AN ORIENTED FRACTAL ANALYSIS FOR THE CHARACTERIZATION OF TEXTURE. APPLICATION TO BONE RADIOGRAPHS

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ABSTRACT: In this communication, we propose an oriented fractal analysis to characterize a texture. A frequency based method is used to measure the H parameter following different directions. The results are displayed on a polar diagram. Its analysis gives coefficients which quantify both the roughness of the texture and its anisotropy. This method is applied to the characterization of trabecular bone architecture by analysis of X-ray films. The whole acquisition process is optimized to obtain a good reproducibility of the results. Two studies show the medical interest of the method.

1. INTRODUCTION

Bone strength is not only depending on bone mass but also on the internal trabecular bone structure. During ageing, the bone mass is always reduced and sometimes this lost increases due to osteoporosis. In this case, the trabecular architecture is strongly modified which reduces the biomechanical competence. To study this architecture at the scale of the trabecular thickness, two techniques are available: histomorphometry [1] and radiography [2]. The first one is expensive and invasive, this is not the case of radiographs.

An X-ray view of a bone is a projection of the 3D complex structure. The resulting image shows a non stationary and anisotropic texture. An oriented fractal analysis can characterize both the roughness of the texture and its anisotropy.

Image lines can be modeled by the fractional Brownian motion (fBm) of parameter H ($0<H<1$) which is linked with the fractal dimension D by $D = 2 - H$. fBm is a non stationary stochastic fractal process which parameter quantifies the roughness of a texture [3]. In the medical domain, such studies have already been carried out in 1D [4] or in 2D [5].

To take into account the anisotropy, it is possible to characterize the texture following several directions. Previous studies have been done with a maximum likelihood estimation of H [6]. Results depend on acquisition conditions, mainly due to interaction between interpolation of the data and estimation method. To avoid these problems, we propose in this communication an oriented fractal analysis based on a 2D frequency approach.

First, the method is described and is applied to bone images. The results of a study of reproducibility is presented. Finally, the medical interest of the method is shown.

2. METHOD

The computation of the power spectral density (PSD) is one of the methods to estimate the H parameter. It is biased and has a relatively high variance on synthetic signals when compared to other methods. But, it has interesting practical properties. First, its implementation is easy and fast. The methodology is the same whatever the dimension of the data, and therefore it can be applied on signals or images without great changes. Second, the scales of measure can be choosen and then artifacts due to low frequency trend or high frequency noise can be avoid. Finally, the relative regularity of PSD surface allows to interpolate the data following all given angles, which is not the case of methods working directly on image data. All these advantages must be considered for a practical application.

The PSD of a 2D isotropic fBm is a revolution surface given by [7]:

$$PSD\ (f_1\ ,f_2\ ) \propto \frac{1}{(f_1^2 + f_2^2\ )^{H+1}}$$

where $\propto$ means proportional to.

In an anisotropic point of view, the PSD can be defined as previously with an H value depending of the orientation:

$$PSD_\theta\ (f_1\ ,f_2\ ) \propto \frac{1}{(f_1^2 + f_2^2\ )^{H(\theta)+1}}$$

where the θ is equal to the tangent of f1 divided by f2.

To realize the measure of $H(\theta)$, we define a vertical plane making an angle θ with the f1 axis and including the revolution axis of the PSD. The intersection between this plane and the PSD is a 1D curve as a function of the frequency. In a log-log coordinate, this 1D PSD becomes for fBm a straight line of slope -2H-2. It is then possible to estimate the H parameter by a linear regression. If the texture is isotropic, the H value does not depend on the angle θ. For an anisotropic texture, the H value depends on the analysis angle and characterizes $H(\theta)$.

We can display this variation on a polar diagram which gives a visual representation of the anisotropy.

To obtain parameters related to the anisotropy and the roughness of the texture, the polar curve $H(\theta)$ is decomposed in Fourier series as :

$$H(\theta)=\sum_{m=-M}^{M} Cm\ e^{im\theta}\quad ,\ 0\leq\theta<2\pi.$$

Due to the symmetry of the diagram, the odd coefficients

C2n+1 are equal to zero. We can give a geometrical signification to the even ones related to the shape of the polar diagram [8]. C0 is the radius of the mean square circle and is also the mean H value. It is related to the average roughness of a texture. If mod(C2)<<C0, then C0-mod(C2) and C0+mod(C2) are respectively the small and big axis of the mean square ellipse (mod means modulus of a complex number). We define an anisotropic index ANI as the ratio between the small axis and the big axis. The orientation of the ellipse is equal to 0.5*argument(C2).

