Bone texture analysis on dental radiographic images: results with several angulated radiographs on the same region of interest

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ABSTRACT

Bone microarchitecture is the predictor of bone quality or bone disease. It can only be measured on a bone biopsy, which is invasive and not available for all clinical situations. Texture analysis on radiographs is a common way to investigate bone microarchitecture. But relationship between three-dimension histomorphometric parameters and two-dimension texture parameters is not always well known, with poor results. The aim of this study is to performed angulated radiographs of the same region of interest and see if a better relationship between texture analysis on several radiographs and histomorphometric parameters can be developed. Computed radiography images of dog (Beagle) mandible section in molar regions were compared with high-resolution micro-CT (Computed-Tomograph) volumes. Four radiographs with 27° angle (up, down, left, right, using Rinn ring and customized arm positioning system) were performed from initial radiograph position. Bone texture parameters were calculated on all images. Texture parameters were also computed from new images obtained by difference between angulated images. Results of fractal values in different trabecular areas give some caracterisation of bone microarchitecture.

Keywords: bone microarchitecture, Texture analysis, Computed Radiograph, Micro-Computed-Tomography, fractal dimension.

1. INTRODUCTION

The BIOREGOS2 project aims to study the bone from several point of views. Fourteen academic research labs in Nantes, Angers and Le Mans are involved in this project from the material characterization, the mechanical, the chemical, and the medical intersections.

Bone microarchitecture is the predictor of bone quality or bone disease like osteoporosis. The study of microarchitecture is based on the measure of width, number, and separation of trabeculae as well as on their spatial organization [1,2]. It can only be measured on a bone biopsy, which is invasive and not available for all clinical situations. Bone texture analysis on radiographs is a common way to investigate bone microarchitecture. But relationship between three-dimension (denoted 3D) histomorphometric parameters and two-dimension (denoted 2D) texture parameters is not always well known, with poor results. [3,4]. This is the long term objective that we look for.

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In this paper, the three different image acquisitions of the same scene are described in section 2. Section 3 presents multiple results gained during the year from the cross study of microarchitecture and the corresponding 2D texture. This paper specifically focuses onto the so-called fractal dimension. This tool is easily implemented in 2D both for the projection radiograph as well as for the slices obtained from the micro scanner. The reader must be aware that it is very easy to derive this value from any binary image without having a true understanding of its "reality". However, in the context of bone microarchitecture, this dimension is interesting to investigate because there is a direct link between its evaluation and the local geometry.

2. MATERIALS AND METHODS

2.1 Parameters and Figure of Merit

The aim of this study is to start from different angulated radiographs [5,6] of the same bone Region Of Interest (ROI) and see if a better relationship between texture analysis on several radiographs and histomorphometric parameters derived from micro CT can be developed. In this paper, we have used ImageJ software as well as Octave software in order to compute the different results.
Three texture parameters are often used for bone characterization:

- Hmean parameter : this is a fractal parameter. It can be derived from a geometric point of view by counting the numbers of disks inside boxes of several dimensions. Notice that this algorithm does not give a very precise idea of a real fractal dimension (this can be only obtained from a multiresolution analysis). However, this algorithm fits very well the structure of the bone composed of trabeculaes. This is why we keep this algorithm in this paper (we also keep the fractal word even if probably denaturated in this context). Fractal dimension of trabecular bone projection texture is especially related to connectivity and porosity. According to different authors [3,8,9], the description of the fractal shapes is given by a single parameter, H (Hurst exponent), related to the fractal dimension, D, by H = 2 - D. The higher H is, the smaller the roughness of the path.
- Run-length : this parameter actually corresponds to the previous parameter but in a 1D sense. It corresponds to counting on a line the length of series of black or white values. In order words, this is the "1D fractal" when the box size is only one pixel hight.
- Co-occurrence [7] parameters. These parameters extracted from Aralick Co-occurences matrices are often difficult to jointly interpret for several directions.

