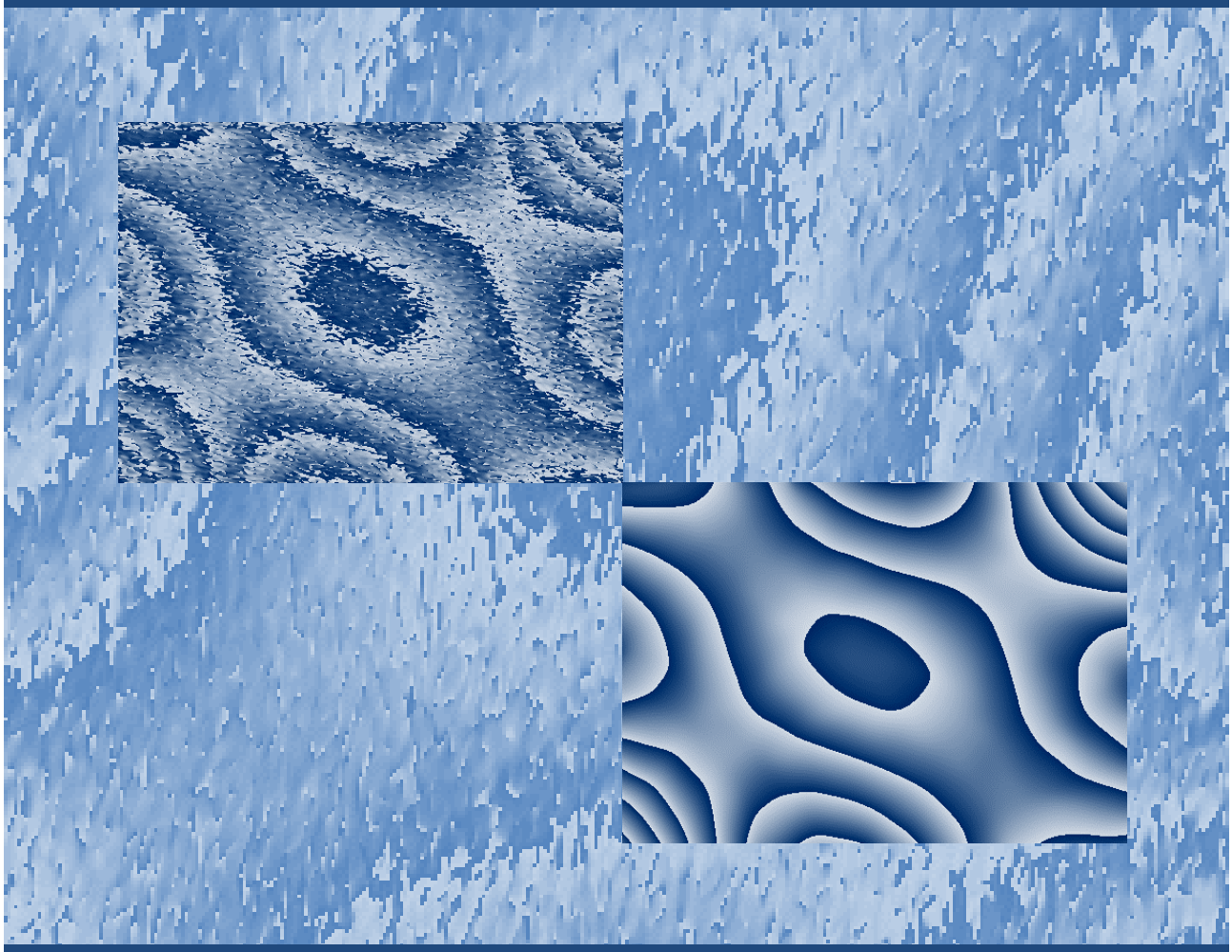
EXPERIMENTAL MECHANICS
New Trends and Perspectives

J.F. Silva Gomes, Mário A.P. Vaz
Editors



Proceedings of the 15th International Conference on Experimental Mechanics, Porto, Portugal, 22-27 July 2012

Edições INEGI

ICEM15

EXPERIMENTAL MECHANICS
(NEW TRENDS AND PERSPECTIVES)

J.F. Silva Gomes, Mário A.P. Vaz (Ed)

Edições INEGI
(2012)

Published by

INEGI-Instituto de Engenharia Mecânica e Gestão Industrial
Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
Tel:+351 22 957 87 10; Email: inegi@inegi.up.pt
www.inegi.up.pt

July, 2012

ISBN: 978-972-8826-22-2
Legal D.N: 295639/09

Printed by:

LusoImpress (Grupo Claret)
Rua Venceslau Ramos, s/n - 4430-929 Avintes, Portugal
Tel:+351 22 787 73 20; Fax:+351 22 787 73 29

Cover design by Nuno V. Ramos (INEGI)

PREFACE

Engineering practice in general and mechanical design in particular are basically exercises of creativity, triggered by specific needs. As the engineering community continues to cross the boundaries of known practices, design and manufacturing techniques into the frontiers of new materials and mechanical systems, energy sources and their effects upon the environment, the opportunities for failure will inevitably increase. If our knowledge of how to engineer systems, structures and components to minimize or prevent failure is to keep pace with modern demanding applications and the intolerance of a safety conscious society, we must develop and apply superior analytical and experimental tools to evaluate the potential for damage or failure of engineering structures and/or components and the associated energy harvesting systems.

Different tools are available to optimize any engineering solution, from which *Experimental Mechanics* has always played a most prominent role. It is related to such diverse disciplines as physical and mechanical sciences, engineering (mechanical, aeronautical, civil, automotive, nuclear, etc.), materials, electronics, medicine and biology, and uses experimental methodologies to test and evaluate the behaviour and performance of all kinds of materials, structures and mechanical systems. Quality control, safety, destructive and non-destructive testing of materials and components, analysis of prototypes and even fundamental research are some of the possible applications of *Experimental Mechanics*. During the last few decades the development of computer based techniques, as well as laser-optics methods, nanotechnologies and nanomaterials, among many other technological advances, added new dimensions and perspectives to *Experimental Mechanics and Testing*.

This volume contains the extended Abstracts of the 564 papers accepted for presentation in the ICEM15-15th International Conference on Experimental Mechanics held in Porto/Portugal, 22-27 July 2012. It is complemented by an accompanying CD-ROM containing the full length text of the papers. The book is organized in three main parts: PART-A, with the abstracts of the 11 Invited Plenary Papers, by distinguished academics and scientists in the field of *Experimental Mechanics*; PART-B, with 289 abstracts distributed by the 12 general main topics (from A to L); and PART-C, with the remaining 264 abstracts from the 20 Special Symposia in ICEM15.

The ICEM15 conference is part of a prestigious series of conferences that was initiated in 1959, in Delft (The Netherlands), and the last one took place in Poitiers (France) in July 2010. All these *Experimental Mechanics* meetings resulted from the belief that of those disciplines associated with advanced product design and manufacture, experimental mechanics techniques have been making continuous and significant advances during the years. Important and dramatic improvements in systems and components design can be made by the use of the latest advances in experimental mechanics techniques applied to energy systems, structures and materials. Their effect on the environment is significant and will help in avoiding global warming and harmful CO_2 emissions.

It is organized by the Faculty of Engineering of the University of Porto (FEUP) and the Portuguese Association for Experimental Mechanics (APAET), under the auspices of the European Association for Experimental Mechanics (EURASEM), and sponsored by a number of national and international organizations, whose support is gratefully acknowledged: SEM-

American Society for Experimental Mechanics, BSSM-British Society for Strain Measurement, JSME-Japanese Society of Mechanical Engineering, IMEKO-International Measurement Confederation, AFM-Association Française de Mécanique, DYMAT-European Association for Dynamics of Materials, INEGI-Instituto de Engenharia Mecânica e Gestão Industrial, LABIOMEP-Laboratório de Biomecânica do Porto, LNEC-Laboratório Nacional de Engenharia Civil, FCT-Fundação para a Ciência e a Tecnologia, FCG-Fundação Calouste Gulbenkian, FLAD-Fundação Luso-Americana para o Desenvolvimento, CCDRN-Comissão de Coordenação e Desenvolvimento Regional do Norte, ABEU-PCO, Professional Congress Organizer, and Teatro Nacional S. João/Secretaria de Estado da Cultura.

We are particularly indebted to all *Symposium Promoters* for the coordination of the different themes and to the authors for their papers and presentations. The different contributions during the conference offered opportunities for thorough discussions with the authors. We acknowledge all of the participants, who contributed with innovations, new research approaches, novel techniques and testing methodologies, and their invaluable critical comments.

