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Original article

Texture analysis of trabecular bone around RM-Pressfit cementless acetabulum in a series of 46 patients during a 5 year period

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ABSTRACT

Background: Cementless total hip arthroplasty (THA) is a common procedure producing excellent clinical results. Their long-term survival is nevertheless burdened by loosening of the acetabular part caused by changes in the distribution of strains around the cup. In this context the RM-Pressfit® cup has been developed, resulting in a more harmonious distribution of the strains.
Hypothesis: Texture analysis of X-ray films can evaluate the evolution of trabecular bone micro-architecture during the five years following THA with a RM-Pressfit® cup.
Material and method: A monocentric series of 46 hips was reviewed regularly within five years post-surgery. Radiographic evaluation of the operated hip was done on frontal digitized radiographs of the pelvis to follow evolution of bone micro-architecture in the #2 zone of De Lee and Charnley. Texture analysis using fractal algorithms was done at D0, 6 months, 1, 2 and 5 years post-THA. The fractal methods used included the skyscrapers and the dynamic blanket methods with 3 different structuring elements (a cross, a horizontal and a vertical vector).
Results: The RM-Pressfit® caused significant changes in the distribution of strains around the acetabulum that preserved the bone volume over a 5-year period post-surgery. This corresponds to an improvement of the trabecular micro-architecture around the acetabular cups.
Conclusion: A statistically significant increase in the four fractal dimensions considered corresponded to an improved trabecular bone micro-architecture revealed by texture analysis, a non-invasive method that can be used on digitized X-ray images.
Level of evidence: IIIb, Case control study, retrospective design.

1. Introduction

The gold standard for total hip arthroplasty (THA) is represented by cemented prostheses for many years [1]. Their long-term failure is due to the release of polyethylene (PE) wear debris responsible for osteolysis and aseptic loosening [2,3]. Cementless prostheses limit the risk of bone/cement loosening and have similar survival rates [4]. The PE acetabular liner is most often inserted in a metal-back. Several studies have reported a stress shielding of the trabecular bone behind this implant, due to increased mechanical stresses [5,6]. A decreased bone volume is observed in the #2 zone described by De Lee and Charnley [7]; this corresponds to a significant risk of aseptic loosening in the long term [8].

The RM-Classic® cup (Mathys, Switzerland), an impacted uncemented PE-cup with an elasticity similar to bone, has been developed to limit the risk of acetabular stress shielding. Its 20-year survival in patients with THA is over 94% [9,10]. Its mechanical properties allow a more harmonious distribution of strains around the cup. We use the 2nd generation of this implant: the RM-Pressfit® acetabulum and the mid-term results seem excellent as reported by others [11–13]. It is a mixed, uncemented, one-piece acetabular component with two integral parts:

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- A PE liner made of high molecular weight type UHMW-PE, with a elasticity modulus close to bone (1000 N/mm^2 against 500 to 6000 N/mm^2 for bone).
- A thin coating made of pure titanium (TiCP), 150 μm thick, grade 4, according to the American Standards of Trade and Measures.

Analysis of bone changes evolution after THA is difficult and can be achieved on various imaging systems, mainly computed tomography (CT) and dual energy X-ray absorptiometry (DXA) [14,15]. They allow a reliable quantitative analysis of the volume of trabecular bone network but do not consider its micro-architecture [16,17].

Texture analysis presents several advantages as it allows early detection of micro-architectural changes in the trabecular network. It is applied on standard radiographs and the method has been validated for early detection of osteoporosis and osteoarthritis [18], and is beginning to be used in the follow-up of patients with THA [19].

The aim of our study was to analyze evolution of bone micro-architecture in the weighting area (#2 zone) by texture analysis, around a RM-Pressfit® acetabular cup for up to 5 years after surgery and to check the absence of stress shielding around this implant.

