Invivo quantification of motion in liver parenchyma and its application in shistosomiasis tissue characterization

*Ahmed M. Badawi , **Ahmed M. Hashem
*Abou-Bakr M. Yossef , **Mohamed F. Abdel-Wahab
*Biomedical Engineering Department, Cairo University, Cairo, Egypt
**Tropical Medicine Department, Faculty of Medicine Cairo University, Cairo, Egypt

ABSTRACT

Shistosomiasis is a major problem in EGYPT , despite an active control program, it is estimated about 1/3 of the population . Deposition of less functioning fibrous tissues in the liver is the major contributory factor to the hepatic pathology. Fibrous tissues consist of a complex array of connective matrix material and a variety of collagen isotopes. As a result of an increased stromal density (collagen content), the parenchyma became more echogenic and less elastic (hard).
In this study we investigated the effect of cardiac mechanical impulses from the heart and aorta on the kinetics of the liver parenchyma. Under conditions of controlled patient movements and suspended respiration, a 30 frames per second of 588*512 ultrasound images (cineloop, 32 pels per cm) are captured from an aTL ultrasound machine, then digitized. The image acquisition is triggered by the R wave of the ECG of the patient. The motion that has a forced oscillation form in the liver parenchyma is quantified by tracking of small box (20-30 pels) in 16 directions for all the successive 30 frames. The tracking was done using block matching techniques (the max correlation between boxes in time, frequency domains, and the minimum SAD (sum absolute difference)between boxes). The motion is quantified for many regions at different positions within the liver parenchyma for 80 cases of variable degrees of shisto. , cirrhotic livers and for normal livers. The velocity of the tissue is calculated from the displacement (quantified motion), time between frames, and the scan time for the ultrasound scanner. We found that the motion in liver parenchyma is small in the order of very few millimeters, and the attenuation of the mechanical wave for one ECG cycle is higher in the shisto. and cirrhotic livers than in the normal ones, also we found that the magnitude of motion is small in the cirrhotic and shisto. livers than in the normal ones. Finally quantification of motion in liver parenchyma due to cardiac impulses under controlled limbs movement and respiration may be of value in characterization of shisto. (Elasticity based not scattering based). This value could be used together with the wide varieties of quantitative tissue characterization parameters for pathology differentiation and for differentiating subclasses of cirrhosis as well as the determination of the extent of bilharzial affection.

1. INTRODUCTION

Ultrasound was first used to diagnose liver diseases in the sixties. The normal liver exhibits a uniform pattern of linear echoes arising from small vessels and the connective tissue framework [1]. Liver cirrhosis is conventionally considered to be the end result of hepatic fibrosis, which is characterized by the formation of numerous nodules. The major pathological consequence of this process is replacement of liver parenchyma by fibrous tissue. Therefore, the deposition of large amounts of collagen associated with a permanent distortion of normal liver parenchyma architecture is the hallmark of pathogenesis of liver cirrhosis.

Changes in tissue elasticity are generally correlated with pathological phenomena. As a result of increased stromal density (collagen), the tissues appear harder, and the elasticity is decreased [2].
In recent years great interest has been devoted to characterization of soft tissues using ultrasound pulse-echo method. A common objective is to find properties that enable discrimination of healthy from diseased tissue [3-19].
Several researchers have described methods to calculate the motion in soft tissue developed by either external or internal mechanical source.

The techniques used to measure tissue motion rely on one of the following procedures:
I- Doppler velocity measurements[20-22].
II- Correlation techniques[23,25-28].
III- Image inspection from M-mode wave forms and B-mode[24].

0-8194-1771-8/95/$6.00

2. DATA ACQUISITION , MATERIALS AND METHODS

Under conditions of controlled limb movement and suspended respiration (full inspiration), liver parenchyma and other soft tissues in the human body will exhibit motion due to mechanical impulses caused by the cardiovascular activity of the heart and aorta. Some biological tissues have both elastic and viscous properties. In liver, the motion takes the form of forced oscillation, resulting from periodic input source. Since cirrhosis is characterized by increased collagen content thus making the parenchyma harder than normal. Thus mobility of the cirrhotic, schistosomal and normal tissues will differ depending on the elastic and viscous properties which depends on the stromal density in the tissues. Thus quantifying the mobility due to cardiac pulsation for the liver parenchyma may lead to prediction of some of the elastic and viscous properties.

In the DAS system, the video output of an aTL sector ultrasound scanner was connected to a Nova Microsonics grabber card. The cineloop images (30 frames per sec) at 3.5 Mhz, triggered with the R-wave are captured in 588*512 pixels, the resolution is 8 bits/pixel (see Figure 1). A s/w program to define the box for matching and for the motion analysis has been developed on a PC-486 HP machine under DOS and WINDOWS environments.
To obtain a reproducible results, the following parameters were standardized :
1-**Ultrasound machine settings:** e.g., TGC, FOCUS, FREQUENCY, and ZOOM controls, which can change the overall image gain and produce zooming effects and hence deviates the image statistics in an unpredictable way. Moreover, the frequency of ultrasound waves used must be the same since the attenuation is frequency dependent.
2-**Tracking Box shape and size:** to obtain a reliable statistics, the number of pixels in the Box must be at least 400 pixels (i.e a region of 20*20 pixels corresponding to about 7mm*8mm), the shape of the box is taken to be square.