Notice that the 27° was derived to allows a specific relationship between radiographs and micro CT. This angle corresponds to a discrete angle in a rectangle triangle where the two orthogonal sides are of relative dimension 2 and 1. This situation gives a Mojette transform angle [10] which can be easily computed from the 3D volume in any directions.

2.2 Digital radiographs

Computed radiography (CR, Kodak RVG system , Rochester, New-York, USA) images of a dog (Beagle) mandible section in molar regions with one tooth were compared with high-resolution micro-CT volumes (denoted µCT) using a Computed-Tomography Skyscan 1072, Kontich, Belgium, voxel size about 19µm. We used also D3A medical systems radiograph (digital radiography system, D3A, Orléans, France) to perform the four same 27° angulated radiographs using another customized positioning system giving the 27° inclination. A Region Of Interest (ROI) including trabecular and cortical bone was determined between tooth roots.

For this study, a Rinn ring (Dentsply) was customized for its arm positioning system. It allows to locate the sample on a specific 3D geometric position within the 2-1 angle relationship mentioned above. Figure 1 presents the customized Rinn ring (fig. 1 -a) as well as a digital radiograph (fig. 1-b) showing a 2D region of interest (2D ROI) corresponding to the trabecular bone that has also been reconstructed in 3D (fig. 1-c) from the micro CT after a manual extraction of the 3D ROI corresponding to the trabecular bone (fig. 1-d).

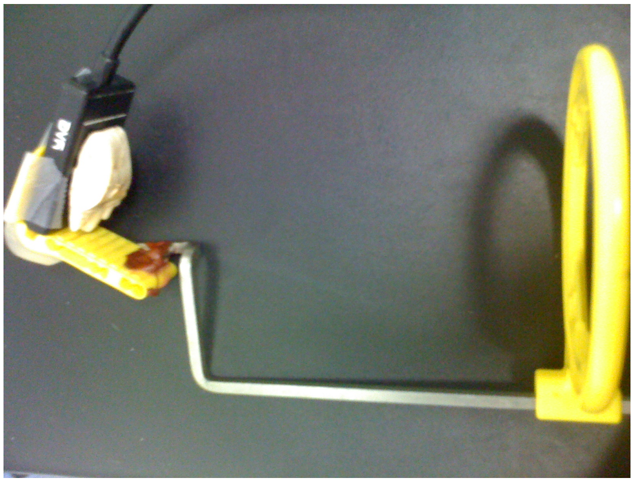


Figure 1-a Customized Rinn ring system (27° down on this picture)