2. Patients and methods

2.1. Patients

Between July 2010 and December 2011, we included all patients undergoing a first-line THA with placement of an RM-Pressfit® type acetabular implant with an alumina-PE friction torque (Mathys, France). One hundred and ten RM-Pressfit® acetabulums were implanted in patients from our orthopedic unit, this corresponds to the launch period of this implant in our hospital. Patients who underwent revision surgery and those with a metal/PE friction couple were excluded. Finally, we included 46 hips in 44 patients, and performed regular clinical and radiological monitoring up to 5 years (Table 1). All subjects gave their informed consent to participate in the study that was approved by the Ethical committed of Angers University Hospital.

Patients had a control X-ray examination on Day 1, at 6 months, 1, 2 and 5 years after surgery. X-ray analyses were performed at the hospital radiological unit and were available via the Synapse software (release 4.4) (Fujifilm Medical Systems, Stanford, USA).

2.2. Texture analysis

Texture analysis of bone micro-architecture was done in the #2 zone bearing zone. Analyses were done on plain pelvis radiographs encoded in 8 bits (256 gray levels: black = 0, white = 255), evaluable

Table 1
Population characteristics.

Gender	Men n = 20/Women n = 26
Average age	71.89 (61–89) years old
Average BMI	26.37 kg/m^2
Primary osteoarthritis	36
Secondary osteoarthritis	10
Traumatic	3
Osteonecrosis	1
Rheumatoid arthritis	2
Rapidly destructive osteoarthritis	3
Dysplastic	1
Charnley's Score	
39%	18
B 52%	24
C 9%	4

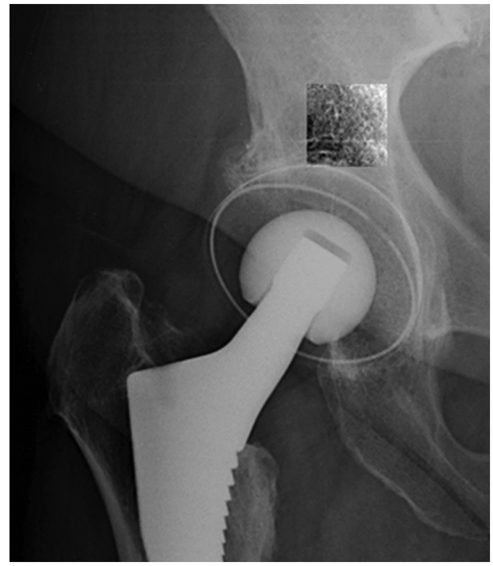

Fig. 1. ROI selection at distance from the cortex of the coxal and the subchondral bone in the #2 zone from a patient with a RM-Pressfit® cementless acetabulum.

by mathematical techniques based on fractal geometry. On X-ray images, bone appeared white and other radiolucent tissues, black.

The area of interest (ROI) was represented by #2 Zone and was selected as a 512 pixel square. The ROI remained at a distance from the subchondral bone and cortices (Fig. 1). We performed a digital image processing to obtain comparable images over time for each patient:

- Scaling the different images was done by taking the diameter of the prosthetic head as reference, on Photoshop® CS5 software (Adobe) to obtain an ROI of 512 × 512 pixels;
- Equalization of the histogram to obtain the same distribution of gray levels ranging from 0 to 255. Deblurring was done by applying a median filter for removing the low-frequency noise (due to X-ray diffusion in soft tissues). A "top-hat" transformation was used to eliminate the high-frequency noise (due to X-ray acquisition and CCD characteristics).

Texture analysis used fractal algorithms whose mathematical bases have been described elsewhere [20] and has been described in a number of papers [21,22].

Briefly, the following fractal algorithms were considered as elaborated upon below.

2.2.1. The Skyscrapers algorithm

Pixels which constitute the image can be viewed as skyscrapers whose height is represented by the grey level, the roof of the skyscrapers being a square of side ε [20]. The surface areas of the image A(ε) is obtained by measuring the sum of the top surfaces (ε^2) and sum of the exposed lateral sides of the skyscrapers. The grey levels of adjacent pixels are then averaged in squares of ε: 2, 4, 8, 16 and 32 pixels to produce new images and A(ε) is calculated for each ε. The fractal dimension (D_{sky}) is then derived from these measurements. This global method analyzes the micro-architecture of bone as a whole.