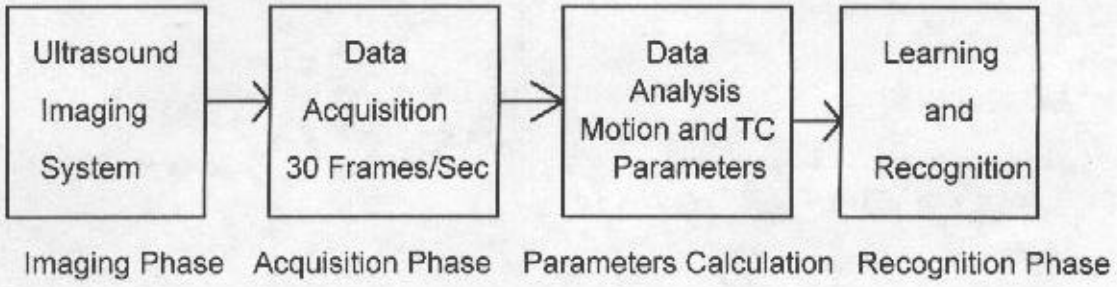


Figure 1: Block diagram for the data acquisition , data analysis , and recognition phases

The small motion due to cardiac impulses between two consecutively B-mode images is quantified using both SAD (sum absolute difference) and correlation .
The correlation[27] is defined below:

$$\rho_{m,n} = \left[\frac{\sum_{i=1}^{l}\sum_{j=1}^{k}(X_{i,j}-\bar{X})(Y_{i+m,j+n}-\bar{Y})}{\sqrt{\sum_{i=1}^{l}\sum_{j=1}^{k}(X_{i,j}-\bar{X})^2 \sum_{i=1}^{l}\sum_{j=1}^{k}(Y_{i+m,j+n}-\bar{Y})^2}} \right] \qquad (1)$$

where the term in the brackets is the correlation between an l*k cell region in image X and the corresponding region displaced by m,n in image Y. $\bar{X}$ and $\bar{Y}$ are the mean pixel values of the corresponding regions in the image. The correlation coefficients are calculated at locations on a grid within a search region centered around the original target box. The tracking scheme is done in 16 different directions around the original box for a distance up to 1 cm from the original box (the motion magnitude is small in liver parenchyma due to cardiac pulsations) see Fig. 2

The position of the max $\rho_{m,n}$ is the new target position. The detectability of movement can occur in both negative and positive directions from the first selected box. Again the target position is determined for max$\rho_{m,n}$ until we perform the tracking for all the 30 frames then the displacement vector is stored two-dimensionally in x and y directions for total movement in one second .

Another algorithm for tracking is done using the min SAD defined as follow:

$$\Psi_{m,n} = \sum_{i=1}^{l}\sum_{j=1}^{k}\left|X_{i,j} - Y_{i+m,j+n}\right| \tag{2}$$

The same is done as in correlation method, but we get the position for the target box at (m,n) corresponding to min $\Psi_{m,n}$.

Both the two techniques yielded approximately the same result in our study for liver since the degree of motion is small and rarely the target box moves greater than 2 pixel in x and y directions (note the dimension of one pixel is =1/32 cm in x direction and 1/24 cm in y direction).

We executed this tracking method for each case at many different position (25 different positions at the subcostal section), then averaged to get an average motion within the parenchyma. This is done for about 80 cases of variable degree of cirrhosis, variable degree of schistosomiasis and of normal liver parenchymas.

Since the target is moving, the velocity of movement is determined using the following equation[29]:

$$V = D_{xy} / (T + \Delta T) \tag{3}$$

where D_{XV}

$$D_{xy} = \sqrt{D_x^2 + D_y^2} \tag{4}$$

T is the time between frames (boxes at the same place) and the catch up time ΔT is given by:

$$\Delta T = D_{XV}/V_S \tag{5}$$

where V_S =(aperture length/scan time t_S) see Fig. 3.

Since ΔT <<T we can simply neglect it from the equation.

