ULTRASONIC MEASUREMENT OF MEAT HETEROGENEITY DUE TO CONNECTIVE TISSUE

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Abstract

Ultrasonic image analysis is proposed as a quantitative technique for assessment of meat quality. We present in this paper experimental results on the measurement of meat macroscopic heterogeneity due to the connective tissue. The method is based on the estimation of the cross-correlation coefficient of echographic signals. In case of a homogeneous scattering medium, theory says that the cross-correlation coefficient rapidly vanishes with the distance between signals. The value of the cross-correlation coefficient depends only on the beam width. In case of a heterogeneous medium (macroscopic connective tissue) the correlation coefficient does not vanish and its value depends on the degree of heterogeneity. The degree of heterogeneity is also estimated through the ratio between the area of the macroscopic echogenic structure and the whole image area. It is shown that the degree of heterogeneity influences both the cross-correlation coefficient and the image surface ratio.

I Introduction

When processing echographic signals for mathematical analysis or image texture analysis, the homogeneity of the region of interest (ROI) is implicitly assumed in most of the cases. It is well known that an ultrasonic propagating pulse is either reflected by large scale structures (i.e. large in comparison to the wavelength) either scattered by small scale structures (in comparison to wavelength). Large structures (boundary between organs, connective tissue, vessels, etc ...) are responsible for specular reflection (mirror-like) and produces visible congruent image. On the contrary, the great number of scatterers randomly distributed (small scale structures like fatty and/or collageneous deposits, cells, fibres, capillarities, etc...) produces random interferences responsible for the statistic fluctuations of the echographic signal. This effect produces graininess or mottling aspect on echographic images, known as the speckle noise (BURCKHARDT 1978, WAGNER 1983). Ultrasonic tissue characterization is used as a quantitative non-invasive technique for assessment of meat quality. OPHIR (1991) had used an elastography method to caracterize biological tissues. BRETHOUR (1989) proposed a method of tissue characterization to marbling score in cattle based on the analysis of speckle texture.

In this paper, we propose a quantitative method of estimation of the degree of meat macroscopic heterogeneity based on the cross-correlation of echographic signals and on mathematical analysis of echographic images.

II Material and methods

II.1 Experimental setup

Experiments were performed in pulse echo mode in a water tank (Fig. 1). In order to scan the meat sample, the ultrasonic transducer was moved by stepper motors in front of the sample. The transducer (focus F=50 mm, diameter D=32 mm, center frequency 4 MHz) was driven by a programmable pulse generator and receiver (Contrôle US). The digitized data (frequency sampling 48 MHz) were transferred to a microcomputer for processing. The experiment was carried out on a bovine *Semitendinosus* muscle. The sample (size : 50x30x30 mm), was embedded in a gelatin gel. It was mounted inside a plexiglass cylinder and placed in the focal plane of the transducer during data acquisition. The measured lateral and axial resolutions were both equal to 0,6 mm at -6 dB. As expected, due to the high value of F/D, this transducer has a short depth focus of 3 mm at -6 dB. The length of the radiofrequency signals was 10.67 μs (i.e. 512 samples at the sampling frequency of 48 MHz) thus corresponding to 8 mm of tissue thickness. The volume was scanned by moving the transducer in step of 0.1 mm over a distance of 50 mm. The meat sample was positioned in the ultrasound beam with the muscular fibres oriented in the scanning direction and perpendicularly to the transducer axis (Fig. 2).

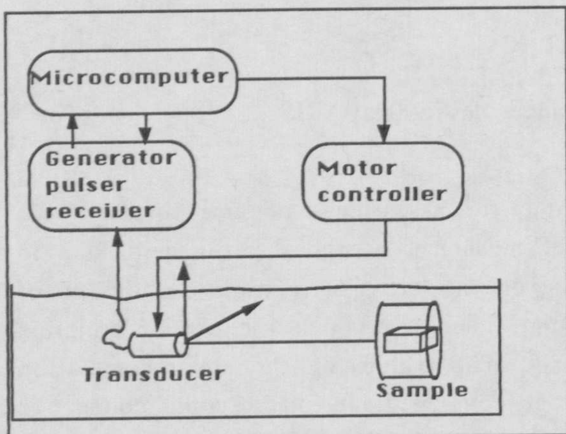

Fig. 1 : Block diagram of experimental setup.