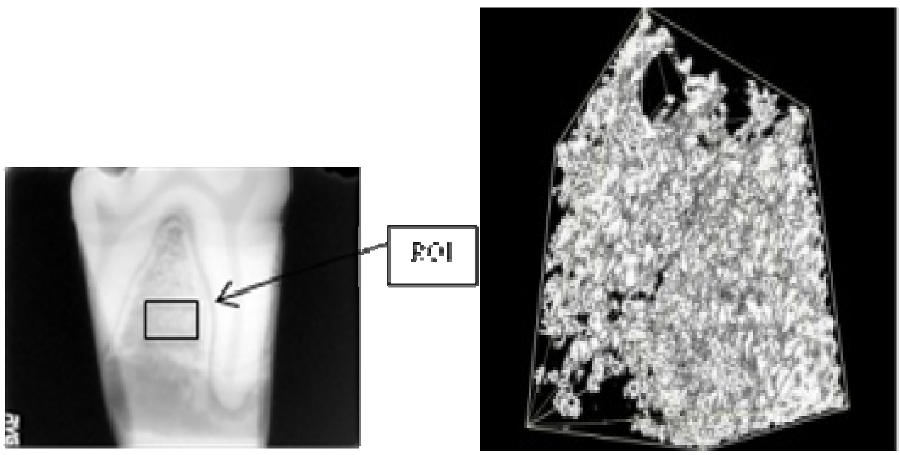


Figure 1-b: Digital dental radiograph Kodak showing the 2D ROI and

Figure 1-c: the 3D corresponding ROI reconstructed by the µCT

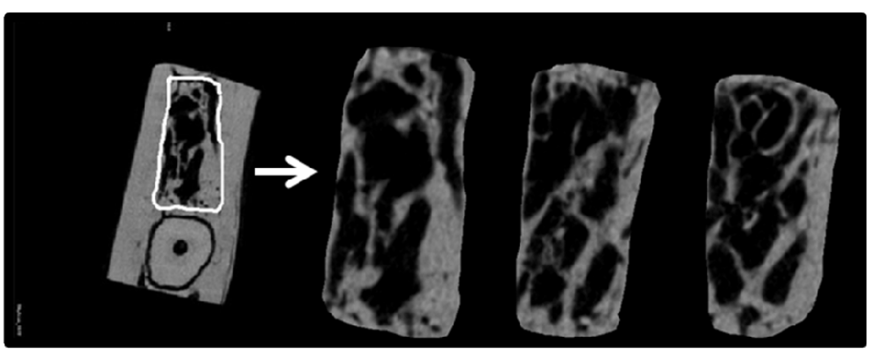


Figure 1-d: individualized section of trabecular bone on several slices (human drawing and interpolation) obtained from the µCT: white represents the bone

Four radiographs with 27° angle (up, down, left, right), were performed from initial computed radiograph position (also imaged). This gives us 5 different images of the same bone region onto the radiographs. The µCT gives the three dimensional (denoted 3D) microarchitecture of the bone. Again a 3D ROI was designed by the odontologist in order to

keep only the bone region. It must be mentioned that this 3D ROI only retains the trabecular bone and does not take into account the cortical bone.
Therefore, we have both the texture of the bone onto the radiograph and its corresponding 3D microarchitecture.

2.3 Texture parameters and fractal dimension

The D3A medical system allows texture analysis (double exposure) on radiographs with Hmean, run-length and co-occurrence results. We performed 8 times the measure on the ROI and on all angulated radiographs.
On radiographs issued from Kodak RVG system and from micro-CT, difference between angulated radiographs was calculated using Image J software. After binarisation of the ROI, fractal dimension of the difference image was also calculated.
According to X-ray angulation on RVG radiograph, there is a displacement of the ROI on the pictures produced by the 27° angulation. This displacement was calculated as an equivalent translation (instead of the true 3D rotation) and images were cropped to perform difference on the same zone.
Several ROI with different bone microarchitecture (according to µCT) were used.

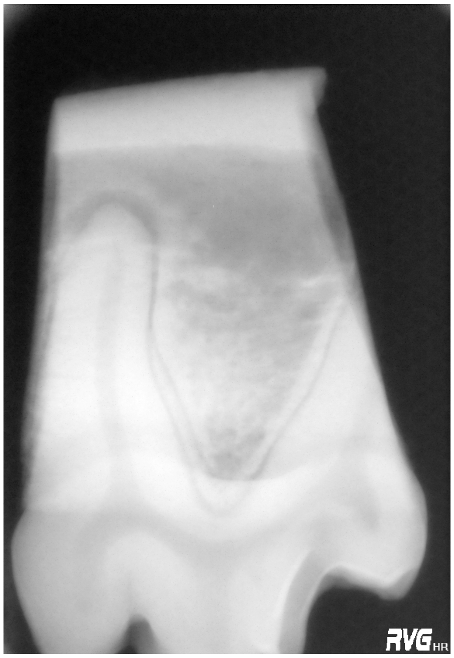
2.4 Bone microarchitecture parameters

Bone microarchitecture parameters on the trabecular zone of the ROI were calculated using µCT software (CT AN,Skyscan 1072, Kontich, Belgium).

3. RESULTS

The customized Rinn ring allowed us to obtain images of the same ROI (region of interest) with precise 27° angulation in all directions (angulation of generator, bone and X ray captor fixed). These images are presented on figure 2 for the centered and 27° up displacment. Figure 3 presents images where a lateral 27° (right and left) rotation from the centered position was performed.