C0 and ANI can represent respectively the mean roughness and the anisotropy of a texture.

3. APPLICATION TO BONE IMAGE TEXTURE

A region of interest (figure 1) corresponding to the trabecular bone is digitized on radiographs. This region is identified by 2 anatomic points A and B.

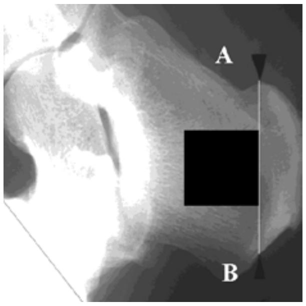

Figure 1 : Xray image of a calcaneum. The region of interest is the black square.

Images are 256 x 256 pixels width with a 8 bit resolution and with a 100µm spatial sampling period (figure 2). Images are non stationary and show details up to the smallest scales. They can be modeled by fBm [9]. An oriented fractal analysis can be done on these images. First, the PSD is to be estimated. To avoid the Gibbs phenomenon on the estimation of the PSD (figure 3), we apply a weighting window on the image :

$$f\,(\,x_1\,,\,x_2) = e^{-a\,(x_1^2\,+\,x_2^2)}.$$

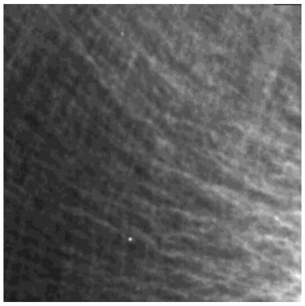

Figure 2 : Digitized region of interest of previous calcaneum.

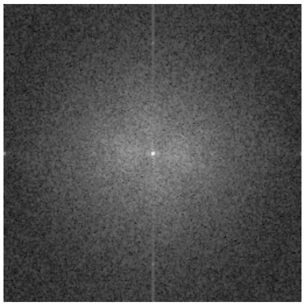

Figure 3 : Representation of Log(1+PSD) of figure 2.

An oriented fractal analysis as describe in paragraph 2 is performed on these images. For any angle, the 1D PSD shows two fractal zones (figure 4) : one in the low frequencies and the other in the high frequencies. This last zone is of interest because it is related to the variation at the scale of the trabecular thickness [10].

36 angles of analysis uniformly distributed between 0 and 2π lead to a polar diagram (figure 5). For this particular case, C0 is equal to 1.07 and ANI is equal to 0.76. The orientation is of 113°.

4. REPRODUCIBILITY OF THE METHOD

Several parameters of the acquisition process (film+digitization) are influent on the polar diagrams and a complete study has been carried out [11]. The process is optimized for our application and main results are presented. To avoid great variations of the Xray process, the same protocol has to be followed for each radiographs (MIN-R Kodak film, same Xray tube, voltage of 48kV, fixed exposure condition 18 mA-s for 0.08 s). More, the Modulation Transfer Function of the X-rays process is measured and we obtained at a spatial period of 100µm an attenuation of 11dB. Following this, a sampling period of 100µm is chosen and allows to analyse modifications at the scale of the trabecular thickness.

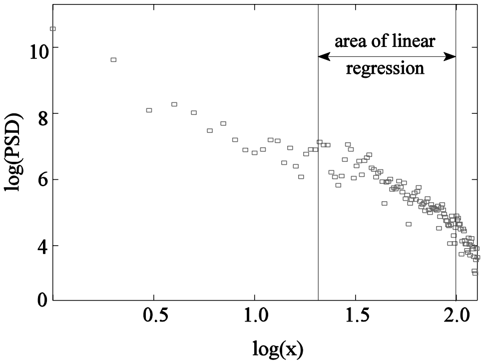

Figure 4 : Fractal area on 1D PSD cut.