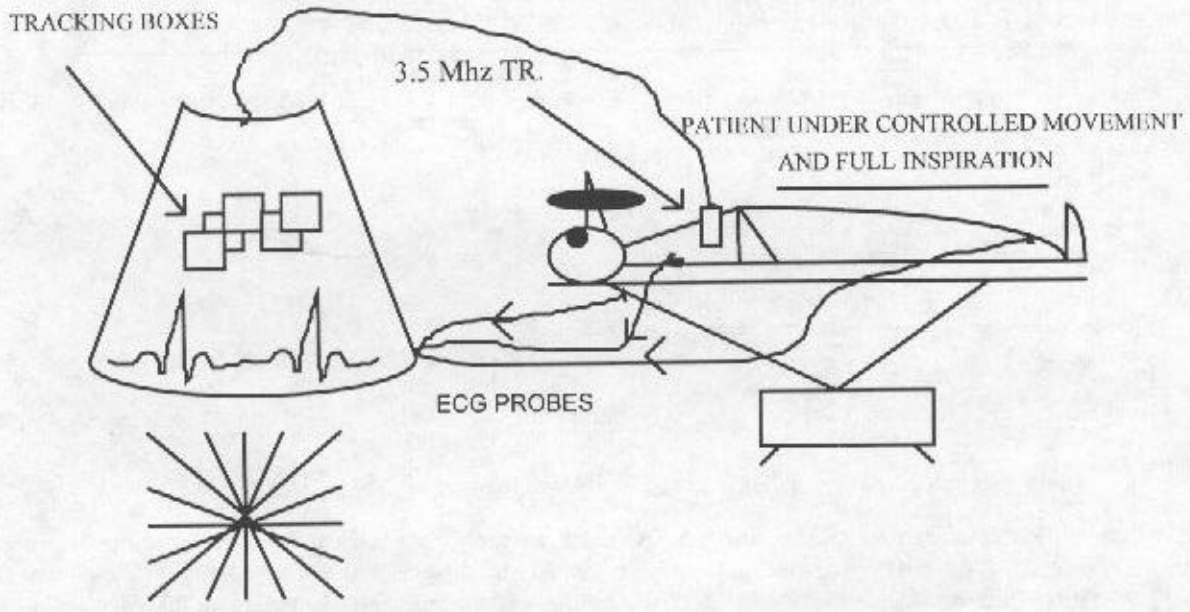


Figure 2: Scanning in 16 directions up to 1 cm away from the original box

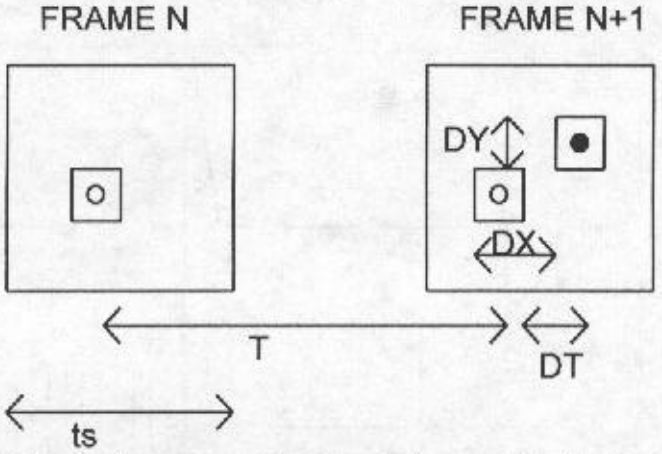


Figure 3: Showing two successive B-mode images Sep. by image period T, the scan time ts , the frame N+1 displaced Dx and Dy adding additional catch up time DT as indicated

3. RESULTS

We executed the tracking methods for each case at many different position within the parenchyma then averaged to get an average motion and an average velocity of movement. This protocol is done for about 80 cases of variable degree of cirrhosis, variable degree of schistosomiasis and of normal liver parenchymas.

Note All the 80 cases performed a needle *BIOPSY* .

We calculated the position vector for certain position of the initial box then we determined the velocity and movement from this position vector then we changed the position of the box at secondary position in the parenchyma then we determined another position vector then we calculated the motion and velocity corresponding to this position.

This is done for 25 different position in the liver parenchyma of the case (at subcostal position) then we average the velocity and motion to get an average motion and average velocity from these 25 measurements. Knowing the x resolution which is 24 pixels per cm and the y resolution which is 32 pixels per cm, the velocity of each frame is calculated (see Fig 4 and its following examples for one sample of the position vector out of 25 for each case).

Positions of movements for normal case for image 2 (Dx, Dy, Velocity)

0	0	0.00000000	0	-1	0.00341145	0	0	0.00000000
0	1	0.00341145	0	0	0.00000000	0	1	0.00341145
0	0	0.00000000	0	0	0.00000000	0	0	0.00000000
0	0	0.00000000	0	1	0.00341145	0	0	0.00000000
2	0	0.00508529	0	0	0.00000000	-1	1	0.00426920
1	0	0.00255062	0	0	0.00000000	-2	1	0.00617717
0	0	0.00000000	0	0	0.00000000	0	0	0.00000000
0	0	0.00000000	0	0	0.00000000	0	0	0.00000000
-1	0	0.00256672	1	1	0.00425954	0	0	0.00000000
0	0	0.00000000	0	1	0.00341145			

