrasonic transducer **9** is determined using an ultrasonic transducer distance detecting means **17** and echo signals received by the transducer **9** at each position are stored.

[0092] Subsequently, the fixed position of the transmitting ultrasonic transducer **8** is changed to a position A**1** and the receiving transducer **9** is also moved along the linear slider and the receiving echo signals at each position are stored. The scanning process is executed repeatedly, and a set of the positions of transmitting transducer **8**, positions of the receiving transducer **9** and echo signals at each positions are stored in a memory of a processor **16**.

[0093] An area of diagnosis is divided into cells as appropriate to construct a numerical model, thereby calculating time (hereinafter referred to as cartilage reflection time) between the signal stored and a echo signal from the surface of the articular cartilage **30**, and time (hereinafter referred to as subchondral bone reflection time) between the signal stored and a echo signal from the subchondral bone **31**. Travel-time curves are determined on the basis of the plurality of the positions of the transmitting transducer **8** and the positions of the receiving transducer **9**, together with the cartilage reflection time and the subchondral bone reflection time.

[0094] Assuming a velocity of the ultrasonic in each cell is constant and the ultrasonic wave propagates straight without refraction through the cell. And refraction takes place when the ultrasonic passes through the cell having the different velocities in adjacent cells. Thus, a travel-time curve is expressed as a polygon made up of a multitude of straight lines. Further, elapsed time Tr (travel-time) is also determined.

[0095] The travel-time is determine using, for example, the linear travel-time interpolation method by Aikawa, et al. (reference: "Seismic Ray Tracing using linear traveltime interpolation", by Aikawa and Kawada, Geophysical Prospecting, 41, pp. 99-111, 1993).

[0096] Since mean acoustic velocities of skin, fat, articular liquid, an articular cartilage, and a subchondral bone are known (see Non-patent document 1), an initial velocity structure (acoustic velocity distribution) of the numerical model is determined using the above mentioned mean velocities.

[0097] The time difference between the predicted travel-time Th, and the detected travel-time Tr is calculated for every travel-time curve, and the acoustic velocities in the respective cells are corrected such that the time differences will become minimum. For correcting the velocities, the simultaneous repetitive reconstruction method (see "geophysical prospecting for construction•disaster-prevention engineers", by Sasa Kohichi, et al., published by Morikita Publishing Co., Ltd.) is used.

[0098] Unless the time difference falls within an allowable value, the travel-time curve is repeatedly corrected following the above mentioned correction process. (see "Refraction Process Seismic Exploration Analysis Method using tomographical techniques" by Odahara, et al., Koei Forum, 9, pp. 7-14, 2001).

[0099] A converged velocity distribution is considered to be the velocity distribution of the area through which the ultrasonic wave has passed. An acoustic velocity has correlation with Young's modulus, and a live body contains a lot of water. Except hard tissues, such as bones and tissues other than bones have almost the same density deviating within 10%, therefore it is possible to determine the hardness (Young's modulus) of articular cartilage utilizing the acoustic velocity distribution.

[0100] As an acoustic velocity in the articular cartilage is about 1600 m/s while an acoustic velocity in the skin is about 1200 m/s, an acoustic velocity in the fat is about 1400 m/s, and an acoustic velocity in the subchondral bone is about 3500 m/s, it is easy to distinguish the articular cartilage from other tissues by evaluating the acoustic velocity distribution of the area and one can estimate thickness and surface roughness of the cartilage.

[0101] Further, the smaller cells will provide more accurate prediction of minute swells and minute cracks on the surface of the articular cartilage.

[0102] For obtaining more accurate acoustic velocity distribution, it is necessary to use much travel-time curves, a number of the travel-time curves are caused to pass through the area of the measurement target by independently moving the respective positions of the bilaterally disposed ultrasonic transducers. Furthermore, the bilaterally disposed ultrasonic transducers are moved along an arc-like manner with the use of a linear slider **10** formed in the shape of an arc, instead of linear movement of the bilaterally disposed ultrasonic transducers.

[0103] Since not only ultrasonic velocity but also an attenuation of the signal (attenuation coefficient) during the propagation differs from one living tissue (an organ) to another and the attenuation coefficient varies depending on a degree of damage of the organ, it is possible to identify an organ and to evaluate the damage with the attenuation coefficient. It has been reported that an attenuation coefficient of the cartilage changes when heavily loaded, which suggests that a damaged cartilage with heavy load can be identified by determining the attenuation coefficient (see "Ultrasonic attenuation in articular cartilage" by Senzig, A. D., Forster, K. F., and Olerud, J. E., J. Acoust. Soc. Am., et al., 92 (2), (1992), pp. 676-681).

[0104] A distribution of the attenuation coefficient can be obtained by the same procedure as shown in FIG. **12**, however, an amplitudes of the echo signals is required, it is difficult to obtain a true attenuation coefficient distribution because the amplitudes are disturbed by noises. On the other hand, in case of the acoustic velocity distribution, the amplitude of the echo signals are not necessary, but only the reflection time from the cartilage and the subchondral bone are required, therefore the acoustic velocity distribution is rarely disturbed by noises, and the method is practical.

[0105] In the ultrasonograph of Embodiment 2, the signal emitted from the transmitting transducer **8** is received by the receiving transducer **9**, whereupon an acoustic velocity distribution is acquired according the procedure shown in FIG. **12**, so that the transmitting/receiving ultrasonic transducer **7** located at the center of the device is not an indispnsable component. Since two reflection times from the cartilage and the subchondral bone are detected from one reception signal, it is possible to determin a detailed acoustic velocity distribution with fewer numbers of measureing points (fewer combinations of the transmitting ultrasonic transducer **8** and the receiving ultrasonic transducer **9**).

