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IN VIVO CHARACTERIZATION OF MICRO ARCHITECTURE OF A HUMAN VERTEBRA BY MICRO-IMAGING

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ABSTRACT

Bone, like any other material, is subject to mechanical fatigue when subjected to repetitive cyclic loading. Cyclic loading in vivo occurs either in workplaces exposed to mechanical vibration or during handling operations or during leisure and sports activities. As an example, the continuous exposure of the human body to intense global vibration can be, in the long run, cause problems of lumbar lesions due to dynamic stresses (mainly compression) in the spine. Bone and microcracks in cancellous bone. Fatigue rupture of vertebral bone is clinically and biologically important. From a clinical point of view, permanent damage and deformity, under cyclic loading, can probably weaken the vertebral body by inducing the migration of joint replacements. The mechanism of fatigue damage in cortical and trabecular bone can cause cracks and their propagation to final rupture. Microcracks observed in the vertebrae contributed to the decrease in vertebral rupture strength. In order to analyze the biomechanical behavior of the vertebrae and to assess the risk of fracture, an in vivo characterization method is applied based on the micro-MRI, aiming to focus on the evaluation the force at rupture of the vertebral body in compression. The method of extracting the shape of cancellous bone by special filters (adaptive filter, Robert's filter, etc.) will be applied, allowing it to be modelled as a slice (2D). This micro slice are created by edge configuration generation and triangulated cube configuration generation in capturing section contour points from medical image per slice, creating B-spline curve with the control points in each layer, producing solid model construction in Planar Contours method. Medical rapid prototyping models are performed in SolidWorks. Layered manufacturing techniques are used for producing parts of arbitrary complexity, which will then be modelled by finite element in fatigue.

Keywords: biomechanics, in vivo characterization, fatigue, micro imaging.

INTRODUCTION

Bone is a metabolically active tissue; it is constantly renewed. It plays an important role in the mechanical functions of support, locomotion and protection of vital organs. Osteoporosis is a skeletal pathology characterized by a decrease in bone strength that increases the risk of fracture (Éric Wagnac, 2011). Strength is mainly determined by bone density and bone quality. Bone quality includes architecture, remodeling, microtrauma (micro cracks) accumulation and mineralization (Bogduk, N., 2005). Medical imaging is also often used as a complementary tool to experimental trials. By evaluating bone mineral density, imaging can partially predict the risk of fracture in a non-invasive way (Anais Garo, 2010). 3D imaging techniques, such as magnetic resonance imaging (MRI) or X-ray tomography (QCT), have gained in resolution and can be used to study bone microarchitecture in a non-invasive way (Emilie Sapin, 2008). In addition, it is also possible to simulate biomechanical tests on three-dimensional volumes taken from finite element analyzes to characterize vertebral behavior. QCT techniques are also used to study the lumbar spine, hip or peripheral sites. The treatment of the 3D images obtained allows a quantitative assessment of the bone structure, or even an evaluation of the mechanical properties of the bone that allow us to go further than simple densitometric deduction (Nicholas Vilayphiou, 2010).

In order to analyze the biomechanical behavior of the vertebrae and to evaluate the risk of fracture, an in vivo characterization method is applied based on the micro-imaging type micro CT or micro-MRI for purpose focused on the evaluation of the effort to rupture of the vertebral body in compression.

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RESULTS AND CONCLUSIONS

Biomechanical Characterization in Fatigue by Medical Micro-Imaging

Contour detection is a fundamental operation in image processing because it is the basis of pattern recognition. Its interest in image segmentation no longer needs to be demonstrated. There are as many contour detection operators as there are Definitions (or models) of contours will also be called "contour" the set of contiguous places or the norm of the two-dimensional spatial gradient is important.

The operators we have studied are based on the local evaluation of the gradient in given directions (Sobel, Prewitt, Roberts) or omnidirectional (morphological gradient).

In view of a judicious choice of operator, our study focuses on the application of the best differential local operators (Roberts, Prewitt, Sobel) and the morphological gradient in terms of thickness, contour location and noise resistance. We illustrate the results obtained by the HRpQCT technique (Figure 1).