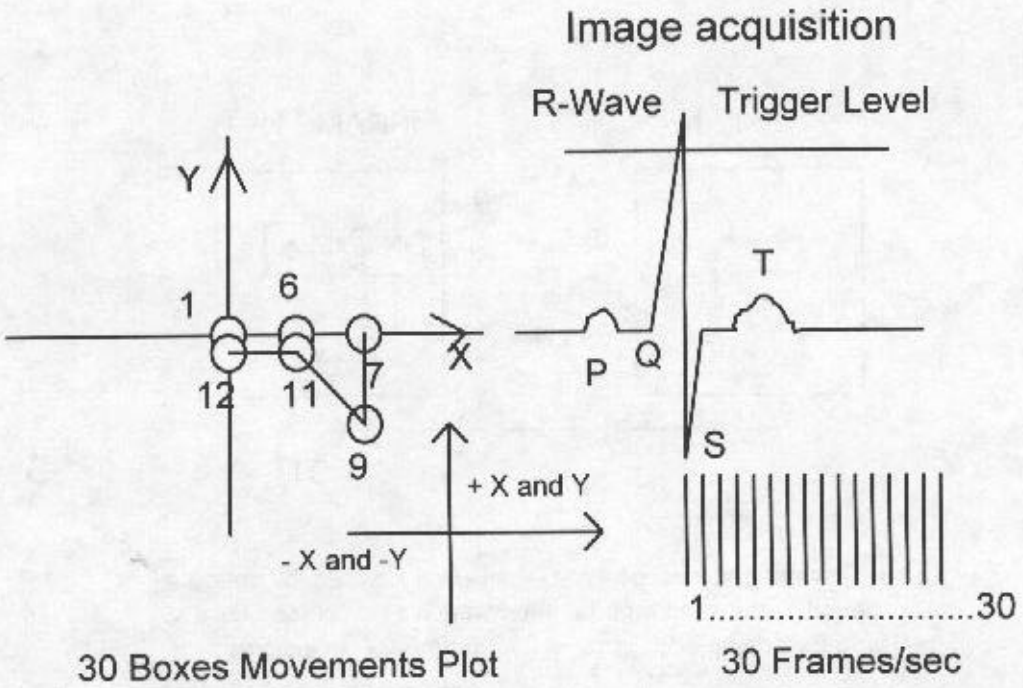
Average Velocity=2.27432 mm/sec

Note The original box is 0 0 0.0000000000

For the Early cirrhosis case of image 1, the average Velocity in all frames =1.13566 mm/sec

For the Cirrhotic case of image 3, the average Velocity in all frames =0.454266 mm/sec

For the Bilharzial case of image 4, the average Velocity in all frames=1.54266 mm/sec



Box Position Graph Movement for the First 12 Frames of Image 1

X	0	0	0	0	0	1	1	0	0	0	-1	-1
Y	0	0	0	0	0	0	0	0	-1	0	+1	0

+ 1 For Upward Movement For Both X and Y

- 1 For Downward Movement For Both X and Y

Figure 4: Samples of the 2-D position vector for Image 1

The average motion and velocity is calculated for each case and we found that the order of magnitude for most of the cases the movement is small (0-6mm/sec) but the range of the movement for the cirrhotic and shitosomiasis cases is smaller in the range (0-2 mm/sec) while that for the normal ones (2-6 mm/sec) is higher.

4. DISCUSSION

The quantification of motion in liver parenchyma due to cardiac impulses for a controlled movement and respiration patients could be taken as a tissue characterization parameters together with the wide varieties of tissue characterization parameters used to diagnose diffuse liver diseases[10-15].

These parameters are four broad categories extracted from the pulse-echo data, these are:

1-Image textural parameters:

These are mean gray level (MGL), gray level variance(VAR), and five of the relevant gray level histogram percentiles. Co-occurence matrix parameters, such as contrast (CON), entropy (ENT), correlation (CORR), and angular second moment (ASM).

2-Speckle parameters:

These are mean scatterer separation (d), diffuse and specular intensity (I_d,I_s), specular standard deviation (σ_s) and a few other related parameters.

3-Radio frequency parameters:
These are attenuation coefficient (α) and backscattering coefficient (μ).
4-Autoregressive parameters:
These are normally 6*6 AR model matrix for a selected ROI (region of interest normally 50*50 pixels).

The sum of all these parameters may exceed 40 but the actual parameters used for classification of diffused diseases are 10 parameters (not including the motion, the total No. is 11).
These significant parameters are The mean gray level (MGL), histogram percentile 9(PER9), contrast (CON), entropy (ENT), correlation (CORR), angular second moment (ASM), attenuation coefficient (ATTEN), speckle separation (d), diffused intensity if scatterer (Id), specular intensity of scatterer (Is). All these parameters correlates pathologically with the state of the disease, for example the contrast value is the degree of coarsness of the tissue and entropy is the homogeneity.
These significant parameters are quantified for an ROI 2*2 cm (64*64 pixels) , at a depth of 4 to 8 cm from the surface of the transducer. We calculated the forementiond tissue caharcterization parameters for all the cases and we constructed our feature vectors for all the patients of different pathologies in the liver (Bilharzial, Cirrhosis, Normal, Fatty, Mixed Bilharzial Cirrhosis).
The feature vector used for classification by one of the classification techniques[10-15], contained the velocity of movement as a new tissue characterization parameter but it has some limitations.

