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Processing of microCT implant-bone systems images using Fuzzy Mathematical Morphology

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Abstract. The relationship between a metallic implant and the existing bone in a surgical permanent prosthesis is of great importance since the fixation and osseointegration of the system leads to the failure or success of the surgery. Micro Computed Tomography is a technique that helps to visualize the structure of the bone. In this study, the microCT is used to analyze implant-bone systems images. However, one of the problems presented in the reconstruction of these images is the effect of the iron based implants, with a halo or fluorescence scattering distorting the micro CT image and leading to bad 3D reconstructions. In this work we introduce an automatic method for eliminate the effect of AISI 316L iron materials in the implant-bone system based on the application of Compensatory Fuzzy Mathematical Morphology for future investigate about the structural and mechanical properties of bone and cancellous materials.

1. Introduction

The relationship between a metallic implant and the existing bone in a surgical permanent prosthesis is of great importance since the fixation and osseointegration of the system leads to the failure or success of the surgery. In the last decade, computational modeling has emerged as a powerful tool to investigate about the mechanical properties of bone and cancellous materials, as well to predict their mechanical strength with virtual or *in silico* experiments [1]. For this purpose, tridimensional models using the Finite Element Method (FEM) are built from micro Computed Tomography scans with a resolution of a few microns. These models and techniques could help to develop computational tools for predicting bone-implant adaptation, prosthesis stability and to design smart biomaterials for bone and tissue regeneration [2,3]. One of the problems presented in reconstruction of these images, is the effect of the iron based implants, with huge artifacts (interface scattering, beam hardening) distorting the micro CT image and leading to bad 3D reconstructions [4,5]. The solution generally to avoid or diminish these artifacts is use Synchrotron Radiation, several filters during the scans, or some standard commercial programs [6,7].
Therefore the goal of this work is to generate clear images from micro CT bone-implant system scans, applying image processing techniques, in particular Compensatory Fuzzy Mathematical Morphology (CFMM) [8-10], for then compile the processed images into a 3D reconstruction. This analysis could help to visualize the effect of implant inclusion into the marrow cavity, for example, and see the osseointegration in a tridimensional level. The images obtained with the conventional microCT

equipment usually have distorting artifacts related with the presence of the metallic implants, and are not easy to process to 3D images. Hence, conventional image processing methods for shape analysis cannot be applied in these cases [11-13]. In this paper we propose to apply CFMM techniques to solve the artifact effect generated by the presence of the implant, and to finally have clear tridimensional images of the bone-implant system, that could be use to different further analysis.

2. Materials and methods

2.1. In vivo samples

In vivo experiments were conducted with 6 Wistar – Hokkaido (WKAH/Hok) male adult rats (weight 350 ± 50 g), according to rules of ethical committee of the National University of Mar del Plata (Interdisciplinary Committee, April 2005/October 2010), taking care of surgical procedures, pain control, standards of living and appropriated death. Implants of stainless steel (AISI 316L) in wire shape were sterilized in autoclave for 20 minutes at 121 °C. Rats were anaesthetized with Ketamine and Xilacine (100mg/Kg, 10mg/Kg) according to their weight. The region of surgery surface was cleaned with antiseptic soap. The animals were placed in a supine position and the implantation site was exposed. A region of around 0.5 cm diameter was scraped in the femur plateau and a hole was drilled using a hand drill of 0.125 cm diameter at low speed. The wire implants were placed by press fit into the medullary canal of the femur. The animals were sacrificed after 8 weeks with an overdose of intraperitoneal sodic thiopental (120 mg/kg) with a previous anesthesia as described above and the femur with implant was retrieved. Conventional X-ray radiographs were taken before retrieving the samples for control of the correct position of the implant into the bone marrow cavity.
The retrieved samples were cleaned from surrounding soft tissues and fixed in neutral 10 wt% formaldehyde for at least 24 h. Then they were dehydrated in a series of alcohol-water mixture followed by a methacrylate solution and finally embedded in poly-methyl methacrylate (PMMA) solution and polymerized for 5 days at 32 ºC.