Figure 2 : a)RVG 0° (centered)



b) RVG 27° up

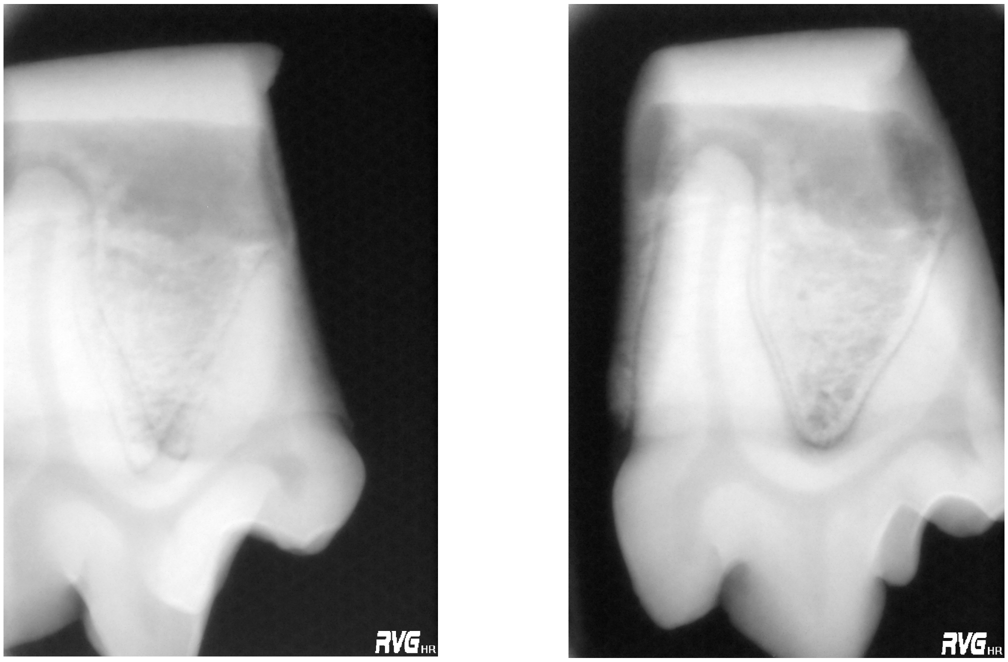


Figure 3 : a) RVG 27° left lateral b) RVG 27° right lateral

Figure 4 : a) trabecular ROI 0° b) trabecular ROI 27° up

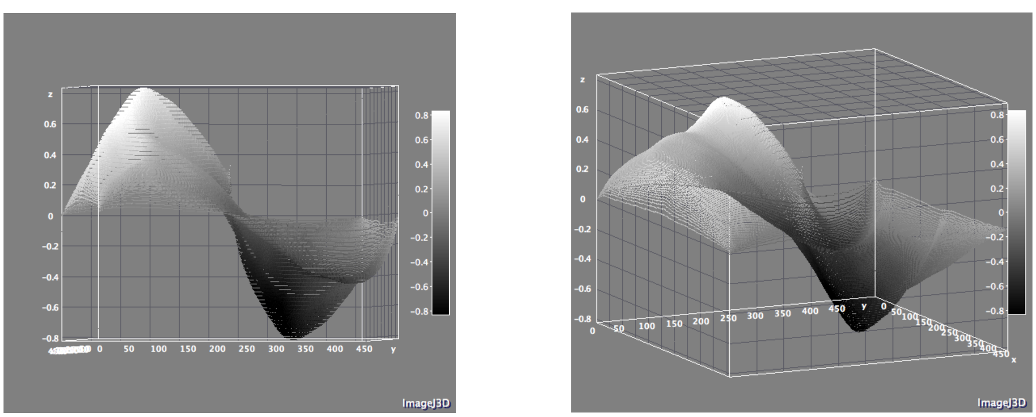


Figure 4 c: 2D correlation of 256x256 trabecular bone ROI : (0° - right lateral 27°) and (0° and 27° up) ROIs

Figure 4-c presents the 2D correlation between centered image (ROI in fig 4-a issued from fig.2-a) and right lateral (ROI in fig 4-b issued from fig 3-b). Instead of doing this computation onto the whole image, only a 256 square ROI corresponding to the trabecular bone region was used. After equalization, these two ROI exhibits the same textures of a lumpy background style.

