

Tohoku University Global COE Programme  
"Global Nano-Biomedical Engineering Education and Research Network Centre"  
Faculty of Engineering of the University of Porto (FEUP)  
Polytechnic Institute of Bragança (ESTiG)



# Japan-Portugal Nano-BME Symposium 2011

**3 June 2011**

Faculty of Engineering of the University of Porto (FEUP)

**6 June 2011**

Polytechnic Institute of Bragança  
(Auditorium Alcino Miguel, ESTiG)



Tohoku University

**FEUP** FACULDADE DE ENGENHARIA  
UNIVERSIDADE DO PORTO

**ipb** INSTITUTO POLITÉCNICO DE BRAGANÇA  
Escola Superior de Tecnologia e Gestão

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Biomedical Institute of Portugal  
(Associação Miguel Bete)

**Publication Office**

Tohoku University Global COE Programme  
Global Nano-Biomedical Engineering Education and Research Network Centre

Department of Biomedical Engineering, Graduate School of Biomedical Engineering, Tohoku University  
6-6-01 Aoba, Aoba-ku, Sendai 980-8579, Japan  
Tel: +81-22-795-7005 Fax: +81-22-795-5031 E-mail: [secretary@nanobme.org](mailto:secretary@nanobme.org)  
URL: <http://www.nanobme.org>

ISBN 978-4-904157-20-6



# Programme

<b>Fri. 3 June 2011</b> Faculty of Engineering of the University of Porto (FEUP)	
15:00	Opening Remarks
	Keynote Lecture Chair: Rui Lima (Polytechnic Institute of Bragança)
15:10	<b>Computational Biomechanics for Respiratory and Micro-circulatory Systems</b> Takami Yamaguchi (Department of Biomedical Engineering, Tohoku University)
	Keynote Lecture Chair: Mónica Oliveira (University of Porto)
15:50	<b>Transport Phenomena Research Center (CEFT): Research on Complex Flows of Complex Fluids</b> Fernando T. Pinho (CEFT, DEMec, Faculty of Engineering, University of Porto)
16:30	Adjournment
19:00	Banquet
<b>Mon. 6 June 2011</b> Polytechnic Institute of Bragança (Auditorium Alcino Miguel, ESTiG)	
14:15	Opening Remarks
	Keynote Lecture Chair: Rui Lima (Polytechnic Institute of Bragança)
14:30	<b>Computational Biomechanics for Respiratory and Micro-circulatory Systems</b> Takami Yamaguchi (Department of Biomedical Engineering, Tohoku University)
15:00	Coffee Break
	Session I Chair: Rui Lima (Polytechnic Institute of Bragança) / Mónica Oliveira (University of Porto)
15:15	<b>Numerical Simulation on Margination of Malaria-infected Red Blood Cells in Microvessels</b> Yohsuke Imai (Department of Bioengineering and Robotics, Tohoku University)
15:30	<b>Analysis of Ciliary Motion and Fluid Flow on the Surface of Tracheal Cells</b> Hironori Ueno (International Advanced Research and Education Organization (IAREO), Tohoku University)
15:45	<b>Numerical Simulation of Cell Depleted Peripheral Layer and Red Blood Cells Motion in Microvascular Blood Flow</b> Davod Alizadehrad (Department of Biomedical Engineering, Tohoku University)
16:00	<b>Gradient Diffusion of Red Blood Cells in a Y-shape Microchannel</b> Cheng-Hsi Chuang (Department of Biomedical Engineering, Tohoku University)
16:15	<b>High Performance GPU Computing of Capsule Flow using Boundary Integral Method</b> Daiki Matsunaga (Department of Bioengineering and Robotics, Tohoku University)
16:30	Coffee Break/ Poster Session

Session II Chair: Yohsuke Imai (Tohoku University)	
17:30	<b>A Numerical Study on the Cooling Power of an Enhanced Convection Solution for Footwear</b> Tiago S. Mayor (Centre for Nanotechnology and Smart Materials (CeNTI))
17:45	<b>Flow of a Blood Analogue Solution through Microchannels with Bifurcations</b> Patrícia C. Sousa (CEFT, DEQ, Faculty of Engineering, University of Porto)
18:00	<b>Motions of Trace Particles and Red Blood Cells in a PDMS Microchannel with a Converging Bifurcation</b> Vladimir Leble (ESTIG, Polytechnic Institute of Bragança)
18:15	<b>Tracking Erythrocytes in a 100 µm Glass Capillary</b> Diana Pinho (ESTIG, Polytechnic Institute of Bragança)
18:30	<b>Classification of Alzheimer's Electroencephalograms using Artificial Neural Networks and Logistic Regression</b> Pedro Rodrigues (ESTIG, Polytechnic Institute of Bragança)
18:45	Adjournment