2.2. Micro CT images

In micro-computed tomography the microCT SkyScan 1072 system was used. The SkyScan 1072 represented high resolution desktop X-ray microtomography (Micro-CT) systems for *in vitro* scanning. Tomographic techniques were applied for the investigation of trabecular microarchitecture of the distal physis of the femur bone in all animals 8 weeks after surgery. Probes were located centrally on the tripod in the middle of the microtomography camera's area of sight and scanned using this parameters: camera pixel size 8.70 μm, Image Pixel Size 4.89 μm, Rotation step 0.150 degrees, exposure 950 ms. Raw scans were reconstructed with the nRecon program (Skyscan, Belgium).

2.3. Compensatory Fuzzy Mathematical Morphology for image processing

In this section it is described the Compensatory Fuzzy Mathematical Morphology (CFMM) that was used for the segmentation of the microstructure of the femoral trabecular bone. This morphology is a particular case of the Fuzzy Mathematical Morphology, based on the replacement of t-norms and s-norms by conjunctions and disjunctions of Compensatory Fuzzy Logic. This is possible by relaxing the constrains imposed by t-norms and s-norms [10]. By replacing t-norm and s-norm by conjunction and disjunction, respectively, was obtained the dilation and erosion operators for the CFMM, called compensatory dilation and compensatory erosion, respectively. For example, for two fuzzy sets μ and ν, the compensatory dilation of μ by ν is defined by:

$$\delta(\mu,\nu)(x) = \sup_{y \in U}\left[C\left(\mu(y),\nu(y-x)\right)\right] \tag{1}$$

where C is a compensatory conjunction.

For two fuzzy sets μ and ν, the compensatory erosion of μ by ν is defined by:

$$\varepsilon(\mu,\nu)(x) = \inf_{y \in U}\left[D\Big(\mu(y),c\big(\nu(y-x)\big)\Big)\right] \tag{2}$$

where D is a compensatory disjunction and $c(a) = 1-a$, $\forall a \in [0,1]$.

Based on these two operators, more complex ones can be defined, as for example compensatory opening, closing and top-hat.

In this paper the top-hat by closing was used. This operator is defined by the following equation:

$$TH_\nu(\mu) = \mu - \varepsilon_\nu\left(\gamma_\nu(\mu)\right) \tag{3}$$

This transform stands out locally dark objects that have been eliminated in the closing filter in a gray scale image.

2.4. Segmentation Method

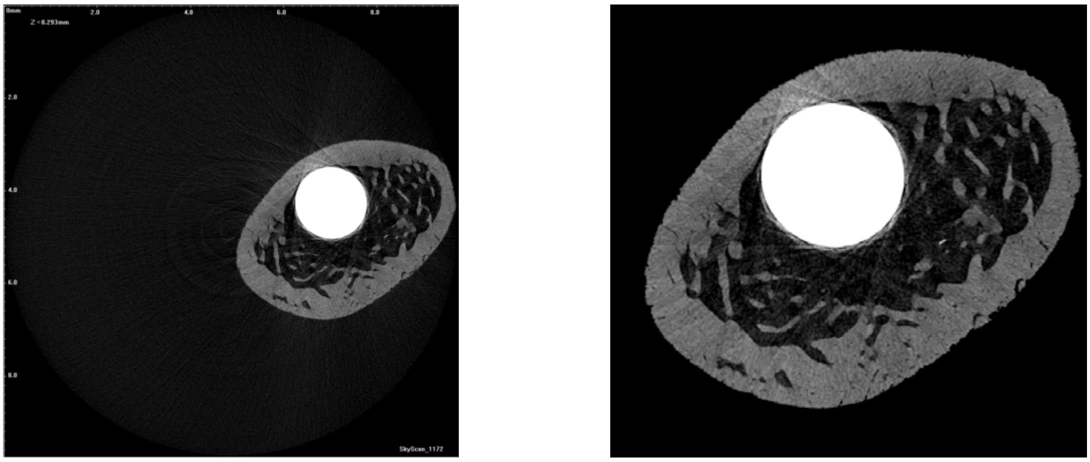
In this section, the algorithm proposed to segment automatically the implant-bone system is described. To show the effects of the algorithm, it was applied to one sequence of microCT. The proposed algorithm is based on two stages:

2.4.1 Background extraction in the bone-implant system

When segmenting microCT implant-bone systems images, a wide range of useless information arises, which has to be discarded as a prior step for classifying the different areas. To obtain effective results during the classification process, it is necessary to work with images containing the femoral bone and eliminate the effect of the iron based implants. The segmentation of the bone tissue is the first step in the trabecular bone classification. A correct segmentation will end, finally, in the success or failure of the upcoming segmentation processes, 3D reconstructions and structural analysis.

For this segmentation, an automatic algorithm was proposed. In a first step, Alternating Sequential Filters (ASFs) by reconstruction was applying using the sequence "CO" (closing-opening) with a cross structuring element and 7 iterations. In this way, a new image was obtained in which the bone zone is homogeneous and then a regions labeling criterion using geodesic distance was applied, which can evolve adapting to the topology of the objects in the image [14-15].

Figure 1 shows the result of the classification after the extraction of the femoral bone by the algorithm proposed.



(a) (b)

Figure 1. Elimination of redundant information (a) Original image, (b) image obtained after applying the proposed algorithm.

2.4.2 Segmentation of bone tissue by Compensatory Fuzzy Mathematical Morphology

In this second step, the method for segmentation of the trabecular tissue is described. Each image stack is considered as a single image for processing.

Step 1: The first step consists in eliminate the implant from the images. A threshold is applied to eliminate the implant. In this case, 250 was used as an umbral because the implant zone is homogenous with 255 value.

Step 2: A compensatory Top–Hat was applied to the images. In this case, a conjunction and disjunction of compensatory logic based on the geometric average for defining the operators of the equations (1) and (2) was applied. A 3x3 Gaussian structuring element was used. This method allowed to emphasize the objects of interest homogenizing the image background, as can be seen in Figure 2.

Step 3: Otsu binarization was applied.

Step 4: In this last step, the morphological gradient, using a 3x3 cross structuring element, is applied to extract the boundaries.

In the next section, the results obtained through the proposed method are described.