We are also indebted to the eleven outstanding *Plenary Lecturers* who highlighted the conference themes with their contributions: Dr. Shaker A. Meguid (University of Toronto/Canada), Dr. Gustavo B. Guimarães (Manufacture Engineering, EMBRAER/Brazil), Dr. Yoshiharu Morimoto (Moire Institute Inc., and Wakayama University, Wakayama, Japan), Dr. Emmanuel Gdoutos (Democritus University of Thrace, Greece), Dr. Robert A.W. Mines (University of Liverpool, United Kingdom), Dr. Sergei T. Mileiko (Russian Academy of Sciences, Russia), Dr. Michael B. Prime ((Los Alamos National Laboratory, USA), Dr. Mário A.P. Vaz (University of Porto, Portugal), Dr. Josef Eberhardsteiner (Vienna University of Technology, Austria), Dr. José Ygnacio Pastor (Technical University of Madrid, Spain), and Dr. Alfredo L. Campos (LNEC, Portugal).

Finally, we wish to express our gratitude to the members of the International Scientific Committee for reviewing the papers and the Proceedings, and to the members of the Local Conference Organizing Committee: António T. Marques, Paulo T. de Castro, A.J.M. Ferreira, Carlos C. António, Jorge Seabra, J.D. Rodrigues, Clito F. Afonso, Álvaro Cunha, Elsa Caetano, and Rui C. Barros, and the National Organizing Committee: João Ferreira (IST, Lisbon), Jorge Gomes (LNEC, Lisbon), José M. Cirne (UC, Coimbra), Paulo G. Piloto (IPB, Bragança), Mário Santos (LNEG, Lisbon).

J.F. Silva Gomes and Mário A.P. Vaz

Porto, July 2012

Organization

FEUP
Faculty of Engineering, University of Porto

APAET
Portuguese Association for Experimental Mechanics

on behalf of

EURASEM
European Association for Experimental Mechanics

Organizing Committee

J.F. Silva Gomes (*Chair)*

Mário A.P. Vaz (*Vice-Chair*)

Local Committee

Álvaro Cunha, António T. Marques, António Ferreira, Carlos C. António, Clito Afonso, Elsa Caetano, Jorge Seabra, José D. Rodrigues, Paulo T. Castro, Rui C. Barros

National Committee

João Ferreita (IST), Jorge Gomes (LNEC), José M. Cirne (FCTUC), Mário Santos (LNEG), Paulo G. Piloto (IPB)

Conference Secretariat

Nuno Pinto, Fernanda Fonseca, M.F. Silva Gomes, Nuno T. Santos

with the support of

ABEU-PCO, Professional Congress Organizer (http://pco.abreu.pt)
Mercatura Conference System (http://www.mercatura.pt)

International Scientific Committee

(*President: Mário A.P. Vaz*)