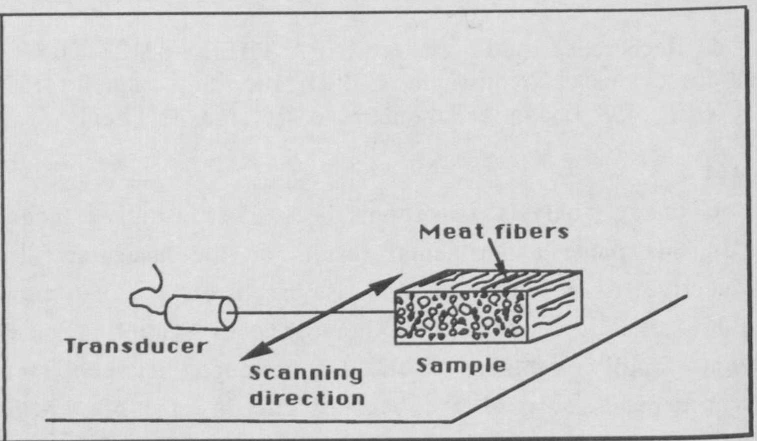

Fig. 2 : Orientation of meat fibers in the scanning direction.

II.2 Signal processing

The whole set of the echographic data corresponding to one scan were processed in order to obtain the echographic image. The whole ROI (8x50 mm) was divided into 5 subregions, each with a 10 mm lateral size. The influence of the hetereogeneity was assessed by processing separately each subregion. In each case, both the cross-correlation coefficient (CCC) $\rho(\delta)$ and the surface ratio were calculated.

II.2.a Cross-correlation

It is stated that, because of the random reflectivity of the scattering medium, the expectation with respect to the medium of the CCC must be calculated. Experimentally, the expectation with respect to the medium of the CCC of the echo is estimated as follows : 1) aquisition of radio frequency signals $e(t_k,\delta_i)$ of a duration of 10,67 μs for various lateral locations δ_i of the transducer at a fixed axial distance, 2) envelope detection, $E(t_k,\delta_i)$ being the envelope detected echo, 3) time integration of $E(t_k,\delta_i)E(t_k,\delta_j)$ and ensemble averaging, with respect to $\delta_i-\delta_j = \delta$, yields $<\sum_{k=1}^{N} E(t_k,\delta_i)E(t_k,\delta_j)>_\delta$. The estimated CCC $\rho(\delta)$ is given by the following relation :

$$\rho(\delta) = \frac{<\sum_{k=1}^{N} E(t_k,\delta_i)E(t_k,\delta_j)>_\delta}{\sqrt{<E(t,\delta_i)^2> <E(t,\delta_j)^2>}} \quad (1)$$

The measured CCC with a focused and unfocused transducers are summarized on Fig. 3. On this figure $\rho(\delta)$ is plotted versus the lateral displacement of the transducer. Each point of the curve $\rho(\delta)$ represents the average of CCC estimated on the set of pairs of echographic lines separated by the same distance δ. For example the data in figure 3 are derived from 100 echographic lines. The CCC corresponding to a shift of 0.2 mm is the average of CCC from A-line pairs 1 and 3, 2 and 4, 3 and 5, etc. Therefore, the points at greater shift represent fewer samples and are less accurate. Small values of δ yield an important correlation. As δ increases, $\rho(\delta)$ approaches an asymptotic value equal to 0.1. The half maximum width of the function $\rho(\delta)$ depends only on the ultrasonic beam width and is therefore larger in case of an unfocused transducer as it is shown on figure 3.

II.2.b Surface ratio

Figure 4.a shows a typical echographic image of the meat sample. High intensity specular reflection on any macroscopic heterogeneities of the ROI produces visible congruent dark images. These heterogeneities have been related to connective tissue by visual observation of the section of the sample submited to ultrasound measurement. Grey level histogram of a homogeneous scattering ROI is different from that obtained in presence of heterogeneities due to the high intensity specular reflection. Thus, slicing the grey level histogram is a method to isolate the specular images and to assess quantitatively

the degree of heterogeneity of the image. Slicing the histogram consist of : a) choosing a threshold value, b) selecting only the signal values (or grey level) which are above the threshold value, c) representing the image with the selected grey level. Images 4.a and 4.b show the comparison between the original image and the final image. The surface