An interesting point of view is given by the displacement in one direction or another one. The 27° rotation gives an idea of the z dimension size of the trabecular region that can be estimated.This was measured and correlated with the 3D micro CT ground truth.

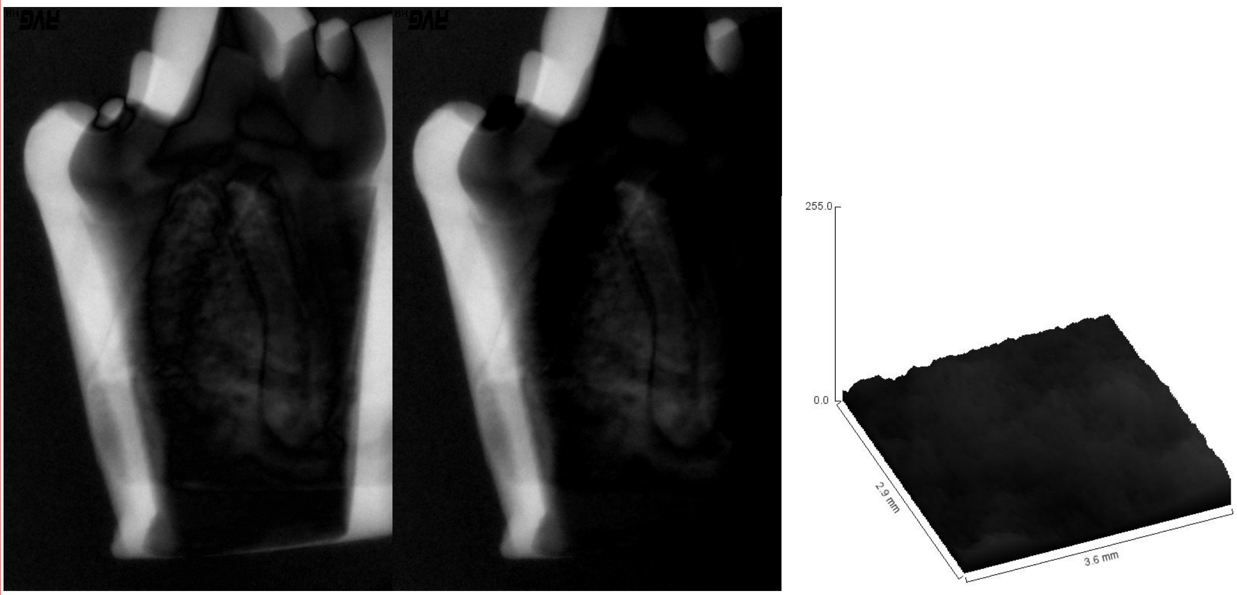


Figure 5 Difference between 0° and 27° left (RVG) Subtraction 0 and 27° left (RVG) Surface plot on difference 0
and 27 ° left (RVG)

Figure 5 shows the difference between centered and 27° images (L1 norm or absolute difference). The simple subtraction between images is also presented but was useless. The trabecular ROI of the difference is presented on the surface plot: it exhibits a very small range of values and the same kind of lumpy background as the ROIs by itself. Doing the same computation with images 27° left and 27° right also gives this kind of difference image still with a small grey level range.

From 0° radiograph and 27° left radiograph, the displacement was measured about 3,01 mm. The knowledge of the angulation and displacement allows for determination of mandible section thickness. This value can be of importance for in vivo experimentation.