Aben, H. (Estonia)
Adams, R. (UK)
Afonso, C.F. (Portugal)
Alexopoulos, N. (Greece)
Ambrósio, J. (Portugal)
André, P. (Portugal)
Angelova, D. (Bulgaria)
Anglada, M. (Spain)
António, C.C. (Portugal)
Banks-Sills, L. (Israel)
Barros, R.C. (Portugal)
Barton, J. (UK)
Bathe, K.J. (USA)
Benta, A. (Portugal)
Bolton, R. (USA)
Botsis, J. (Switzerland)
Branco, F.A. (Portugal)
Bremand, F. (France)
Caetano, E. (Portugal)
Camanho, P. (Portugal)
Campos, J.A. (Portugal)
Campos, J.R. (Portugal)
Cardeira, C. (Portugal)
Castro, C.F. (Portugal)
Castro, P.T.de (Portugal)
Cavalli, M. (USA)
Chen, T. (Taiwan)
Chenot, J-L (France)
Cirne, J. (Portugal)
Correia, A. (Portugal)
Costa, Luísa (Portugal)
Cottron, M. (France)
Croccolo, D. (Italy)
Cunha, A. (Portugal)
Datta, S. (USA)
Daum, W. (Germany)
Degrieck, J. (Belgium)
Dietrich, L. (Poland)
Duarte, T. (Portugal)
Eberhardsteiner, J. (Austria)
Emri, I. (Slovenia)
Esteves, J.L. (Portugal)
Fangueiro, R. (Portugal)
Fernandes, A. (Portugal)
Fernandes, V. (Portugal)
Ferreira, A.J. (Portugal)
Ferreira, J. (Portugal)
Figueiras, J. (Portugal)
Fonseca, E. (Portugal)
Freddi, A. (Italy)
Freire, J.L. (Brazil)
Furlong, C. (USA)
Gabbar, H.A. (Canada)
Galietti, U. (Italy)
Gameiro, M. (Portugal)
Gdoutos, E. (Greece)
Genovese, K. (Italy)
Geraldes, M.J. (Portugal)
Gilchrist, M. (Ireland)
Ghosh, Ashok (USA)
Gomes, J. (Portugal)
Gonçalves, M. (Portugal)
Guedes, R.M. (Portugal)
Hejum, Du (Singapore)
Hoa, S.V. (Canada)
Hutchings, I. (UK)
Igartua, A. (Spain)
Iliescu, N. (Romania)
Jacquot, P. (Switzerland)
Jones, N. (UK)
Jorge, R.N. (Portugal)
Kennedy, D. (Ireland)
Klein, H.W. (Germany)
Kourkoulis, S. (Greece)
Laermann, K. (Germany)
Langseth, M. (Norway)
Leão, C.P. (Portugal)
Lebedev, A. (Ukrain)
Lee,D.G. (Korea)
Li, Jackie (USA)
Lino, J. (Portugal)
Lopes, H. (Portugal)
Lopez, G. Ruiz (Spain)
Lopez, M.A. (Portugal)
Loureiro, A. (Portugal)
Lu, Jian (Hong Kong)
Maia, Nuno (Portugal)
Mal, A. (USA)
Marques, A.T. (Portugal)
Marques, J.C. (Portugal)
Martins, R. (Portugal)
Masato, Y. (Japan
Meguid, S.A. (Canada)
Melo, F.Q. (Portugal)
Michaelis, K. (Germany)
Mileiko, S.T. (Russia)
Miller, R.E. (Canada)
Mimmi, G. (Italy)
Mines, R. (UK)
Miranda, A. (Portugal)
Miranda, Rosa (Portugal)
Miyano, Y. (Japan)
Moreira, P. (Portugal)
Morimoto, Y. (Japan)
Moshaiov, A. (Israel)
Moura, M.F. (Portugal)
Navarro, C. (Spain)
Navas, H. (Portugal)
Dourado, N. (Portugal)
Olabi, Abdul G. (Ireland)
Pais, L. (Portugal)
Pappalettere, C. (Italy)
Patoor, E. (France)
Pereira, M.S. (Portugal)
Pieczyska, E. (Poland)
Pierron, F. (France)
Piloto, P. (Portugal)
Pinho, F. (Portugal)
Pires, J.N. (Portugal)
Pollan, R. (Spain)
Prime, M. (USA)
Ragulskis, M. (Lithuania)
Ramesh, K. (India)
Ramos, I. (Portugal)
Reddy, J.N. (USA)
Reis, A. (Portugal)
Restivo, M.T. (Portugal)
Rocha, A.B. (Portugal)
Rodrigues, H. (Portugal)
Rodrigues, J.D. (Portugal)
Rodrigues, J.P. (Portugal)
Ruiz, G. (Spain)
Sainov, V. (Bulgaria)
Santos, A. (Portugal)
Santos, M. (Portugal)
Santos, T. (Portugal)
Schaer, G. (Canada)
Sciammarella, C.A. (Italy)
Seabra, Jorge (Portugal)
Segadães, A. (Portugal)
Semenski, D. (Croatia)
Servin, M. (Mexico)
Silva, A.J. (Portugal)
Silva, J.M. (Portugal)
Silva Gomes, J.F. (Portugal)
Silva, Lucas (Portugal)
Silva, M.G. (Portugal)
Silva, S. Carmo (Portugal)
Sjödahl, M. (Sweden)
Soares, C.M. (Portugal)
Solsona, F.A. (Spain)
Suleman, Afzal (Portugal)
Takagi, T. (Japan)
Talaia, M. (Portugal)
Tamuzs, V. (Latvia)
Tavares, J.M. (Portugal)
Teixeira, M.C. (Portugal)
Thomsen, O.T. (Denmark)
Tooren, M.J. (Netherlands)
Truman, C.E. (UK)
Umeda, T. (Japan)
VanHemelrijck, D. (Belgium)
Varum, H. (Portugal)
Vasques, C. (Portugal)
Vaz, Mário P. (Portugal)
Viegas, X. (Portugal)
Vieira, C. (Portugal)
Vieira, T. (Portugal)
Vila-Real, P. (Portugal)
Vilas-Boas, J. (Portugal)
Wang, Wei-Chung (Taiwan)
Weng, G. (USA)
Yoneyama, Satoru (Japan)
Yoon, Y.C. (Singapore)
Zhang, Y. (USA)
Zhang, Z. (China)

EXPERIMENTAL MECHANICS
New Trends and Perspectives

J.F. Silva Gomes, Mário A.P. Vaz (Ed)

Proceedings
ICEM15-15th International Conference on Experimental Mechanics
Porto/Portugal, 22-27 July 2012