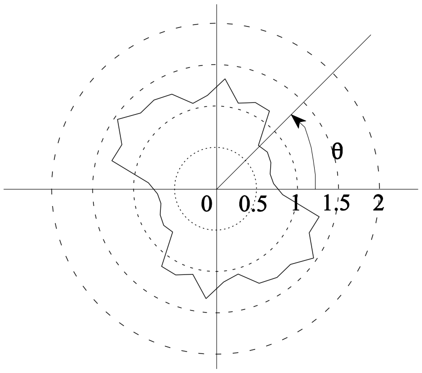

Figure 5 : Polar diagram of image on figure 2.

The digitization process is optimized for an optical density of X-rays films in the interval [0.4,3]. A lighting table Zeiss of 7800 Lux is chosen which has spatial variations less than 3% in a square area of 4x4 cm corresponding to the size of the region of interest.

Photometric distortions (vignetting and $\cos^4\theta$ law) in lens of the CCD camera are characterized. Controls are chosen to obtain minimal distortions. The aperture number is kept to 8.

The fractal analysis of texture is very sensible to the blur by involving an overestimation of the H parameter. Then, before each digitization campaign, we control the sharpness of the image by a semi-automatic process.

Gains and offset of the frame grabber and camera are automatically computed to have a mean dynamic of 220 grey levels.

An averaging process of 256 accumulations allows us to reach a signal to noise ratio of 50 dB.

A specific software has been developed to control the whole digitization process.

Geometric linked artifacts can also disturb our analysis: rectangular pixels of the CCD sensor, filtering at the output of the CCD shift register and sampling on a grid different from the CCD sensor one. Then, we propose to evaluate these effects on our analysis. It consists in digitizing the trabecular bone on the same film with a rotation around the optical axis of the camera of 10° between each acquisition. For these 36 images, we have reported the 36 polar diagrams by turning each one with an angle equal to the opposite angle of the rotation of the camera. The results reported on the same diagram show that all the polar diagram are nearly superimposed (figure 6). It means that the anisotropy of the diagram is related to the one of bone texture and that the artifacts of the acquisition and analysis processes have no significant influence.

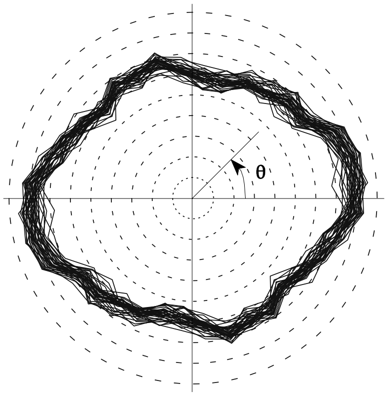

Figure 6 : Superimposed polar diagrams.

5. MEDICAL INTEREST OF THE METHOD

To prove the medical interest of the method, two studies have been carried out.

First, we have digitized 25 calcaneus radiographs from a control population and 28 from an osteoporotic one. As the structure is depending on the age, the two populations have to be fitted relatively to this parameter. The mean age of the osteoporotic population was 74.4±14.4 and the one of the control population was 77.3±12.1. The mean architectural quality is different for these two groups and should be pointed out by our oriented fractal analysis. The next table gives respectively the mean ± standard deviation for C0 and ANI for the two populations.

	Control	Osteopo.
C0	1.242 ±0.187	1.030 ±0.244
ANI	0.910 ±0.064	0.849 ±0.093

A student t test with a level of significance of 1% has been performed to evaluate the difference between the mean values.

Results show that both the mean C0 and ANI values are statistically different between the control and the osteoporosis populations while the mean age was identical. This means that on average, the architectural difference is pointed out by C0 and ANI.

To confirm these results, a second study has been carried out. We know that osteoporosis decreases the biomechanical competencies due to structural changes. As an oriented fractal analysis is supposed to be related to these changes, C0 and ANI should be correlated with biomechanical parameters. Then, some mechanical compression tests have been performed on a series of 42 bones from post-mortem subjects. This study involves destructive tests on bone tubes. We first took some radiographs to perform our texture analysis. Static tests of compression were applied to the tubes and we measured for each bone the ultimate strength (σu), the elastic modulus (Ee) and the densification modulus (Ed) [12]. The next table gives the correlation coefficients between the fractal and mechanical parameters.