The limitition of using the motion as a parameter value for characterizing diffuse diseases is that we should prevent patients from any movement or respiration during cineloop acquisition of images (7sec at least). The accuracy of the tracking method used for calculating motion is very high, it can calculate motion in the order of 1 pixel movement (1/32cm in axial direction and 1/24 cm in lateral direction). Many groups has detected the motion for calculating the velocity of blood[27,29] .
Other group used fourier analysis of the correlation between A-scans to separate three types of liver tissues, the normal liver , the metastatic and the histologically normal liver[25].
Another group has used the velocity fields analysis for determining the heart motion 30.

This work is done to be used together with the varieties of quantitative tissue characterization parameters extracted from the pulse-echo data aiming at differentiating diffused liver pathologies (shistosomiasis and cirrhosis), aiming at predicting some elastic properties of tissues invivo and in following up the cirrhosis changes after treatment. The conclusion is that we can use the motion of the liver parenchyma due to cardiac impulses for a patient of controlled limb movement and respiration as a tissue characterization parameters to classify diffuse liver diseases.

5. ACKNOWLEDGMENTS

This study was partially supported by the Egyptian ministry of health and US-AID sponsored shistosomiasis project grant no's 02/04/022 and 02/03/13

6. REFERENCES

1. Kossof G: Display techniques in ultrasound pulse echo investigations. JCU 2:61, 1974.
2. J. Ophir, I. Cespedes, H. Ponnekanti, Y. Yazdi and X. Li,"Elastography: A Quantitative Method for Imaging the Elasticity of biological Tissues", Ultras. Imag. 13, 111-134 (1991).
3. Chung-Ming Wu, Yung-Chang Chen, and Kai-Shang Hsieh, "Texture Features for Classification of Ultrasonic Liver Images.", IEEE Trans. on Medical Imaging, Vol. 11, NO. 2, June 1992.
4. Roman Kuc, "Clinical Application of An Ultrasound Attenuation Coefficient Estimation Technique for Liver Pathology", IEEE Trans. on Biomedical Engineering, vol. BME-27, NO. 6, June 1980.
5. Robert C. Waag,"A review of tissue characterization from ultrasonic scattering", IEEE Trans. on BME.,vol.31,NO.12, DEC. 1984.
6. Oosterveld BJ, Thijssen JM, "Texture in Tissue Echograms Speckle or Information?" J Ultrasound Med 9:215-229, 1990.

7. A. M. Youssef, A. A. Sharawi, IEEE symposium on ultrasound in philadelphia 1990 "K-sodata clustering analysis for diffuse liver disease".
8. D. Sclaps, U. Rath, J. F. Volk, I. Zuna, A. Lorentz, K. J. Lehmann, D. Lorentz, G. V. Kaick, W. J. Lorentz, "Ultrasonic tissue characterization using a diagnostic expert system". In bacharach, S. L. edn. :Information processing in medical imaging, p. 343, Martinus Nijhoff, Dordecht, 1886.
9. A. M. Youssef, A. A. Sharawi, Ahmed M. Badawi, IEEE symposium on ultrasound,philadelphia 1990, "Ultrasound velocity in cervix uteri for the diagnosis of cervical incompetence".
10. A. M. Badawi, A. M. Youssef, Annual Meeting of Egy. Society of Gastro. and Egy. Soc. of Ultras., December 1992,"Effect of Static Compression on the Acoustical and Textural Parameters of the Liver with Correlation to Diffuse Diseases".
11. A. M. Badawi, A. M. Youssef, Annual Meeting of Egy. Soc. of Gastro. and Egy. Soc. of Ultrasonography, December 1992, "Tissue Characterization of Diffuse Liver Diseases Using Neural Nets".