[0106] However, if the position of the probe **5** is deviated from the perpendicular to the articular cartilage, the ultrasonic wave emitted from the transmitting ultrasonic transducer **8** is not reflected to the direction of the receiving ultrasonic transducer **9**, so that the echo signals from either of the articular cartilage or the subchondral bone cannot be detected. Accordingly, when the probe **5** is diposed perpendicular to the articular cartilage, the echo signals from the respective surfaces of the articular cartilage and the subchondral bone are likely recevied by the receiving transducer, the transmitting/receiving transducer **7** is diposed at the center of the device for detecting the direction of the transducer.

[0107] An example of various types of information of the articular cartilage, detected by the ultrasonograph of the embodiment 1 or 2 displayed on the display **14** is shown in FIG. **14**. The signal intensity of the transmitting/receiving ultrasonic transducer **7** for indicating whether the probe **5** is positioned in an adequate angle is displayed by a horizontal bar at the upper left corner of the disply **14**. An operator can recognize visually whether the angle of the probe **5** is adequate or not.

[0108] According to the relation between the ratio of signal intensity variation (the transducer distance)–the maximum signal intensity as shown in FIG. **9**, the obtained result of the thickness and the inclination value (the signal intensity variation)/(the transducer interval variation) are displayed numerically at the upper right. Further, by displaying the signal intensity and the inclination, together with the acoustic velocity distribution, one can underdtand a state of the damage of the articular cartilage, minute swells, and minute cracks visually.

[0109] The surface of a normal articular cartilage is smooth, but once the surface is damaged with cracks and defects, the surface becomes uneven and is no longer smooth. By visualizing the velocity distribution inside the articular cartilage, one can tell the state thereof by analyzing the velocity distribution. In the visualized velocity distribution, if a boundary between the articular cartilage and the skin area is indicated as a straight line, the surface is consider to be smooth and in the normal state. If the boundary is indicated as a curved line having small unevenness, one can tell that there might exist small bumps and pits on the surface of the articular cartilage.

INDUSTRIAL APPLICABILITY

[0110] According to the present invention, it is possible to obtain thickness as well as hardness of an articular cartilage, minute swells, minute cracks of the articular cartilage without inserting a probe into a cavitas articulare. Further, it is possible to obtain thickness as well as hardness of a blood vessel in the vicinity of the skin, minute swells, minute cracks of the blood vessel through the skin and it is possible to diagnose a progress state of a disorder of the articular cartilage through the skin. It is also possible to determine thickness as well as hardness of a bone in the vicinity of the skin, minute swells and minute cracks through the skin.

1. An ultrasonograph comprising:

a probe having a transmitting/receiving ultrasonic transducer provided at center thereof, a transmitting ultrasonic transducer and a receiving ultrasonic transducer symmetrically movable with respect to the transmitting/receiving ultrasonic transducer;

a processor for obtaining signal intensity at a certain transducer distance between the symmetrically movable transducers, by processing echo signals of the receiving ultrasonic transducer and the transmitting/receiving ultrasonic transducer, and

a display for displaying a relation between signal intensity and the transducer distance, and an echo signal of the transmitting/receiving ultrasonic transducer.

2. The ultrasonograph according to claim **1**, wherein assuming a transducer distance where the maximum signal intensity as a center value, obtaining a (signal intensity deviation)/(transducer distance deviation) as a signal deviation ratio, plotting the maximum signal intensity along the horizontal axis and the signal deviation ratio along the vertical axis, thereby indicating degree of damage of the articular cartilage by the location of the plot.

3. An ultrasonograph comprising:

a probe having a transmitting/receiving ultrasonic transducer at the center thereof, a transmitting ultrasonic transducer provided on one side of the transmitting/receiving ultrasonic transducer and a receiving ultrasonic transducer provided on the other side thereof so as to be independently movable;

a processor for obtaining acoustic velocity distribution across the cross section of a diagnosis object, by processing echo signals of the receiving ultrasonic transducer, echo signals of the transmitting/receiving ultrasonic transducer and the transducer distance between the movable ultrasonic transducers; and

a display for displaying the acoustic velocity distribution and a signal of the transmitting/receiving ultrasonic transducer.

4. The ultrasonograph according to claim **3**, wherein obtaining an ultrasonic travel-time of the diagnosis object utilizing signals obtained by changing respective positions of the transmitting ultrasonic transducer or the receiving ultrasonic transducer, and obtaining the difference between the detected ultrasonic travel-time and the travel-time based on an acoustic velocity distribution of a numerical model of the diagnosis object repeatedly until the difference converges within an allowable value.

5. The ultrasonograph according to claim **1**, wherein the receiving ultrasonic transducer and the transmitting ultrasonic transducer are tilted at an angle in a range of 45 to 85 degrees.

* * * * *

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公开(公告)号	US20100030077A1	公开(公告)日	2010-02-04
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摘要(译)

超声波检查仪包括探头5，探头5在其中心设置有发射/接收超声换能器7，探头5包括发射超声换能器8和接收超声换能器9，它们相对于发射/接收超声波可对称地移动。换能器7.使探头5与诊断区域的皮肤接触，使用换能器7的回波信号将探头5的方向调整为垂直于诊断对象。然后，发射超声换能器8的回波信号和发送/接收超声换能器7，并且处理超声换能器8,9之间的距离以获得信号强度。结果显示在显示器14上，以在视觉上指示关节软骨的厚度，硬度和表面状况，从而可以在不将探针插入腔管的情况下诊断关节软骨。