2.2.2. The dynamic blanket algorithm

The blanket method calculates other fractal dimensions by using dilatation and erosion of an image [23]. Three structuring elements were used: a cross, a horizontal and a vertical vector. Given a size ε for the structuring element, a dilatation and an erosion of the image provided two covering new images: respectively the upper and the

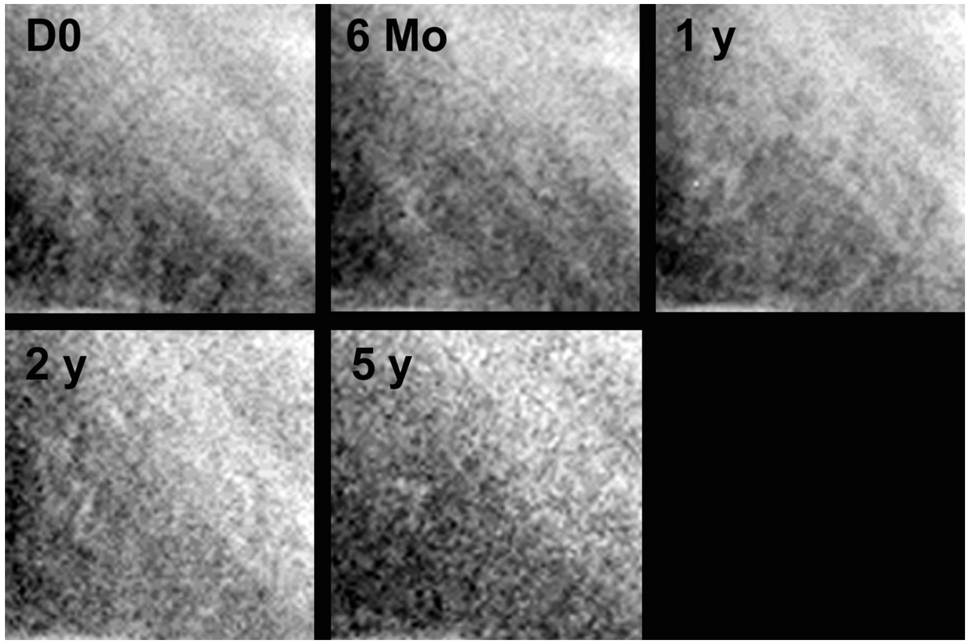

Fig. 2. Typical time course evolution of the trabecular bone micro-architecture in the same ROI in the different X-ray images of the same patient.

lower one. The volume of the blanket, i.e., the volume enclosed between the dilatation and erosion images, was measured and the size of the structuring element was increased as above. Three fractal dimensions were derived from these measurements. $D_{BLANK}-$ analyzes the horizontal bone trabeculae, $D_{BLANK}|$ the vertical bone trabeculae, $D_{BLANK}+$ tests the honeycomb aspect of the trabecular network.

2.3. Statistical analysis

Data collection was performed on Microsoft Excel® software. Values were standardized and expressed as a percentage of the initial fractal dimension (at Day 0) for each patient. The percent changes of the fractal dimensions were calculated for each patient. For each fractal parameter, results were expressed as mean ± standard error of the mean, which allows for the fluctuation of the patient sample over time. Statistical analysis was done with the Systat® software (Systat, San José, CA). We performed an analysis of variance (ANOVA) and used the Fisher's Minimal Significant Difference (Fisher LSD) test as a post-hoc test. In all cases, $p < 0.05$ was considered significant.

3. Results

We analyzed 46 hip replacements in 44 patients. Two patients died before the end of the study, five were lost to follow-up, and one had an early re-intervention with implant change. Therefore, the analysis covered 38 complete files.

All patients were evaluated at D0, 6 months, 1, 2 and 5 years. Evolution of the trabecular bone texture in the #2 bearing zone is illustrated Fig. 2.