12. A. M. Badawi, A. M. Youssef, and Salim M. Emara , "Fuzzy Reasoning in Ultrasound Tissue Characterization of Diffuse Liver Diseases ", Proc. Conference on Electrnics, Circuits &Systems Cairo Nile Hilton Egypt , 1994.
13. A. M. Badawi, A. M. Youssef, and Salim M. Emara , "Ultrasound Tissue Characterization of Diffuse Liver Diseases Using Fuzzy Rules ",Proc. of International Fuzzy Systems Conference, Louisville, march, 1993.
14. Yasser M. Kadah, Aly A. Farag, Abou-Bakr M. Youssef, Ahmed M. Badawi, ANNIE Nov. 93 St. Louis, Missouri,"Statistical andNeural Classifiers for Ultrasound Tissue Characterization".
15. Yasser M. Kadah, Aly A. Farag, Abou-Bakr M. Youssef, Ahmed M. Badawi, SPIE Sept. 93 at Boston, Massachusetts,"Automatic Tissue Characterization from Ultrasound Imagery".
16. Insana M. F, Wagner R. F., Garra B. S. et al,"Analysis of Ultrasound Image Texture via Generalized Rician Statistics", Opt Eng. 225:743, 1986
17. Nicholas D, "Evaluation of Backscattering Coefficients for Excised Human Tissues, Results, Interpretation and Associated Measurement", Ultrasound Med Biol 8:17,1982
18. A. M. Youssef, Sclaps D., Lorentz W. J.,"Ultrasound Textural Synthesis Using 2-D Autoregressive Models for Pathology Characterization", SPIE, 1987
19. E. Walach, A. Shmulewitz, Y. Itzchak, and Z. Heyman, "Local Tissue Attenuation Images Based on Pulsed-Echo Ultrasound Scans", IEEE on BME, Vol 36, No. 2, Feb., 1989
20. Yamakoshi Y. Suzuki M. and Sato T.,"Imaging the elastic properties using low frequency vibration and proping ultrasonic wave", Japanese Meeting of Applied Physics, Spring 1987 Tokyo.
21. Lerner RM, Huang SR, Parker KJ. "Sonoelasticity images derived from ultrasound signals in mechanically vibrated tissues", Ultrasound in Med and Biol 1990; 16:231-239.
22. Parker KJ. Huang SR, Musilin RA, Lerner RM., "Tissue responce to mechanical vibrations for sonoelasticity imaging", Ultrasound in Med and Biol., 1990, 16:241-246
23. Diockenson RJ and Hill CR: "Measurments of soft tissue motion using correlation between A-scans", Ultrason. Imaging 4:71-82, 1982.
24. Eisenscher A.; Schweg. Toffler, E.;Pelletier, G.; Jacquemard, G. "La palpation echographique rythmee-Echosismographie", J. Radiol. 64:225-261;1983
25. M. Tristam , D. C. Barbosa, D. O. Cosgrove, J. C. Bamber and C. R. Hill, "Application of fourier analysis to clinical study of patterns of tissue movement", Ultrasound in Me. and Biol., Vol. 14 , No 8, pp: 695-707, 1988
26. M. Tristam , D. C. Barbosa, D. O. Cosgrove, D. K. Nassiri, J. C. Bamber and C. R. Hill, "Ultrasonic study of invivo kinetic characteristics of human tissues", Ultrasound in Me. and Biol., Vol. 12,, No 12, pp: 927-737, 1986
27. Laurence N. Bohs, and Gregg E. Trahey, "A novel method for angle independent ultrasonic imaging of blood flow and tissue motion", IEEE transaction on BME, Vol. 38, No. 3, March 1991.
28. Gregg E. Trahey, Stephen W. Smith, and Olaf T. Von Ramm, "Speckle Pattern Correlation with lateral aperture translation: Experimental results and implications for spatial compunding", IEEE BME Vol. 33, No. 3, May 1986.
29. Ramez E. N. Shehada, richard S.C. Cobbold and Peter A. J. Bascom,"Ultrasound methods for investigating the non-newtonian characteristics of whole blood", Initial work notes.
30. Guy E. Mailloux, Andre Bleau, Michel Berttrand and Robert Petitclerc, " Computer analysis of heart motion from two-dimensional echocardiogram", IEEE trans. on BME, Vol 34, No. 5, May 1987