	σ_u	E_e	Ed
C_O	0.584	0.460	0.543
ANI	0.323	0.270	0.336

A student t test with a level of significance of 1% has been performed to evaluate these correlation coefficients :

$$t = \frac{\rho \sqrt{n - 2}}{1 - \rho^2}$$

where ρ is the observed correlation coefficient and n is the size of the series. Results show that there is no correlation between ANI and the mechanical parameters. But, the correlation is present between C0 and the mechanical parameters. This shows that the average roughness of the texture seen on the X-ray view is correlated with the biomechanical competence of the bone.

6. CONCLUSION

In this paper, we have presented an oriented fractal analysis to characterize an anisotropic and non stationary texture. The results are presented on a polar diagram and by a decomposition in Fourier series, we obtained two parameters, C0 and ANI which represent respectively the mean roughness and the anisotropy of the texture. We applied this technique on numeric images of bone radiographs. The acquisition process is optimized in order to obtain a good quality for the images.

This technique is applied on bone images of 2 different populations (control and osteoporotic) and a statistic test shows that both C0 and ANI values are different between these 2 populations. Finally, mechanical compression tests were performed on bones and we obtained a correlation between C0 and the biomechanical parameters.

The results presented show that an oriented fractal analysis could characterize bone architecture.

REFERENCES

[1] E.F. Eriksen, D.W. Axelrod, F. Melsen, *Bone Histomorphometry*, Raven Press, New York, 1994.

[2] S. Grampp, M. Jergas, C.C. Glüer, P. Lang, P. Brastow, H.K. Genant, *Radiologic diagnosis of osteoporosis*, Endocrine Radiology, Vol.31, N°5, p.1133-1145, September 1993.

[3] A.P. Pentland, *Fractal-Based Description of Natural Scenes*, IEEE Trans. Pattern Anal. Machine Intell., N°6, p.661-674, November 1984.

[4] T. Lundhal, W.J. Ohley, S.M. Kay, R. Siffert, *Frational Brownian Motion : A Maximum Likelihood Estimator and Its Application To Image Texture,* IEEE Trans. on Medical Imaging, Vol MI-5, N°3, p.152-161, September 1986.

[5] S. Hoefer, H. Hannachi, M. Pandit, R. Kumaresan, *Isotropic Two-Dimensional Fractional Brownian Motion and its Application in Ultrasonic Analysis*, 14th Conference of the IEEE EMBS, N°3, p.1267-1269, 1992.

[6] G. Jacquet, W.J. Ohley, M.A; Mont, R. Siffert, R. Schmukler, *Measurement of bone structure by use of fractal dimension*. 12th Conference of the IEEE EMBS, N°3, p. 1402-1403, 1990.

[7] M.F. Barnsley, R.L. Devaney, B.B. Mandelbrot, H.0. Peitgen, D. Saupe, R.F. Voss, *The Science of Fractal Images*, Springer-Verlag, 1988.

[8] C. Léger, J. Thiel, R. Lédée, F. Patat, L. Pourcelot, *Left Ventricle Modelling by Discrete Polar Fourier Transform Using Echocardiographic Images*, 14th Conference of the IEEE EMBS, N°2, p.410-411, 1992.

[9] R. Jennane, R. Harba, *Fractional Brownian Motion: A Model For Image Texture*, Vol.3, p.1389-1392, EUSIPCO, Sept. 1994.

[10] R. Harba, G. Jacquet, R. Jennane, T. Loussot, C.L. Benhamou, E. Lespessailles, D. Tourlière, *Determination of Fractal Scales on Trabecular Bone X-Ray Images*, Fractals, Vol. 2, N°3, p.451-456, 1994.

[11] T. Loussot, *Etude et Optimisation d'un Système de Numérisation de Clichés Radiographiques : Application à l'Analyse de l'Architecture Osseuse*, PhD Thesis, University of Orléans, Nov. 1995.

[12] A. Jullien, E. Lespessailles, J.P. Ildefonse, G. Jacquet C.L. Benhamou, *Relation entre les Propriétés Biomécaniques de l'Os Trabéculaire du Calcanéum et sa Dimension Fractale*, Archives of Physiology and Biochemistry, Vol.103, N°3, July 1995.