ANALYSIS METHODS OF CT-SCAN IMAGES FOR THE CHARACTERIZATION OF THE BONE TEXTURE: FIRST RESULTS

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A*bstract* : Osteoporosis is a bone pathology inducing an increased fragility of the skeleton. With the lengthening of the duration of life, this pathology is going to concern an increasing population. A better knowledge of the quality of the bone structure can help a best prevention of the fracture risk. The bone mineral density is not the unique factor to determine the quality of the bone structure. The trabecular bone structure play an important role on the strength of the bone. The ultimate objective of the planned work is to propose a way for the characterization of the bone texture from the analysis of CT-Scan images. This would allow an assistance to the diagnosis in the discrimination of healthy from pathologic patients. This paper emphasizes a preliminary study concerning the selection of some characterization tools of the bone texture. The selectivity is lead by the analysis of respective sensitivities of considered methods.
We are going to study here several methods of texture analysis. These methods are based on the fractal geometry whose application to the analysis of texture is recent. We also give examples of results on healthy and pathological patients.

Keywords: Bone texture, CT-Scan images, Fractal method.

1. INTRODUCTION

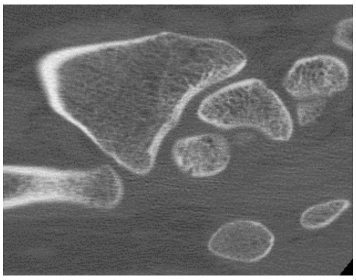
Osteoporosis is a bone pathology inducing an increased fragility of the skeleton. Its appears more frequently by women for hormonal reasons (menopause). It is also linked to the advancing age: indeed, at the age of 70, the density of the skeleton has decreased by 1/3. With the lengthening of the duration of life, this pathology is going to concern an increasing population. It often entails fractures of the wrist and of the femur neck (55000 fractures per year in France, which causes death in 25% of the cases).

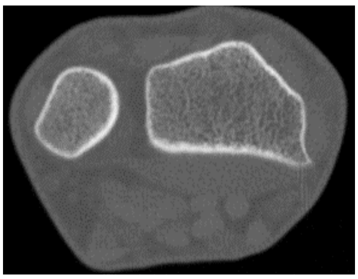
A better knowledge of the quality of the bone structure can help a best prevention of the fracture risk. Indeed, a healthy person owns large and long bone frameworks which characterize the quality of the bone structure. At the opposite, the patient bearing bone pathology shows an altered fractured bone structure. Among currently proposed methods, the needle biopsy remains traumatic and therefore is rarely practices.

The ultimate purpose of the planned work is to give the means of characterizing the bone texture from the analysis of CT-Scan images. This would allow assistance to the diagnosis in the discrimination of healthy from pathologic patients. This paper emphasizes a preliminary study concerning the selection of some characterization tools of the bone texture. There are generally 3 classes of analysis related to the texture characterization in images: (i) the statistical, (ii) structural (iii) and the fractal analysis.

Statistical parameters account for local properties of the image. Structural parameters inform on both the physical limits of the objects framing the image and the homogeneity of the surface of these objects. Finally the fractal geometry gives a measurement of the complexity and the global irregularity of the bone texture.

The distal radius is an usual site of osteoporotic fractures, rich in trabecualr bone. We have studied this site. The study will be done for the first time to our knowledge on images coming from CT-Scan slices of the inferior extremity of the radius. 8 contiguous slices will be selected for each patient: 4 axial and 4 frontal slices (Figures 1 and 2). The thickness of slices is l mm; the images are of size 512*512 pixels; each pixel having been quantized to 4096 or 256 Grey levels. The voxel size is 0,2mm x 0,2mm x 1mm. The whole process is runned on a manually selected region of interest (R.O.I.) located so that it only contains trabecular bone. This square-shaped region is size varying according to the patient morphology and contains a thirty of grey levels.





Figures 1and 2 : Frontal and axial slices.