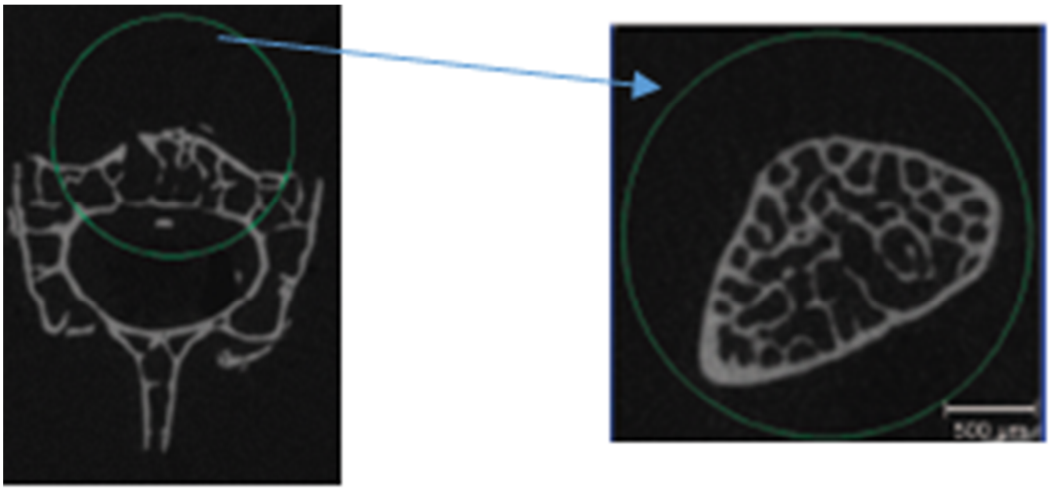


Fig. 1 - R.o.i of the vertebra

The operators of Sobel and Prewitt make it possible to locally estimate the norm of the two-dimensional spatial gradient of a gray-scale image. They amplify the regions of strong local variations of intensity corresponding to the contours (LEONARD DE VINCI, 2013). Robert's gradient consists of two stages. In a first step, the two convolution filters are applied to the image. The first of these filters makes it possible to detect the contours having a direction going from the upper corner of the image to the lower right corner (or vice versa) than the second filter makes it possible to detect contours having a direction going from the lower left corner of the image in the upper right corner (or the opposite). We thus obtain two images, it is then enough to merge the two images by using a standard calculus. Robert's filters are a discrete approach of the derivative one of a function the gradient of this function (Figure 2).

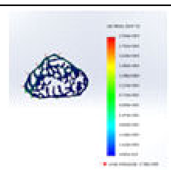
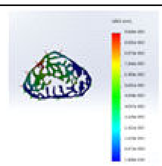
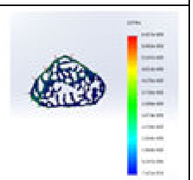
Filtering, thresholding and binarization of the image	Segmentation in Spline curve	3D layer modeling	Mesh	Results of the Von Misses stress (N / mm2)	Results of the resulting displacement (mm)	Results of the deformation
						

Fig. 2 - General Bio modeling Process Path for Characterization of the vertebra

FATIGUE STUDY

In the general case, there are several damage events, which differ from one another by the magnitude of the stresses undergone and by other parameters. Miner has proposed two principles that allow for cumulative damage.

The damage caused by an occurrence of an event is measured by the inverse 1/N of the number N of times that this event must be repeated to bring the part of the new state to failure.

The damage caused by a succession of events is the sum of the damages caused by each of them.

Note that these two principles are coherent. If we suppose that the same event always causes the same damage and if we impose as damage unit the damage that leads the system to failure then the first principle is a consequence of the second.

If 1/N is the damage of event A and if nA is the number of occurrences of this event during a test or use of the system then the total damage D caused by all events A, relatively to a failure, is defined by the Miner equation: D = nA / NA.

The interaction analysis shows that the number of fatigue cycles before failure decreases, as expected, when the applied stress σapp is higher. This effect is all the more significant as the bone density D is low and the age A is high. It is noted that for a low stress, of the order of 20% of the ultimate stress of the vertebrae, the age A and density D factors have a negligible effect (not significant effect) on the life span N of the lumbar spine.

A cyclic force with an amplitude of 50 N is applied to generate fatigue damage for 200 Iterations (days), (Figure 3); under these conditions, the local deformation exceeds 3500 με in some elements.

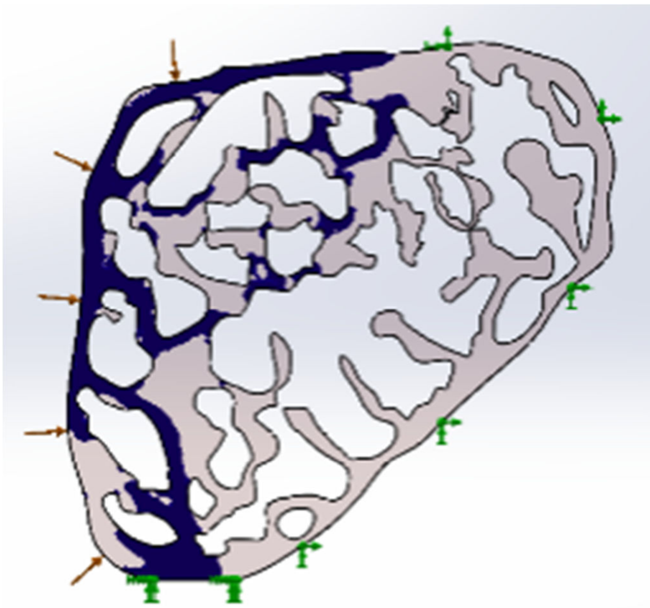


Fig. 3 - Contour of the simulated fatigue damage (cycles = 1.e +10).

CONCLUSIONS

The aim of this work was to contribute to the improvement of knowledge on the mechanical, structural and tissue properties of the vertebral bone. Clinically, bone imaging modalities are now effective in diagnosing and following most bone pathologies in adults. As far as the field of research is concerned, numerical simulation now makes it possible to validate and understand many experimental tests.

The second part of this work was dedicated the correlations obtained between some architectural parameters measured on HRpQCT images and the bone resistance suggest a lower resolution; the sampling rate of the HRpQCT images being 78 µm provides sufficiently precise information on the trabecular network architecture

Finally, the study of trabecular tissue characteristics should relate the information provided by microradiography and / or very high resolution tomography (2 µm) techniques (visualization and understanding of the appearance of micro-cracks in the structure bone), and its mechanical properties, essential for understanding and simulating the load behavior of healthy or pathological vertebral bone. The long-term goal is to be able to predict fracture risks as accurately as possible without the need for mechanical testing and without the use, as far as possible, of invasive traumatic techniques (biopsies).

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