Poster Session	
	<b>Flow of Red Blood Cells in Capillary Networks</b> Ana Couto/Lúcia Teixeira (Polytechnic Institute of Bragança)
	<b>Analysis of the Cell-Free Layer in a Circular Microchannels: Trajectories of Labeled Red Blood Cells</b> Catarina Meireles (Polytechnic Institute of Bragança)
	<b>Synthesis of Magnetic Iron Oxide Nanoparticles for Biomedical Applications</b> Cidália Gomes/Luís Veiga (Polytechnic Institute of Bragança)
	<b>Production of Chitosan Based Films Enriched with Essential Oils for Biomedical Applications</b> Diana Vilas-Boas/Erica Leite (Polytechnic Institute of Bragança)
	<b>Experimental and Numerical Characterization of Displacement Field on Biological Tissues</b> João Ribeiro (Polytechnic Institute of Bragança)
	<b>Dynamic Sedimentation Measurements of Physiological Fluids in Biomedical Devices</b> Valdemar Garcia (Polytechnic Institute of Bragança)
	<b>Development of a Microfluidic Device for Partial Cell Separation</b> Rui Lima/Mónica Oliveira (Polytechnic Institute of Bragança)

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# Experimental and Numerical Characterization of Displacement Field on Biological Tissues

João Ribeiro<sup>\*1)</sup>, Hernâni Lopes<sup>1)</sup>, and Bebiana Mendonça<sup>1)</sup>

1) ESTIG, Polytechnic of Bragança, Bragança, Portugal  
E-mail: jrbeiro@ipb.pt



## Abstract

In this work is done a characterization of displacement field on different kind of biological tissues by numerical and experimental techniques. The experimental method is a full-field optical technique called by Digital Image Correlation and for the numerical simulation is used a commercial code of finite elements designated by Ansys®.

## 1. Introduction

The need to understand the behavior of biological tissues, especially human tissue, has stimulated the development of experimental and numerical techniques that allow the characterization of such materials. The most popular classification of human biological material is: hard and soft tissues. Typically an example of hard material is the bone and for soft material is the skin or the muscle. Traditionally, the mechanical study of this type of materials has been done with conventional techniques developed for the study of materials with a linear and isotropic behavior, such as tensile tests, which allow the average values determination of some mechanical properties [1]. Nevertheless, these materials have a very different mechanical behavior of conventional ones, therefore the need to use techniques which allow a comprehensive analysis of these tissues behavior, and the optical techniques are more suitable for this purpose because they can measure without contact and obtain information of a global sub-micrometer resolution. However, nowadays the use of experimental tests has been frequently replaced by the numerical simulation using finite element, with important advantages from the standpoint of saving financial costs and time consumption.

One of the most important experimental optical technique used in the biological material characterization is the Digital Image Correlation (DIC). The DIC is a measurement technique which uses a mathematical correlation method to calculate the displacement on the plane surfaces of components or structures subjected to thermal or mechanical charges. This technique is based on the use of random patterns on the component surface. The technique compares two images, acquired in different states, one before deformation and another after deformation. The two images may also be designated as the reference image

(before deformation) and deformed image [2]. The correlation between the two states is done by:

$$f^*(x^*,y^*)=f(x+u(x,y),y+v(x,y)) \quad (1)$$

where  $u$  and  $v$  represent the displacement fields.

In this work were done two different experimental tests using the DIC to characterize hard and soft materials behavior and the respectively numerical comparison with a commercial finite elements code, Ansys®.

## 2. Hard Biological Materials

This study intends to analyze the behavior of bovine cortical bone in the vicinity of a metal implant interface, under the action of various loads. Cortical bone is a material with a highly porous structure, which prevents the accurate measurement of deformation using conventional experimental methods, for this reason the measurements were implemented with DIC technique.

The apparatus developed to simulate the interface between bone and implant is presented in Fig. 1.

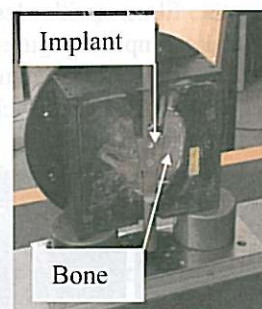


Fig. 1. Apparatus used for measuring deformations on the bone-implant interface.

The apparatus was subjected to a uniform loading applied by a universal testing machine. During the charging test were captured images in successive increments of 30 N until 1000 N. The DIC system used was the Aramis of GOM, which allows the computation of sub-pixel and this way, the determination, with high resolution, of displacement and strain fields occurred during the test. In Fig. 2 presents an example of the displacement field measured in two orthogonal directions with DIC, for a load of 1000 N.