A distinction may be made between two approaches for texture analysis: the statistical and the structural approach. In statistical approaches, texture is quantified on the basis of the (local) spatial distribution of the grey-values parameters [1][2][3][4] [5][6][7].

In structural techniques, the image is described in terms of textural elements and their spatial relationships. Most of the texture-analysis algorithms described in the literature have been used for classifying rather dissimilar textures. Since the visually perceived differences in bone texture in radiographs are subtle, the texture-analysis method has to be rather sensitive. Various statistical methods of texture analysis were applied in order to translate the differences in bone structure into a set of textural. Current research is focused on morphological texture parameters and on comparing the usefulness of the different techniques in distinguishing patients with clinical osteoporosis from their healthy contemporaries [8][9][10][11].

We will study here two methods of texture analysis. The first one is based on the fractal geometry whose application to the analysis of texture is recent. After a brief recall on this geometry in section 2, we examine 3 methods for calculation of the fractal dimension: the method of boxes, the method of variations and the method of morphological covering in section 3. We expose their implementation and the results obtained on synthetic images in section 4. The second method of analysis retained is an original one. Called the ’method of the three-dimensional relief", it is related to the structural analysis and is based on the study of primitives. After a general description of this method in section 5, we present the tools used in the different processing steps then its implementation on CT-Scan images. We expose their implementation and the results obtained on real images. Finally, in section 6 the conclusion and the prospects.

2. FRACTALS

The bone structure is relatively good for fractal geometry because of its complicated and un-regular character. The fractals used for the bone structure analysis come from the fact that one of these fractal characteristics (the fractal dimension) varies with the structure alteration of the trabecular bone (specially in osteoporosis) and so with the thinning down of the trabeculation. The fractal dimension is given by :

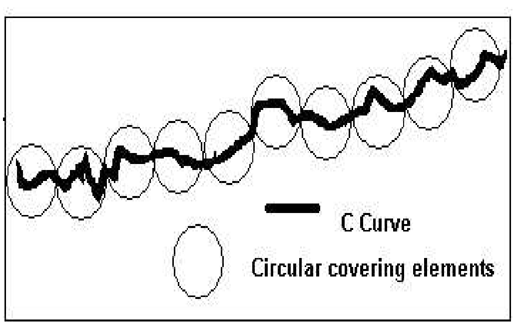
$$D_f = -\frac{\text{Log}\,(N(\varepsilon))}{\text{Log}\,\varepsilon} \qquad (1)$$

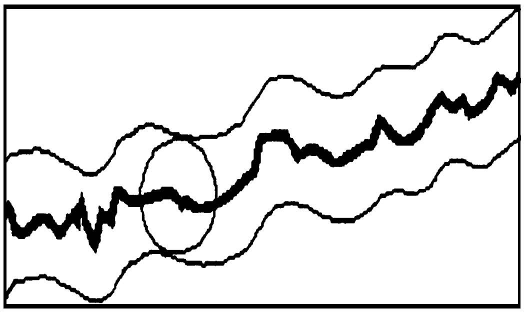
where N(ε) represent a size (surface, volume,...) characterizing the object when searching for its fractal dimension. ε represents the resolution with wich the size is calculated. Hausdorff [12] Minkowski [13] and presented the fractal dimension of the object in the beginning of this century.

- The Hausdorff dimension

This calculation method of the fractal dimension uses a circular covering element whose diameter is ε. The following figure (Figure 3) gives an example of covering of a C curve by circular connected elements.
We name N(ε) the minimum number of the covering elements which allowed the curve description. Then, we obtain then the fractal dimension according to Hausdorff:

$$D_f = \lim_{\varepsilon \to 0} \frac{\text{Log}\,N(\varepsilon)}{\text{Log}\,(\frac{1}{\varepsilon})} \qquad (2)$$





Figures 3 and 4 : Hausdorff and Minkowski dimension.