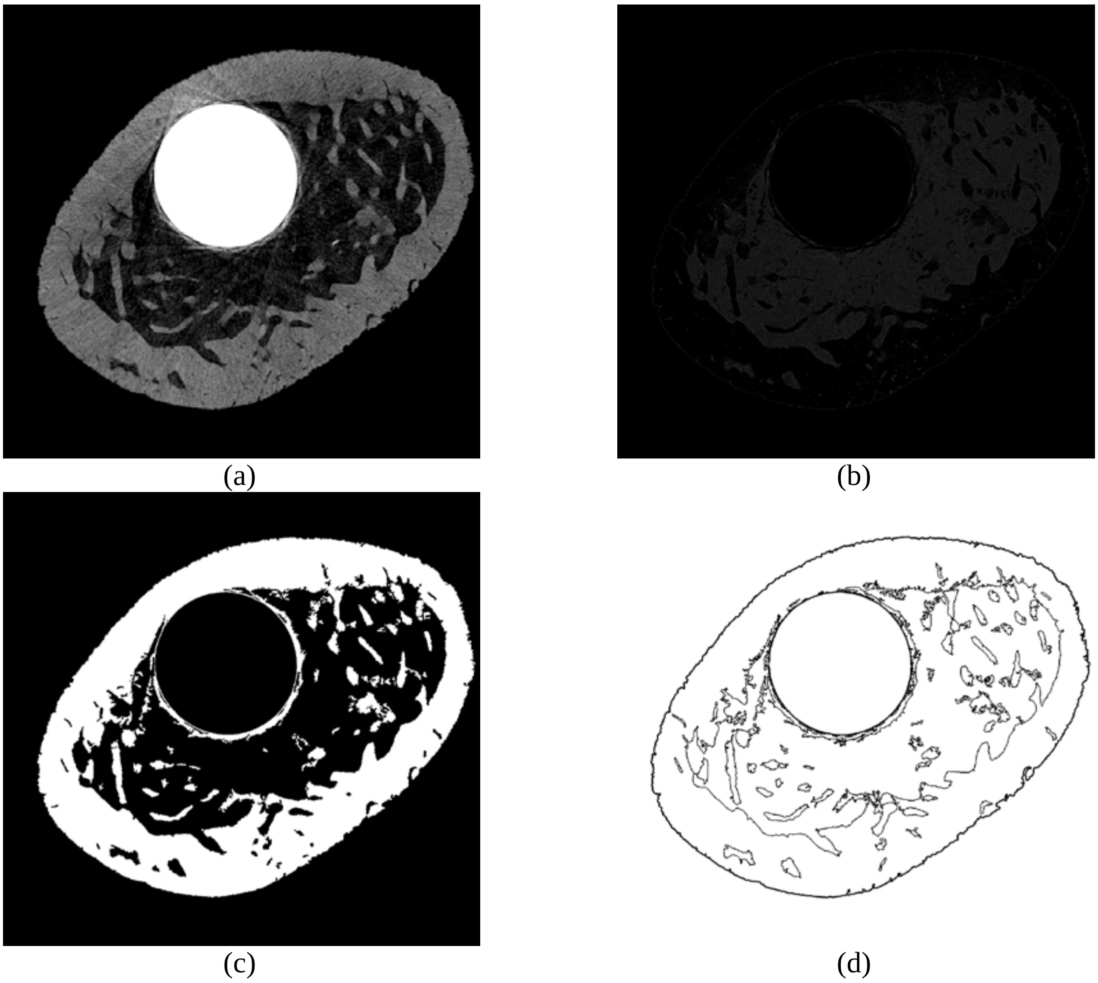


Figure 2. Segmentation of the trabecular tissue in microCT images. (a) Original image, (b) image obtained after applying compensatory Top–Hat, (c) image obtained after binarization, (d) boundary.

3. Results and discussion

The effect of the implant in the microCT images was studied for all six implant-bone samples. As the artifact is the same for all (is the same type of implant), only one sample is presented here.

Figure 3 show 3D reconstructions for the same stack of images, in the first case without processing and in the second case after applying the proposed method. The reconstruction was made by a tridimensional model using the Finite Element Method (FEM) [16]. The artifact effect related with the metal implant present in the images is showed in Figure 3b. Figure 3c shows a more precise 3D reconstruction obtained by applying techniques of image processing, in particular, CFMM operators. This kind of models have a particular interest, given that they help to predict the bone adaptation with the implant, the prosthesis stability and to design smart biomaterials for bone and tissues regeneration.