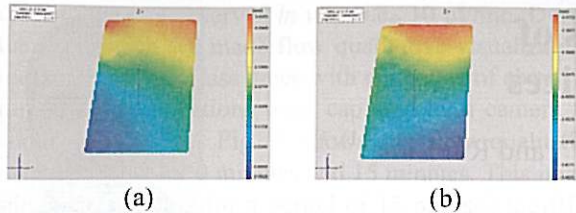


Fig. 2. Displacement field in the directions: x (a) and y (b), for a load of 1000 N.

The numerical simulation of the test was performed using the finite element program Ansys®. It was created a model with geometry and dimensions identical to that used experimentally and was generated a mesh, they were applied incremental loads with the same value which were used in experimental testing until a maximum of 1000 N. In Fig. 3 shows the simulated displacement fields for the loading of 1000N.

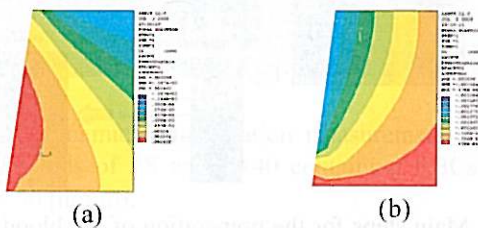


Fig. 3. Displacement field in the directions: x (a) and y (b), for a load of 1000 N, determined with Ansys®.

In the comparative analysis between the results obtained experimentally and numerically determined can be verified that the interface behavior is qualitatively similar.

### 3. Soft biological Materials

For the characterization of soft biological material was used human pelvic tissue. This material has a hyper-elastic mechanical behavior. Samples of hyper-elastic material were used in tensile tests and each sample was previously prepared applying on their surface a random pattern of black dots.

The sample had a parallelepiped geometry which dimensions are represented in table 1.

Table 1. Sample dimensions.

Thickness [mm]	Length [mm]	Width [mm]
1.348	13.08	9.619

The tested material has hyper-elastic properties and, the deformations occurring are very high. This property brings difficulties for the use of interferometric optical techniques because could occur speckle decorrelation. The DIC technique is an optical technique that allows the measurement of displacement and strain fields for these kinds of materials. In Fig. 4 presents an example of the displacement field measured with DIC, for a load of 0.25 N.

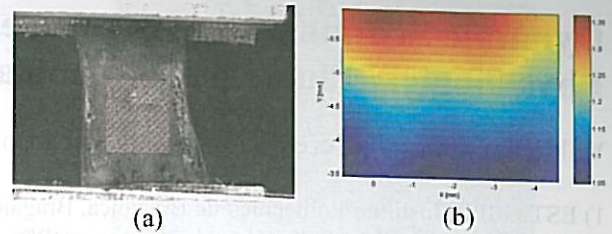


Fig. 4 Measuring the displacement field with DIC: (a) sample of tissue tested and (b) displacement field measured in the vertical direction.

A numerical simulation was done using the Ansys®. The dimensions and geometry of model is identical to the experimental sample. Was used the experimental data of tensile test for the simulation of hyper-elastic material. For this case the mathematical model applied was the Mooney-Rivlin with three parameters [3]. The boundary conditions were: the base fixed and applying a load of 0.25 N on top. In Fig. 5 shows the displacement field for two orthogonal directions.

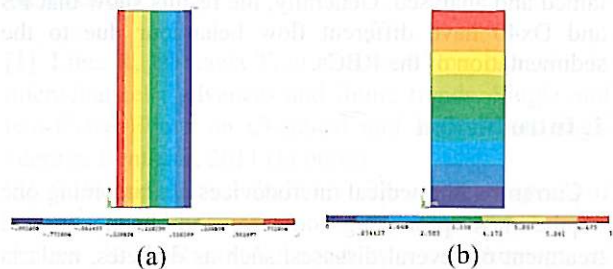


Fig. 5. Displacement field in the directions: x (a) and y (b), for a load of 0.25 N, determined with Ansys®.

The hyper-elastic material behavior has some differences between the experimental and numerical results; however there is a tendency for the same behavior for a region far from the applied load.

### 4. Conclusions

The technique of Digital Image Correlation proved to be well adapted to the measurement of displacement fields on biological tissues. The numerical simulations show that it is possible to use them as an alternative to experimental tests; however the numerical algorithms for biological materials must be improved.

### References

- [1] Afonso J, Martins P, *et al.* Mechanical properties of polypropylene mesh used in pelvic floor repair. *Int Urogynecol J* 19, 375–380, 2008.
- [2] Marcellier H, Vescovo P, *et al.* Optical analysis of displacement and strain fields on human skin. *Skin Research and Technology* 7, 246-253, 2001.
- [3] Taber L. *Nonlinear Theory Elasticity: Application in Biomechanics*. World Scientific Publishing, London, 2004.