- The Minkowski dimension:

In the same way as the Hausdorff dimension calculation, we have a circular covering element of diameter ε. Unlike the previous method, every point of the C curve is considered. That is to say that each point of this curve must be the center of a covering element. Therefore the set of these covering elements forms a case around the C curve. The surface S(ε) of this case can then be computed (Figure 4). Minkowski defines then the fractal dimension in this way:

$$D_f = \lim_{\varepsilon \to 0} \left(2 - \frac{\text{Log}\,S(\varepsilon)}{\text{Log}\varepsilon} \right) \qquad (3)$$

For this example the topologic dimension of the investigated curve is equal to 1. The fractal dimension of this curve will lie between [l;2]. We see that the fractal dimension will vary between the topologic dimension value and the topologic dimension plus 1. An object having a fractal dimension equal to the topologic dimension will be very regular (for example a plane, a straight line). At the opposite, an object that has a higher fractal dimension will be a more complex one.

3. The calculation methods of the fractal dimension

As we have seen, the fractal dimension calculation lays on the parameter variation characterization, as the perimeter, the surface or the volume; it depends on the size of the covered element. There are a lot of methods for fractal analysis like the methods of the boxes, the method of variations and the morphological covering method. For these methods, the fractal considered object is a 3D representation of the trabecular bone. Indeed, we can consider that the component (z) represents the Grey level value of our picture. In each pixel will have a third component which is the Gray level of the pixel (i,j).

3.1. The method of the boxes

It constitutes the reference method. The fractal dimension calculated uses the Hausdorff definition. To cover the considered fractal volume, we use a cube with a side ε. Let N(ε) is the number of cubes of a given size (ε) that covers the whole object. If plotting the evolution of the Log curve N(ε) in function of ε, we obtain then the curve figure 5. The fractal dimension is given by the slope Log N(ε) = *f* (Logε).

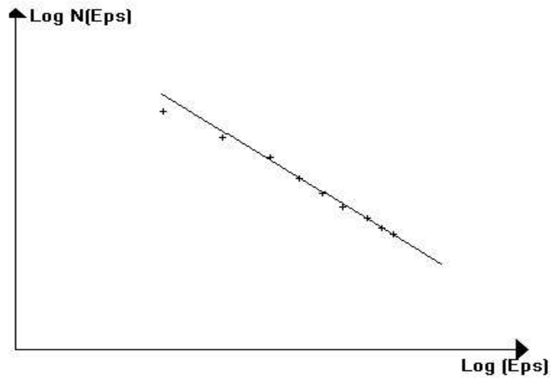


Figure. 5: Evolution of the Log curve N(ε) in function of ε.

Application of the method

In order to put this method, we have to cut our image into squares of size ε. These squares are labeled ε_i. We search the maximum value of Grey levels (Max_NdG) of each square. These maximum values will be enable us to determine the boxes numbers to pile on the ε_i surface in order to recover our volume.

$$Nb\_Boite_{\varepsilon} = \frac{Max\_NdG}{\varepsilon} \qquad (4)$$

where $\frac{Max\_NdG}{\varepsilon}$ takes the higher integer value. The total number of boxes will be given by:

$$N(\varepsilon) = \sum_i Nb\_Boite_{\varepsilon} \qquad (5).$$

We find then the fractal dimension from the slope Log N(ε) =f(Log ε).

3.2. Method of variations

This method allows to determine the fractal dimension at Minkowski's meaning. [6] exposed this method for the fractal dimension calculation of the curve. We have realized an extension of this method in order to adapt it at the characterization of our surface. Like the Minkowski definition given previously, this method searches to define the covering case. In our situation the initial object is a surface, our case will then be a volume one. This case will be determined from the maximum variation of the Grey level, upon a window (size ε), for every surface point. The window will have to be moved on the whole S surface. The maximum variations are represented by the extreme values of the gray level, in fact the minimum and maximum upon a same window. This variation will change according to dispersion of the Grey level, the higher will be the element size, and the more important will be the potential maximum variation.