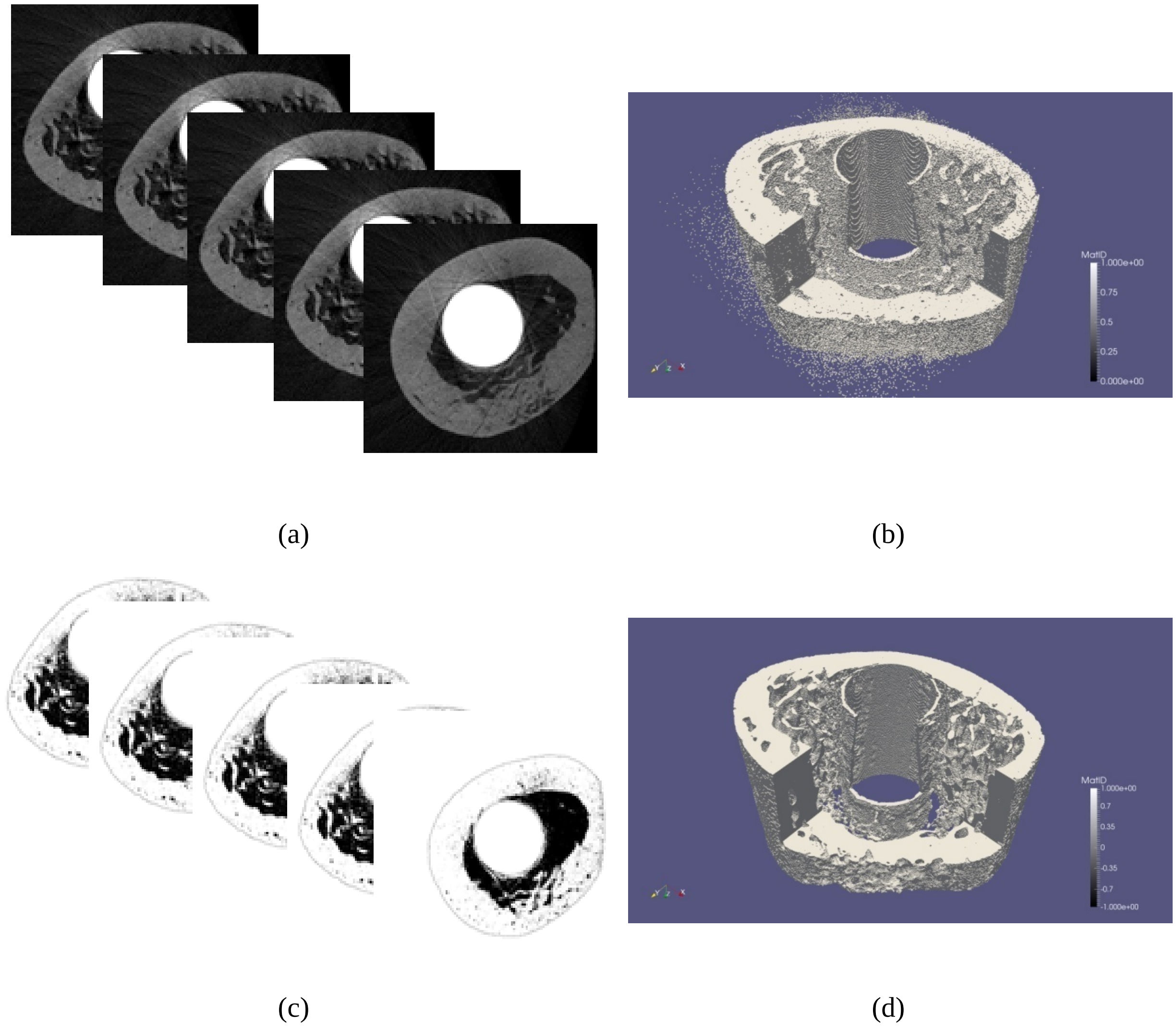


Figure 3. (a) Stack of images unprocessed. (b) 3D reconstruction no efficient. (c) Stack of images segmented by the proposed method. (d) 3D reconstruction efficient of the structure and topography of bone-implant system.

The same procedure was applied in different implanted samples (different times, surface treatment, etc), and the effect of the implant was corrected in all cases. Therefore, the obtained 3D images are now visually clean and are a starting point to measure different bone parameters, as bone attachment and density.

4. Conclusions

This work presents an automatic segmentation of the bone-implant system in conventional microCT images in a rat femur model. The Fuzzy Mathematical Morphology helps to extract the huge artifacts generated by iron based implants in microCT images. The method can be adapted to several implant cases and different types of metals since it is not a conventional filter, allowing the user to segment the trabecular bone at the periphery of metallic implants, obtaining clear images to process them and create 3D reconstructions.