A statistically significant increase in the fractal dimensions occurred over time:

- a 2.67% increase was noted at 5 years for D_{sky} and the differences were statistically significant at 1, 2 and 5 years from D0 (Fig. 3,3A);
- a 2.44% regular increase was observed at 5 years for $D_{BLANK}+$ and was statistically significant at 6 months, 1, 2 and 5 years from D0 (Fig. 3B);
- a 1.72% increase was observed at 5 years for $D_{BLANK}-$, and results were statistically significant at 1 and 5 years from D0 (Fig. 3C);
- a 1.82% regular increase was observed for $D_{BLANK}|$ and results were statistically significant at 1 and 5 years from D0 (Fig. 3D).

4. Discussion

In the present study, we did not encountered any technical difficulties to implant the RM-Pressfit® cup. The choice of this device was validated during the orthopedic staff. In case of foreseeable difficulties, another device was chosen. In case of denser bone, a more generous reaming was done to obtain a bloody bone allowing osseointegration of the RM-Pressfit®. We did not deplore mechanical aseptic loosening during time course of the present study.

Texture analysis of X-ray images from patients with the RM-Pressfit® implant, evidenced a statistically significant increase over time in the fractal dimensions of the peri-prosthetic bone in #2 zone. Periprosthetic bone remodeling, the transfer of stress after THA, and thus analysis of the evolution of the trabecular bone network, have been developed to analyze the mechanical causes of arthroplasty failure. CT and DXA are the most commonly used methods [6,7]. However, they require additional costly imaging and use high X-ray doses that cannot be used in the long term survey of patients.

Conventional radiography is used in daily practice and is part of the routine monitoring of THAs. The resulting image is a two-dimensional (2D) projection of the 3D bony structure [24]. Digitization of X-ray images, encoded in 256 gray levels, allows the use of new analytic methods such as texture analysis using fractal algorithms. Several groups have considered that texture analysis can provide valuable analysis of the trabecular micro-architecture, whose bases have been described elsewhere [25–28]. This non-invasive technique allows to observe changes that the human eye cannot evaluate because it is sensitive to about 40 gray levels while a digital image contains 256 [21,25,29,30]. The regular increase in fractal dimensions observed here indicates a re-enforcement of the trabecular bone scaffold around the RM-Pressfit® cups as texture analysis is correlated with bone micro-architecture [26]. Texture analysis is a reliable and accurate tool, detecting early changes in