Application of the method

Let T be the side value of our squared picture I, each pixel of this picture will be referenced by its co-ordinates (i,j). For each of these points, we are going to determine the maximum and the minimum value of the Grey level upon the neighborhood selected by the window (sized ε). We obtain:

$$\text{Max\_fen}_\varepsilon(x,y) = \max_{\substack{x-\varepsilon/2 \le i \le x+\varepsilon/2 \\ y-\varepsilon/2 \le j \le y+\varepsilon/2}} I(i,j) \quad (6)$$

where the couple (x,y) represents the co-ordinates of the windows center. In a same way we define:

$$\text{Min\_fen}_\varepsilon(x,y) = \min_{\substack{x-\varepsilon/2 \le i \le x+\varepsilon/2 \\ y-\varepsilon/2 \le j \le y+\varepsilon/2}} I(i,j) \quad (7)$$

After obtaining the set of the minimum and maximum values for our picture, we can calculate the volume case G_V:

$$G\_V(\varepsilon) = \sum_x \sum_y \text{Max\_fen}(x,y) - \text{Min\_fen}(x,y). \quad (8)$$

So we calculate the volume cases for different sizes of the window, these windows are always applied to the original picture and not in a recursive way. However the convolution between a T size square picture of and a ε size window, gives us a resulting square picture of size:

$$T - 2 \times \text{INT}\left(\frac{\varepsilon}{2}\right) \quad (9)$$

This size of the resulting picture depends on our ε window size. For two different windows which are respectively the size ε and ε', the resulting picture will not have the same dimension. This difference of the dimension will generate a graphical representation of volume cases in function of the ε size, which will be non-linear. In this process, we must keep the picture size constant. For this purpose, we arbitrary decided to stop the calculation of the volume case for a maximum window size equal to the half size of original picture. We obtain the cases calculated by ε= 3 at ε=T/2.The set of the values of the volume cases value gives us the curve: Log G_V(ε) = f(Log ε)

To reach at the fractal dimension, we calculate the linear regression of this curve. We then obtain the slope, which will be noted:

$$\left[\frac{\text{Log } G\_V(\varepsilon)}{\text{Log } \varepsilon}\right]'$$

The fractal dimension is determined as follow way:

$$D_f = 3 - \left[\frac{\text{Log } G\_V(\varepsilon)}{\text{Log } \varepsilon}\right]' \quad (10)$$

Upon this equation we have the constant 3 due to the calculation of the fractal dimension by the volume (topologic dimension equal 3). We define another parameter, which is the fractal signature. The fractal signature represents the average of the local slopes that is to say the slope between two consecutive values ε. We have then:

$$\text{local\_slope} = \frac{\text{Log } V(\varepsilon) - \text{Log } V(\varepsilon-2)}{\text{Log } \varepsilon - \text{Log } (\varepsilon-2)} \quad (11)$$

$$\text{sign\_f} = 3 - \text{average}(\text{local\_slope}) \quad (12)$$

3.3. Method of the morphological covers

[14] suggested this method. It consists in the calculation of the area covering the surface to be characterized. In order to determine the covering surface, we must define a lower surface and an upper surface. Both surfaces make then a covering of the original surface. Grey level erosion and dilation of the original picture respectively determine the lower and upper surfaces. The differences (between the erosion and dilation) are summed on each pixel. It will give the volume V(ε) covering the surface of the picture. Let D_ε and E_ε be the results of the dilatation and erosion of the central point (i,j) of the window convolution with ε size, we have:

$$V(\varepsilon) = \sum_i \sum_j \left(D_\varepsilon(i,j) - E_\varepsilon(i,j) \right) \quad (13)$$

In this volume we're going to look for a surface. In order to obtain the covering area of this surface, we calculate the differential volume dV(ε). We obtain then:

$$A(\varepsilon) = \frac{dV(\varepsilon)}{d\varepsilon} \qquad (14)$$

Like with the previous method, the differential volume dV(ε) must be computed on a picture of constant size. We then obtain at the following expression:

$$A(\varepsilon) = \frac{V(\varepsilon_a) - V(\varepsilon_p)}{d\varepsilon}, \text{ Where } \varepsilon a > \varepsilon p \qquad (15)$$