As a future work, the proposed method will be validated with the goal to investigate about the structural and mechanical properties of trabecular bone and cancellous-like materials.

5. References

[1] Hart, R T. Bone Modelling and Remodelling: Theories and Computation. In *Bone Mechanics Handbook, Second Edition*. CRC Press, Boca Ratón, 2001.

[2] A. Gomez Sanchez, W. H. Schreiner, J. Ballarre, A. Cisilino, G. Duffó, S. Ceré. Surface modification of titanium by anodic oxidation in phosphoric acid at low potentials. Part 2. In vitro and in vivo study. Surface and Interface Analysis. ISSN 1096-991. (2013). DOI 10.1002/sia.5298.

[3] Miaraa, B, Rohanb, E, and Labatc, B. Piezomaterials for bone regeneration design – homogenization approach. *Journal of the Mechanics and Physics of Solids*, 53, 11 (2005), 2529-2556.

[4] R. Bernhardt, D. Scharnweber, B. Müller, P. Thurner, H. Schliephake, P. Wyss, F. Beckmann, J. Goebbels, H. Worch, J. Gasser, J. Kirkpatrick, B. Rahn, Comparison of microfocus- and synchrotron x-ray tomography for the analysis of osteointegration around TI6AL4V-implants, European Cells and Materials 7 (2004) 42-51.

[5] F Edward Boas & Dominik Fleischmann. CT artifacts: Causes and reduction techniques, Imaging Med. (2012) 4(2), 229-240.

[6] C.A. Neldam, E.M. Pinholt, Synchrotron μcT imaging of bone, titanium implants and bone substitutes - A systematic review of the literature, Journal of Cranio-Maxillofacial Surgery 42 (2014) 801-805.

[7] J.W. Song, J.Y. Cha, T.E. Bechtold, Y.C. Park, Influence of peri-implant artifacts on bone morphometric analysis with micro-computed tomography, The International journal of oral & maxillofacial implants 28 (2013) 519-525.

[8] Bloch I. (2005). Fuzzy spatial relationships for image processing and interpretation: a review, Image and Vision Computing 23: 89-110.

[9] Bloch I. and Maitre H. (1995). Fuzzy mathematical morphologies: A comparative study, Pattern Recognition 28: 1341-1387

[10] A. Bouchet, J.I. Pastore, R.E. Andrade, M. Brun, V. Ballarin, Compensatory Logic applied to Digital Image Processing, in: R.E. Andrade, J.M. Gómez, A.R. Valdéz (Eds.) Towards a trans-disciplinary technology of Business and Organizational Intelligence: Gathering Knowledge Discovery, Knowledge Management and Decision, Shaker Verlag, Aachen, University of Oldenburg, Alemania, 2011, pp. 226-239.

[11] J. Serra, Image analysis and mathematical morphology, Vol. 1, Academic Press, London, 1982.

[12] J. Serra, Image analysis and mathematical morphology, Vol. 2, Academic Press, London, 1988.

[13] R. González, R. Woods, Digital Image Processing, Addison Wesley1996.

[14] Pastore J, Moler E, & Ballarin V. "Procesamiento digital de imágenes a través de filtros morfológicos direccionales", Revista Argentina de Bioingeniería. Vol 14 N 1, pp 14-21, 2008.

[15] Pastore J, Moler E & Ballarin V. "Segmentation of brain magnetic resonance images through morphological operators and geodesic distance", Digital Signal Processing, Vol. 15, pp 153-60, 2005.

[16] Arbenz P, van Lenthe G H, Mennel U, Muller R, and Sala M. "Multi-level micro-finite element analysis for human bone structure", Workshop on State-of-the-Art in Scientific and Parallel Computing, Sweden, 2006

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