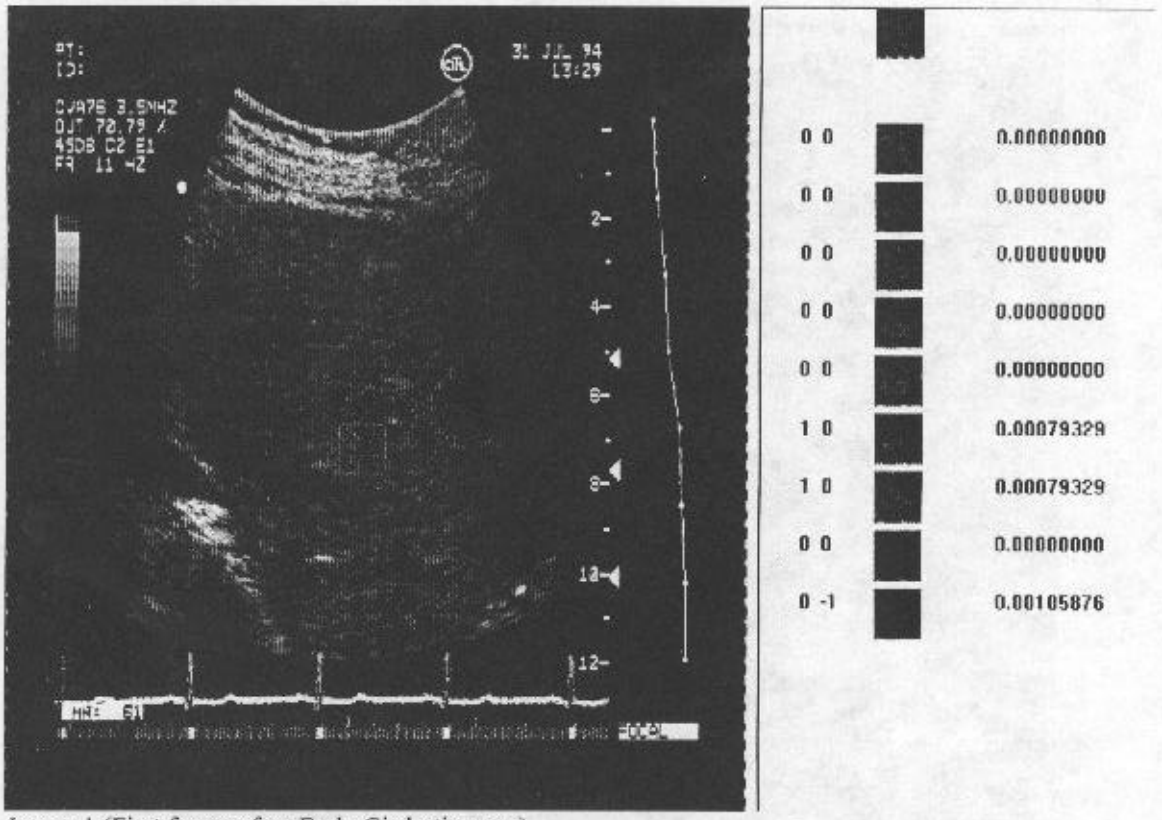


Image 1 (First frame of an Early Cirrhotic case)

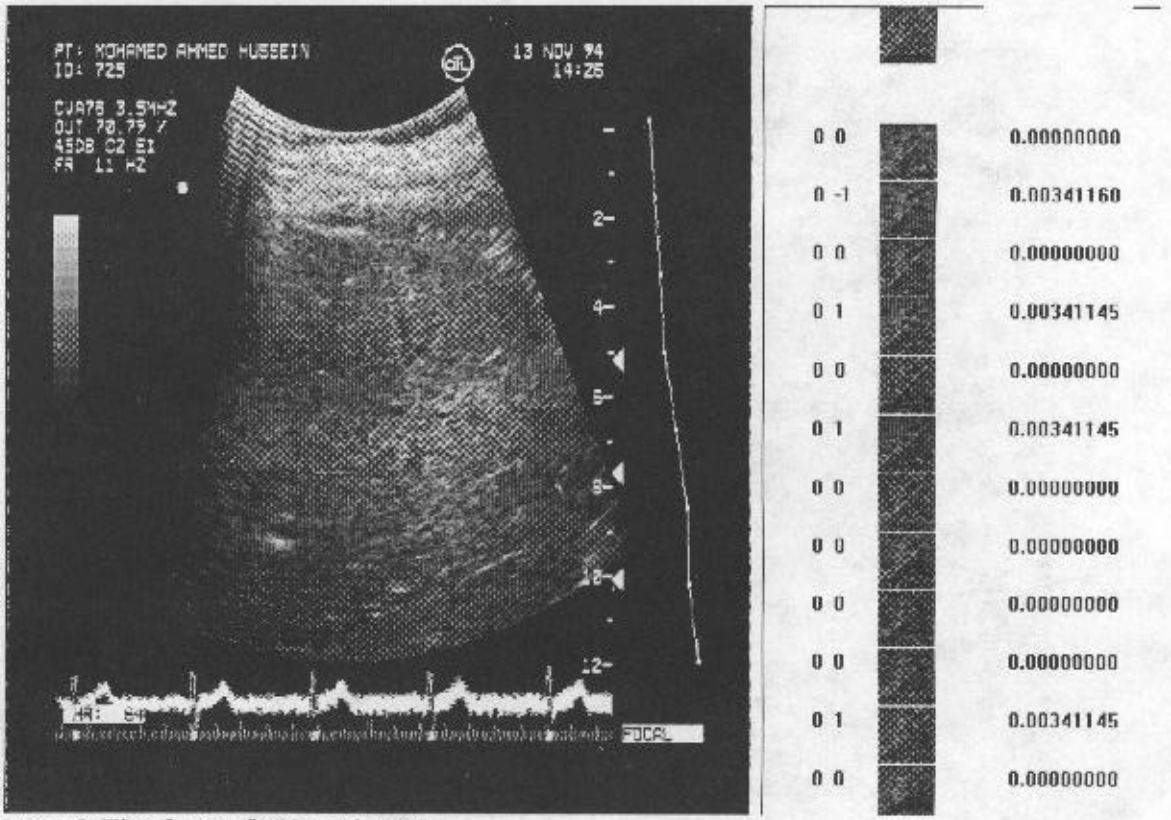


Image 2 (First frame of a Normal case)