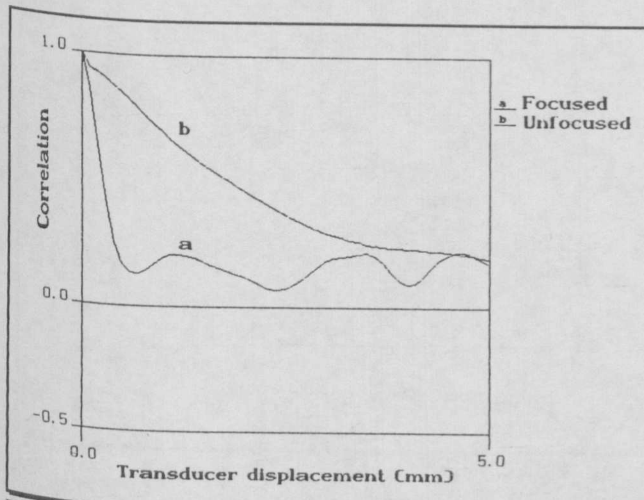

Fig. 3 : CCC $\rho(\delta)$ of the echo, measured in a homogeneous scattering tissue fantom, for : a) focused transducer, b) unfocused transducer.

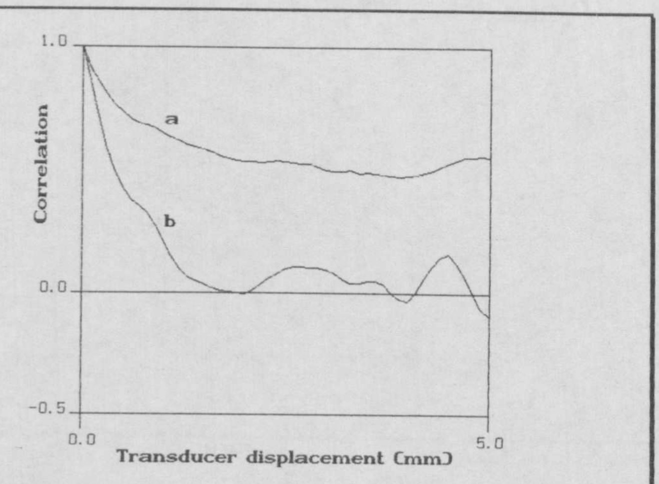

Fig. 5 Correlation on two different ROI.

ratio is estimated by the area of the structures still visible in the final image divided by the area of the original image.

III Experimental results and discussion

Figure 4. shows the echographic images of two different subregions of the same sample. On the first image (4.a) a macroscopic heterogeneous region is selected within two solid lines. On the third image (4.c)

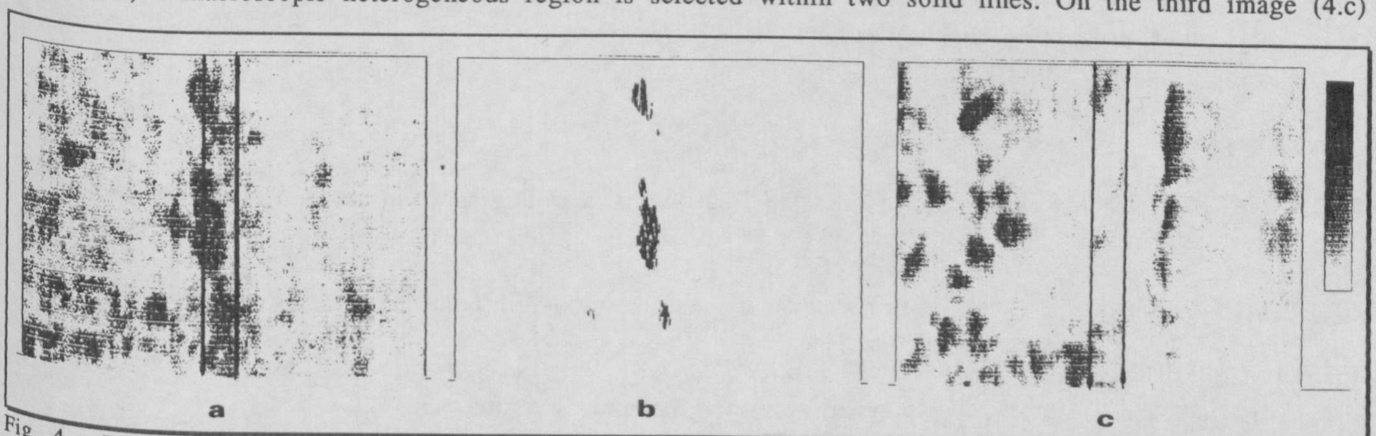

Fig. 4 : Echographic images. 4a : Selected region with macroscopic heterogeneities. 4b : Final image resulting from grey level histogram slicing. 4c : Homogeneous scattering region.