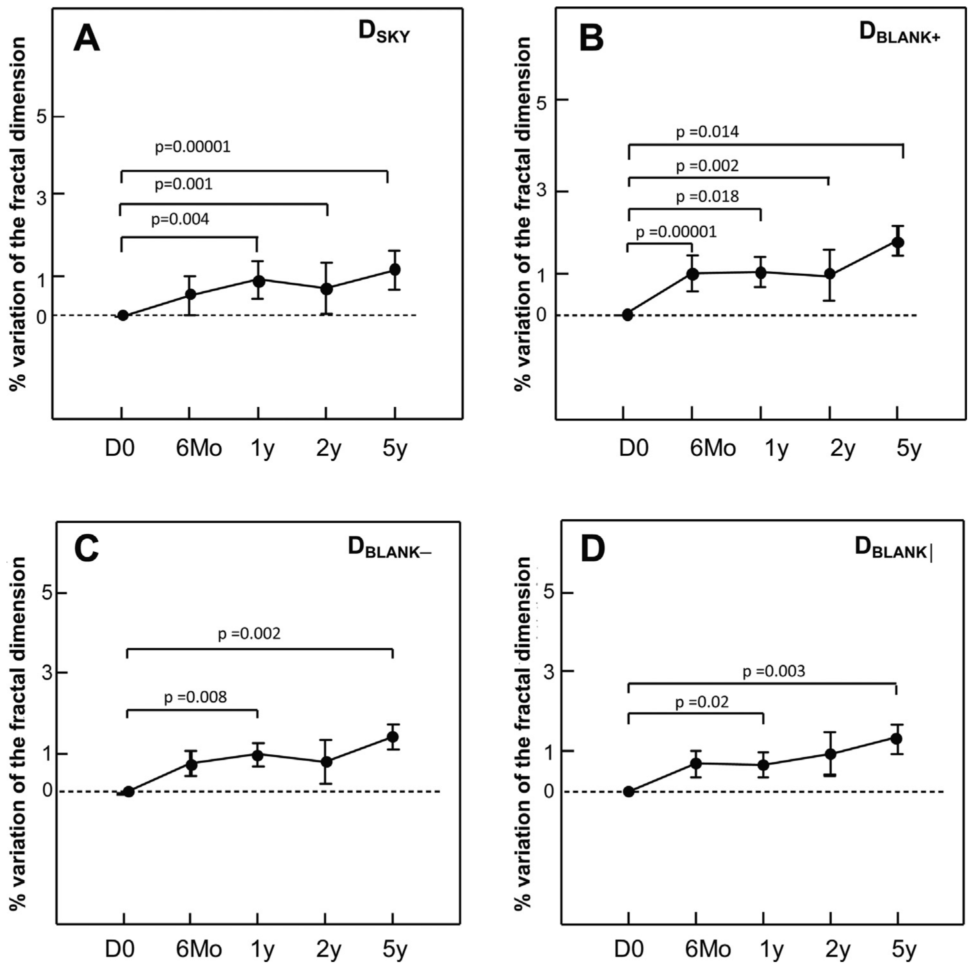

Fig. 3. Analysis of the fractal dimensions determined in #2 zone in this series of patients. A. Skyscrapers algorithm. B. Blanket method; cross structuring element, C. Blanket method; horizontal structuring element, D. Blanket method; vertical structuring element.

the organization of micro-architecture of bone before they were clinically evidenced [18].

Only two studies from the same group have used texture analysis for THA follow- THA [19,31] and showed micro- and macroarchitectural changes leading to peri-prosthetic osteolysis. Here, we found that texture analysis using fractal algorithms was a reliable tool to study a database already present in our hospital. By digital treatment and careful selection of the ROI, radiographs could be compared over time for each patient.

Acetabular metal back implants induce modification of the stresses applied to bone and provoke an adaptive bone remodeling. Moore considers that stress shielding in the #2 zone as a sign of osseointegration of a metal-back implant due to the rigidity of the metal back [32,33]. This has been confirmed by radiographic, CT or DXA studies [6–8,14]. A statistically significant decrease in bone density around cemented metal-back implants has been reported by several authors [7,16]. Rarefaction of acetabular bone favors aseptic loosening and can induce additional complication during THA revisions [8,17].

Absence of stress shielding around RM-Pressfit® cups is reported on CT-scans after a 1.5 year follow-up [12]. We obtained concordant results by texture analysis with a complexification of the trabecular bone network over time reflecting an adaptive remodeling process with a reorientation of the trabecular axes according to Wolff's law [22,23,34]. Peri-acetabular trabecular bone consists of trabeculae oriented in 3D allowing a harmonious distribution of stresses at the hip. We found significant modifications to the honeycomb organization of the trabecular bone, and also in the horizontal and vertical orientation. However, there are limitations to the precise interpretation of texture analysis: We have no information as to the nature of this evolution. Does it correspond to the creation of new trabeculae or is it a thickening of pre-existing ones? This question cannot be resolved with the current tools and only an analysis of high-definition CT scans or a histological analysis could answer this question [26].

5. Conclusion

This is the second study using the analysis of the bone texture around the THA and the first on the RM-Pressfit® cups. The RM-Pressfit® implant could preserve peri-prosthetic trabecular bone until a 5-year period post-surgery as a statistically significant complexity of the bone micro-architecture could be evidenced. Results obtained need to be confirmed with other types of acetabulum.

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Disclosure of interest

The authors declare that they have no competing interest.

Authors' contributions

A. Coupry selected the patients, performed all analyses of X-ray films by texture analysis and contributed to write the manuscript.

L. Rony participated in collecting the data and reviewed the article.

F. Ducellier participated in collecting the data and coordinated the study.

L. Hubert coordinated the study and reviewed the article.

D. Chappard wrote the fractal algorithms used for texture analysis, performed the statistical analysis and contributed to write the manuscript.

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