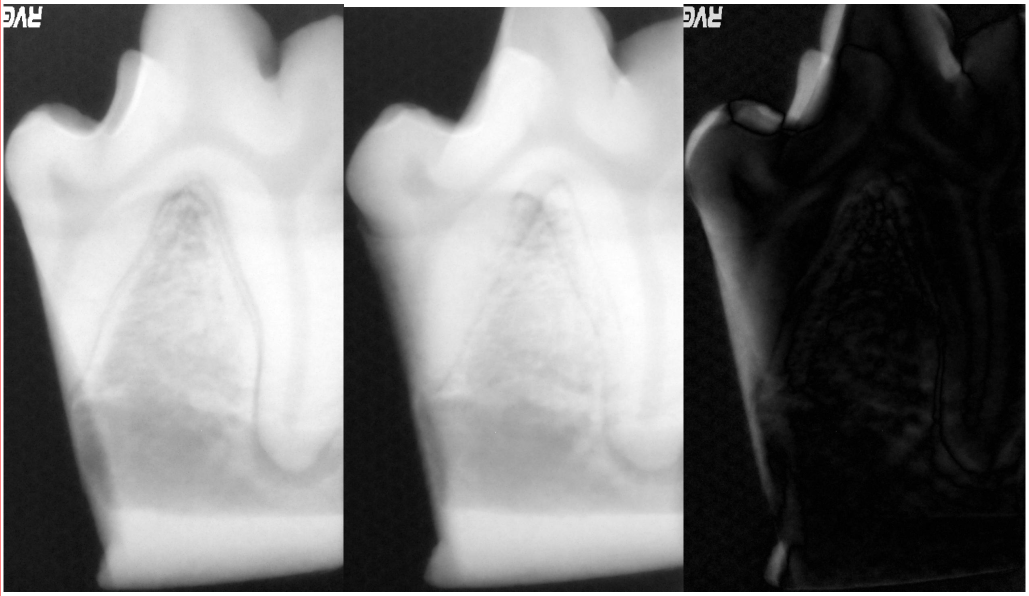


Figure 6 Difference from 0 and 27° left images after a correction of displacement

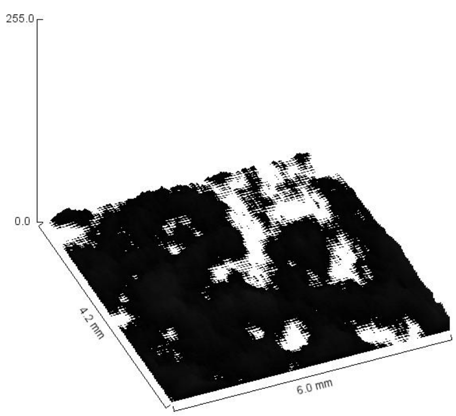


Figure 7 Plot of the difference from 0 and 27° left images after a correction of displacement

After the displacement has been corrected (as in Figure 6), the difference computed between the two images showed in Figure 7 regions zero valued. This is correct to have at least some regions (both trabecular bone and trabecular separation) that are superimposed and dissapear with the difference.
The bone parameter extracted from the micro CT are recalled in Table 1 below. The average trabecular thickness is around 0.6 mm while the average trabecular separation is 0.5 mm. One can find 1.05 trabeculae per mm. These measures are essential since they explain a relative organisation of the micro architecture as well as they lead to the main opinion for the medical viewpoint. The fractal dimension computed here will be discussed later on.

Next are presented Table 2 and Table 3 where the fractal dimension where computed. However, instead of taking the original ROI, here we first computed the difference image between two ROI images of different orientations. In Table 2, the computations were made on centered and 27° acquired radiographs. On Table 3, we computed DRR from the micro CT stack for different orientations. Thus in the second case, there is no need to correct for displacement since the center of the volume is always projected on the center of the projection. Figure 8 shows two images obtained by this DRR procedure which involves the Mojette projector at angle (2,1) corresponding to the 27° angle.