the selected region shows on the contrary a homogeneous scattering zone. Both the selected regions stand in the focal zone of the transducer and the corresponding data were processed. Figure 5 (see Fig. 3) represents the CCC estimated in both cases and clearly shows a strong correlation between the echographic signals in case of heterogeneity. The mean level reached by the CCC for high δ value is 0.52 for figure 5 curve (a) and 0.05 for curve (b). The measured surface ratio yield 8.47 % for curve (a) and 0.0 % for curve (b). On figure 6.a are plotted the CCC corresponding to five selected different regions and the result must be compared to the value of the surface ratio. On figure 6.b the mean level of the CCC is plotted versus the surface ratio. The mean level increases with the surface ratio. Obviously the surface ratio is related to the degree of macroscopic heterogeneity and increases with it. As shown on figure 6.b, The CCC is positively correlated to the surface ratio, and is also dependent on the degree of macroscopic heterogeneity of the ROI.

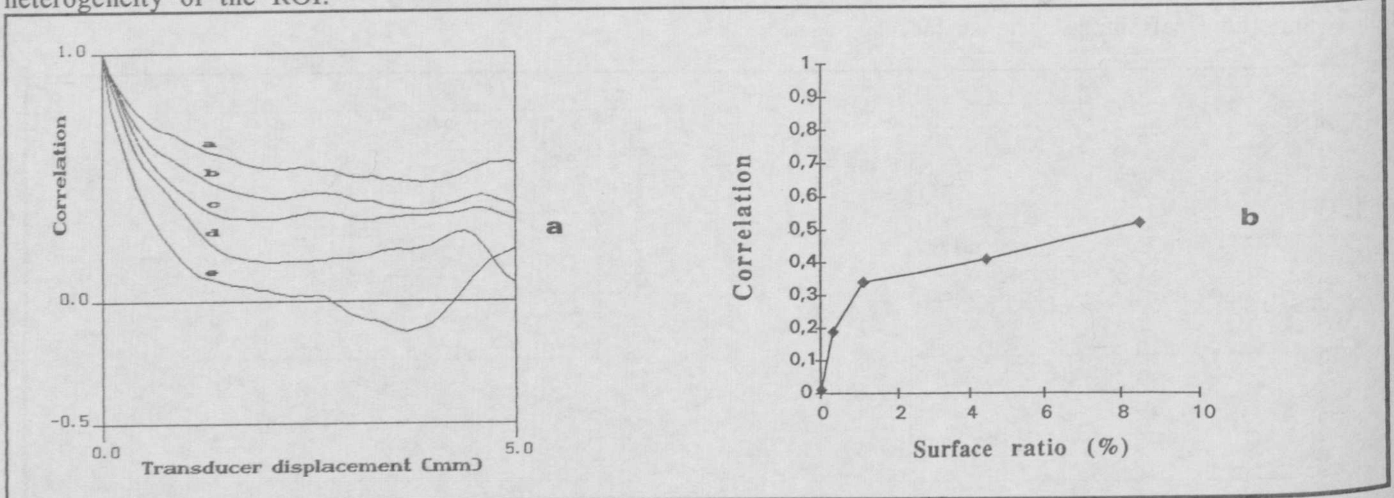

Fig. 6 : (a) : Correlation on different ROI, (b) : Correlation level versus surface ratio.

IV Conclusion

The degree of heterogeneity of a ROI was estimated by the ratio between the area of the macroscopic echogenic structures selected by histogram slicing and the area of the whole image. The correlation coefficient, calculated for the different regions of interest, was shown to increase with the degree of heterogeneity measured by the surface ratio. Thus we propose two quantitative indices for ultrasonic assessment of meat heterogeneity due to the connective tissue. The surface ratio is derived from the ultrasonic image and measures the visible heterogeneities. The correlation coefficient is not only related to the degree of heterogeneity but also to other tissue features not visible on the image such as tissue anisotropy or periodicity in the tissue scattering function. As the assumption of heterogeneity of the ROI is most of the time implicitely made, the surface ratio is an interesting quantitative index for the assessment of meat heterogeneity for it can be estimated in real time and can be used to select homogeneous ROI if required by other processing techniques.

V References

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