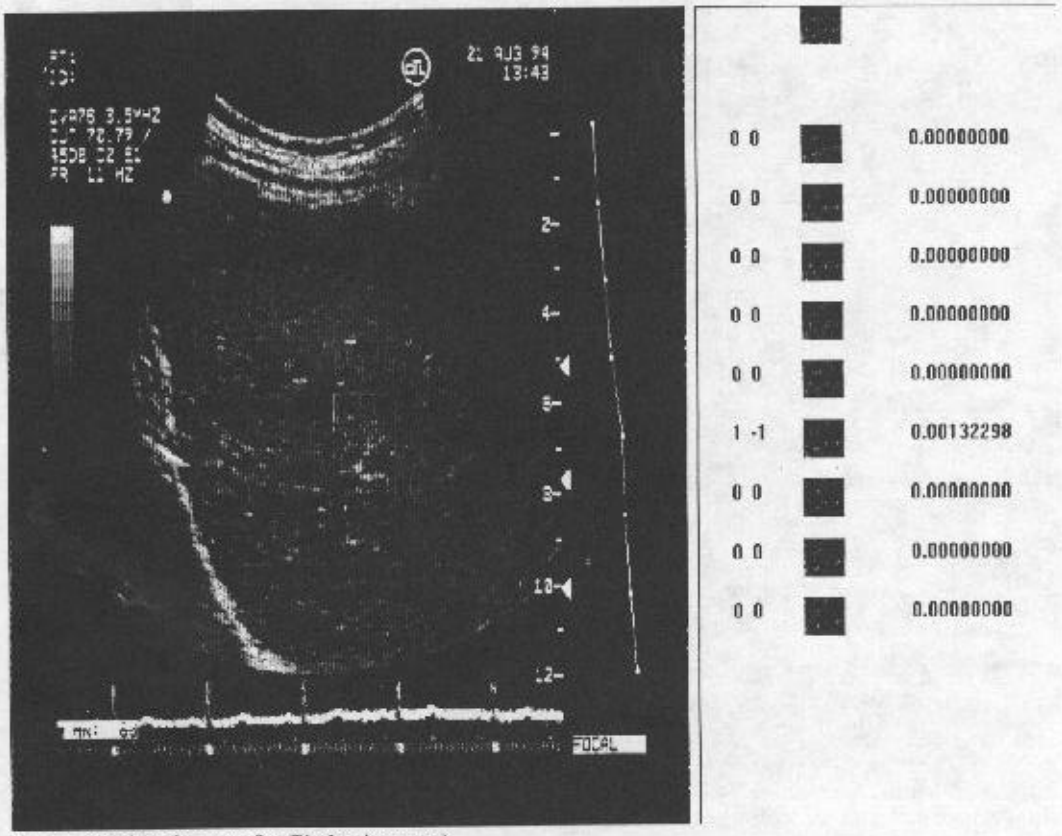


Image 3 (First frame of a Cirrhotic case)

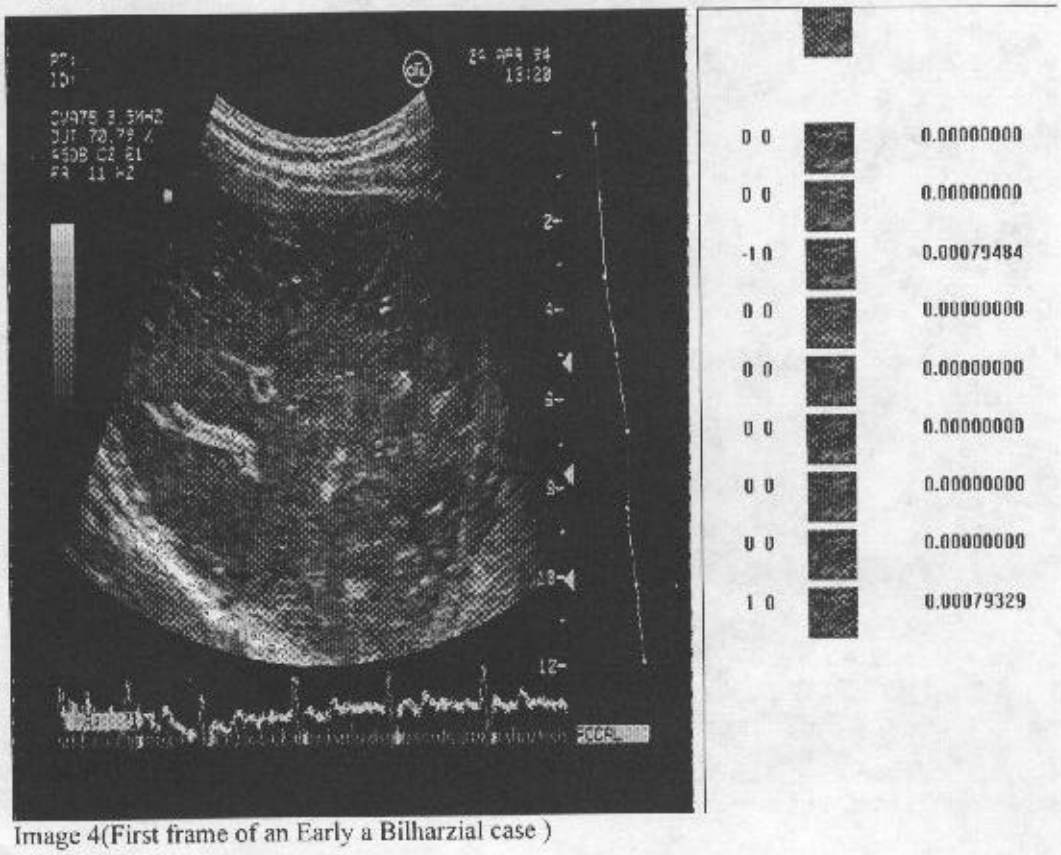


Image 4(First frame of an Early a Bilharzial case)