As the size of the window must be odd, the variation of ε between the two successive windows will be equal to 2:

$$A(\varepsilon) = \frac{V(\varepsilon) - V(\varepsilon - 2)}{2} \qquad (16)$$

This method using the definition of the fractal dimension given by Minkowski, we get:

$$D_f = 2 - \left[\frac{\text{Log } A(\varepsilon)}{\text{Log } \varepsilon} \right] \qquad (17)$$

where [[$\frac{\text{Log } A(\varepsilon)}{\text{Log } \varepsilon}$] represents the slope of

Log A(ε)=*f*(Log ε)

In the same way as the variation method, we define the fractal signature given by:

$$\text{Local\_slope} = \frac{\text{Log } A(\varepsilon) - \text{Log } A(\varepsilon - 2)}{\text{Log } \varepsilon - \text{Log } (\varepsilon - 2)} \qquad (18)$$

and sign_f= 2 - average(local_slope) (19)

[3] has showed that the best results are obtained by the use of a vertical or a horizontal window. After we presenting the different methods of the calculation, we are going to see their application in the environment of the subject.

4. Application on synthetic pictures

To verify the validation of the results, we had to generate some fractal pictures with a known dimension. In order to generate some fractals, Mandelbrot introduced the Fractional Brownian movement. This Fractional Brownian movement of translation and rotation, unceasing and unconsidered, introduces another parameter H which defines the fractal dimension as follows :

$$Df = Dt + 1 - H \qquad (20)$$

with Df fractal dimension, and Dt topologic dimension.

The H variable taking its values in the interval [0;l], we find a dimension superior or equal to the topologic dimension. We used the Saupe algorithm [15]. It consists in the search of the half point of the two points coming from a function, in a recursive way. At the end of the algorithm we obtain then a fractal picture as by the figure 6.

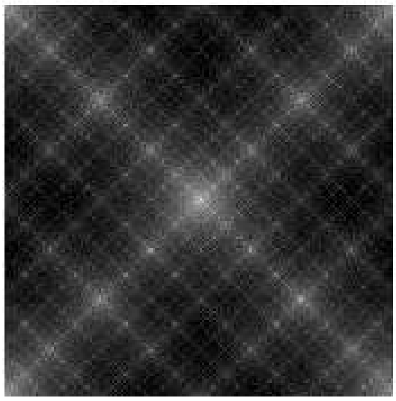


Figure 6 : Synthetic fractal image.

By varying the H parameter, we can obtain a set of picture which dimension lies in the interval [2;3]. The dimension of the generated pictures are 2,001; 2,1; 2,2; 2,3; 2,4; 2,5; 2,6; 2,7; 2,8; 2,9; 2,999, that is to say 11 various dimensions.

4.1. Results and discussions

The method of boxes, although easily set up, has a major inconvenient which is the error rate of the fractal dimension [16]. Indeed, during the volume description by a structuring element, the occupation rate of this values on the curve is not taken into account. This method of variations, give us after experimentation some values of the fractal dimension between 2,188 and 2,76 (Figure 7). It reduces then the expected range of the dimension (between 2 and 3).

The method of morphological covering produces a more spread variation of the fractal dimension [2,25;3.23]. However it delivers systematically overestimated results (Figure 8).

For the two last methods, we see a good correlation between the calculated and generated fractal dimension.