Table 1: bone parameters extracted from the micro CT

Tissue volume	TV	57.2 mm^3
Bone volume	BV	39.43 mm^3
Percent bone volume	BV/TV	68.94%
Tissue surface	TS	114.17 mm^2
Bone surface	BS	229.24 mm^2
Intersection surface	i.S	93.16 mm^2
Bone surface / volume ratio	BS/BV	5.8 1/mm
Bone surface density	BS/TV	4.01 1/mm
Trabecular pattern factor	Tb.Pf	-1.22 1/mm
Structure model index	SMI	-0.33
Trabecular thickness	Tb.Th	0.65 mm
Trabecular number	Tb.N	1.0566 1/mm
Trabecular separation	Tb.Sp	0.5035 mm
Degree of anisotropy	DA	2.226 (0,55070)
Fractal dimension	FD	2.09

Table 2 Fractal dimension of ROI on µCT radiographs

Micro CT radiographs(DRR) – ROI on the difference between 0 et 27°			
name	Position (left top pixel)	size	Fractal value
ROI1	X=320,Y=360	128/128 pixel	1,9066
ROI2	X=320,Y= 360	194/194 pixel	1,7608
ROI3	X=360,Y=300	128/128 pixel	1,6445
ROI4	X=360,Y=428	128/128 pixel	1,7379
ROI5	X=360,Y=300	128/256 pixel	1,7299

Table 3 Fractal dimension of ROIs difference on µCT radiographs DRR

Difference of images	ROI number	Fractal value	Difference of images	ROI number	Fractal value
Diff 0 - 3,675°	ROI1	1,985	Diff 0 - 13,5°	ROI1	1,9379
Diff 0 - 3,675°	ROI2	1,8143	Diff 0 - 13,5°	ROI2	1,7627
Diff 0 - 6,75°	ROI1	1,9491	Diff 0 - 20,25°	ROI1	1,9012
Diff 0 - 6,75°	ROI2	1,8144	Diff 0 - 20,25°	ROI2	1,7202
Diff 0 - 3,675°	ROI1	1985	Diff 0 - 27°	ROI1	1,9066
Diff 0 - 3,675°	ROI2	1,8143	Diff 0 - 27°	ROI2	1,7608
Diff 0 - 6,75°	ROI1	1,9491	Diff 0 - 33,75°	ROI1	1,9109
Diff 0 - 6,75°	ROI2	1,8144			

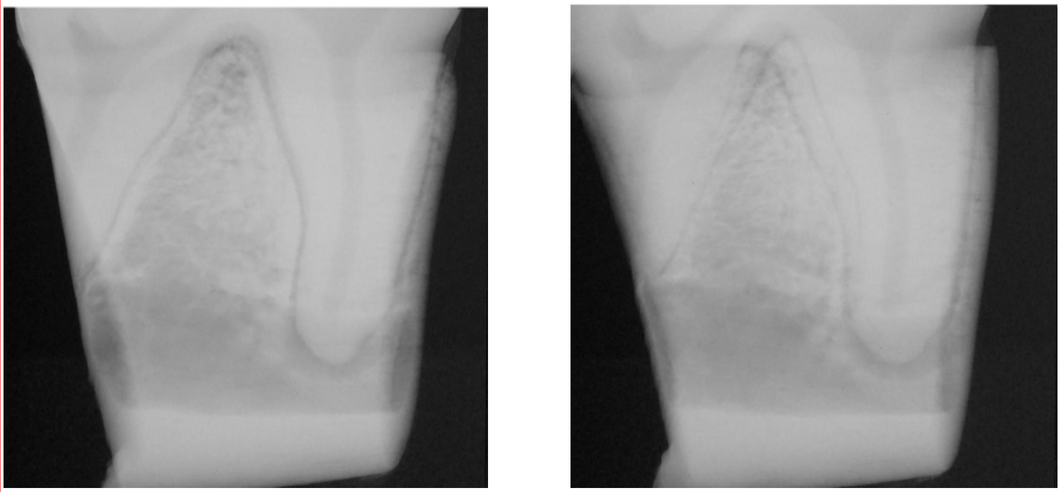


Figure 8 Mojette Digital Reprojected Radiographs(DRR) obtained from µCT slices of the same ROI (region of interest) with precise 0° and 27° angulation (rotation of bone, generator and X ray captor fixed).