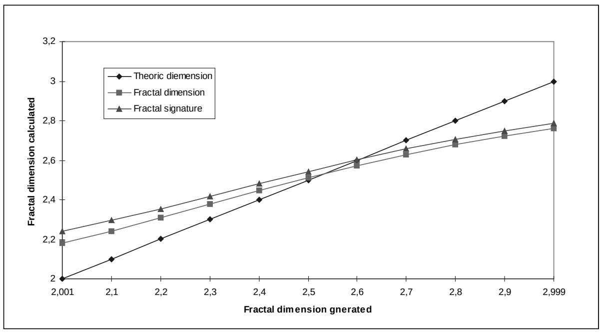


Figure 7: Fractal dimension by the method of variation

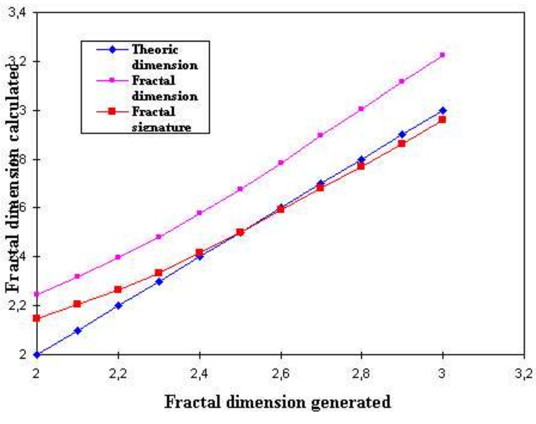


Figure 8: Fractal dimension by morphological covering

We applied these two methods on real bone texture images and it is noted that: (i) concerning the method of the variations, we find the same results, we obtain values of fractal dimension between 2,06 and 2,56. This method reduced thus well the range of value of dimension This reduction involved a bad discrimination of the healthy patients and patients having an osseous pathology. This error occurred on 15 patients on a total of 25 patients whom were reached or not. (ii) concerning the method of the morphological covers, we find a range of variation of fractal dimension quite higher than the theory. On the 25 patients tested gave us that only one error of discrimination.

We thus proposed to study, why we obtained values higher than maximum theoretical dimension for the method of the morphological covers. We initially directed our study towards the influence of the number of Grey levels of an image on fractal dimension and multi fractal concept.

We then plotted the curve Log A(ε).f(Log ε), for three different dynamics: 4 bits, 8 bits and 12 bits (Figure 9). We can note that the lines are parallel and thus have identical slopes. Consequently, fractal dimensions will be equal.

For the planned clinical use, the goal is not to measure the exact value of the fractal dimension, but mainly to control its variations according to the bone texture alteration. In this case a maximal range of variation of this fractal dimension can give to the selected method a best sensitivity in discriminating healthy patients from bone pathologic patients. Among the investigated methods, the method of morphological covering gives us the widest range of the measured values. Consequently we retain it's two following parameters: the fractal dimension and the fractal signature.

We developed original methods for the analysis and the characterization of the bone texture. These methods are based on the numerical processing of CT-Scan images.

They led us to define some parameters that could make possible the discrimination between healthy patients and patients with bone disorders. These parameters are the followings: (i) The dimension, (ii) and the fractal signature.

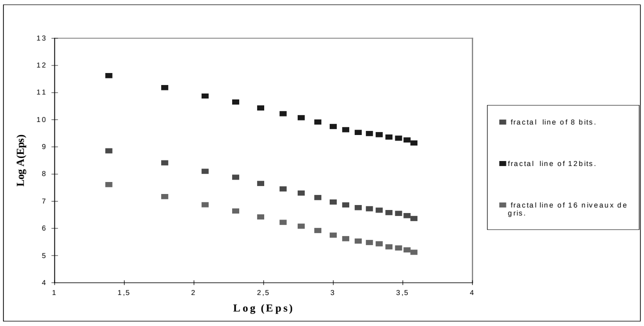


Figure 9: Influence of dynamics on fractal dimension

They come from a variant of the morphological covering method. The alteration of this method leads us to calculate the fractal dimension not from a volume but from an area.

All these parameters were investigated during a preliminary study on a limited number of patients. This work is being carried on with a larger population in order to refine these parameters, and perhaps to propose other ones. We're planing to study the dispersion of the measured values within homogeneous groups of patients such as the correlation of our results to these from the bone mineral density to control their validity.

6. CONCLUSION

We developed original methods for the analysis and the characterization of the bone texture. These methods are based on the numerical processing of CT-Scan images. They led us to define some parameters that could make possible the discrimination between healthy patients and patients with bone disorders. These parameters are the followings :

The dimension and the fractal signature: they come from a variant of the morphological covering method. The alteration of this method leads us to calculate the fractal dimension not from a volume but from an area.

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