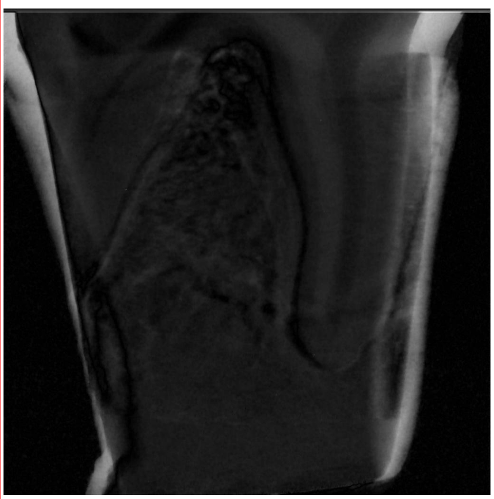


Fig 9-a Difference 0 and 27° left(µCT)

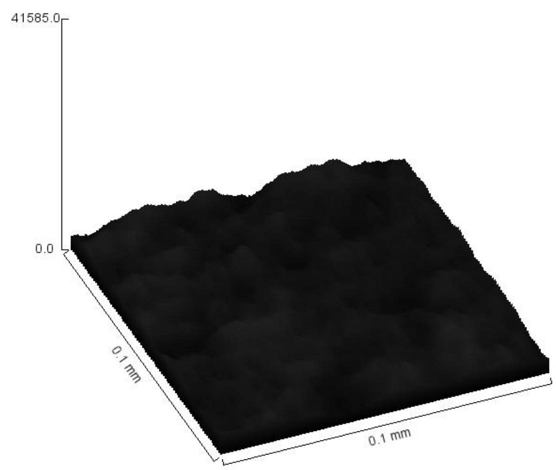


Fig 9-b: Surface plot on difference 0 and 27 ° left (µCT)

Figure 9 shows the difference image of the 2 images presented in figure 8. The plot of the ROI exhibits no valley as it was the case in figure 7. This difference image of the ROI can be characterized by the same lumpy background found in figure 5. This was the case for all DRR ROI differences images. Thus, we computed the fractal value of all these differences ROI and the results are presented in Table 3.

In order to compute the fractal value, all these images were finally binarized (with different thresholds without significant changes).As shown in Table 3, the fractal dimension of a ROI of a difference of angulated radiographs is always the same whatever is the angulation (between 3, 675° and 33,75°). In the other hand, the fractal dimension of different ROI of the same difference of angulated radiographs is not the same, especially according to different bone microrchitecture (µCT determination).

Therefore, the fractal dimension of a ROI of a difference of angulated radiographs seems to be a constant parameter correlated to bone microarchitectecture.

This parameter cannot be correlated to Hmean, because this a fractal dimension of the difference image. Without double exposure system, this parameter can give information on bone micro-architecture. Correlated texture analysis on several angulated images gave better informations on bone micro-architecture. The influence of number of angulated radiographs (between 3 and 5), of the angle (27°) will now be studied for further works.

These results allows for completing the analysis between the 2D radiographs that can be obtained in a routine manner from patients and the 3D underlying bone structure.

4. CONCLUSION

Improvement of measurement of texture parameters with several angulated radiographs could allowed a better correlation with bone architecture descriptor and an easy diagnostic. Links between 2D radiographs and 3D micro CT for bone characterization have already been studied. However, the digital tools used here and the high correlations obtained allows for optimistic future characterization on alive bone through only radiographs. The fractal dimension of a difference of angulated radiographs is a constant parameter that can be correlated to bone microarchitectecture. The way of correlation needs further works. Angulated radiographs allowed a better correlation between texture parameters and bone microarchitecture. 3 to 5 angulated radiographs could be an easy way to provide a good knowledge of bone microarchitechture, obtained in a routine manner from patients in a lot of medical applications.

5. ACKNOWLEDGEMENTS

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