SYMPOSIUM_13
Biomedical Applications and 3D Rapid Prototyping

Coordinators:

Elza M.M. Fonseca(*)
Department of Applied Mechanics, Polytechnic Institute of Bragança, Portugal
Maria Cristina M. Teixeira(*)
Department of Basic Sciences and Life, Polytechnic Institute of Bragança, Portugal

(*)Associate Editors for the papers in this Symposium

PAPER REF: 2711

EVALUATION OF THE CORTICAL BONE THICKNESS IN LUMBAR VERTEBRA USING CT AND RP EXPERIMENTAL TECHNIQUES

Elza M.M. Fonseca[1(*)], Luisa M.S. Barreira[2], Maria Cristina M. Teixeira[3]

[1, 2]Department of Applied Mechanics, Polytechnic Institute of Bragança, Bragança, Portugal
[3]Department of Basic Sciences and Life, Polytechnic Institute of Bragança, Bragança, Portugal
[(*)]*Email:* efonseca@ipb.pt

ABSTRACT

The main objective of this paper was to assess the cortical bone thickness of human lumbar vertebra, through Computed Tomography (CT) images by using both image processing software and rapid prototyping (RP) experimental methodologies. The study here presented focus sixteen postmenopausal patients from the North of Portugal, with age between 50 and 85 years, collected from May to June 2011. All clinical data were obtained in a Medical Centre of Radiology and Imaging, in Porto. Results regarding cortical bone thickness and biomechanical resistance of human lumbar vertebra are presented. The acquirement of accurate values concerning cortical bone thickness could improve the prediction of fracture risk.

INTRODUCTION

Bone Mass Density (BMD) is a good predictor of fractures, particularly at the spine (Beaupied 2007). Nonetheless, fracture risk assessment based only on trabecular BMD, disregards other features of bone's biomechanical competence. Age-related physical changes include decreased cortical thickness, one of several structural changes that translate to alterations in bone's strength and risk for fracture (Epstein S, 2006). Thus, consideration of cortical bone thickness clearly improves the prediction of fracture risk. CT is the most common technique used for examination in medicine, because it permits the visualization of soft tissues and bone structures (Cavalcanti, 2001). Actually, CT images can be processed using specific software that allows analysing the bone geometry and creating 3D templates of anatomical specimens.

RESULTS AND CONCLUSIONS

The current study was based on spine CT images and previous results from BMD exams. Women were previous classified according to BMD score, as a normal, osteopenic and osteoporotic. The cortical thickness in the body of the lumbar vertebra (L2-L5) was evaluated using two methodologies. First, the cortical thickness was measured in different layers, through 5 anatomical positions, using image processing software (iQ-VIEW). The 3D visualization of the medical images was obtained using InVesalius 3.0 (FREE Beta2 Software, C.T.I. Renato Archer). Fig. 1 represents a CT and all different anatomical positions considered for this study. Second, an experimental technique RP was used to measure the cortical thickness in different body of lumbar vertebra. This method was originally introduced in industry to improve design and reduce product development time, now being applied to medicine, allowing an immediate and intuitive understanding of the most complex 3D geometry (McGurk, 1997). Each segment of lumbar vertebra was produced with a monochromatic 3D ZPrinter from digital data using RP experimental technology. Using this

technique the cortical bone thickness will be measured and compared with the values previous obtained. Fig. 2 shows the experimental RP procedure used for measuring some different lumbar vertebra slices of a female patient with 52 years (F52).

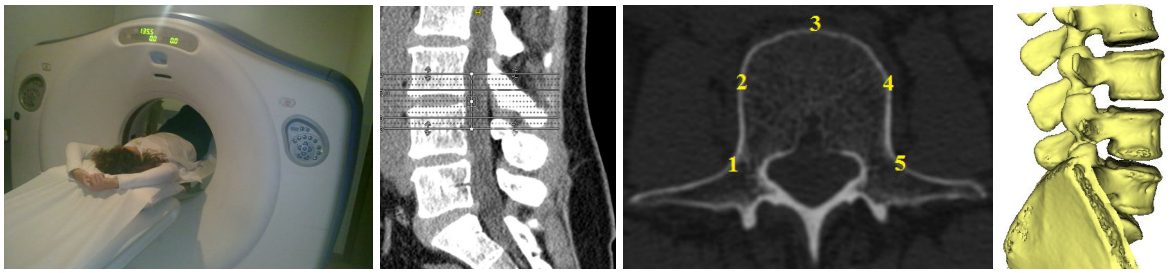


Fig. 1 - CT obtained in medical clinical to measure the cortical lumbar vertebra (L2-L5).

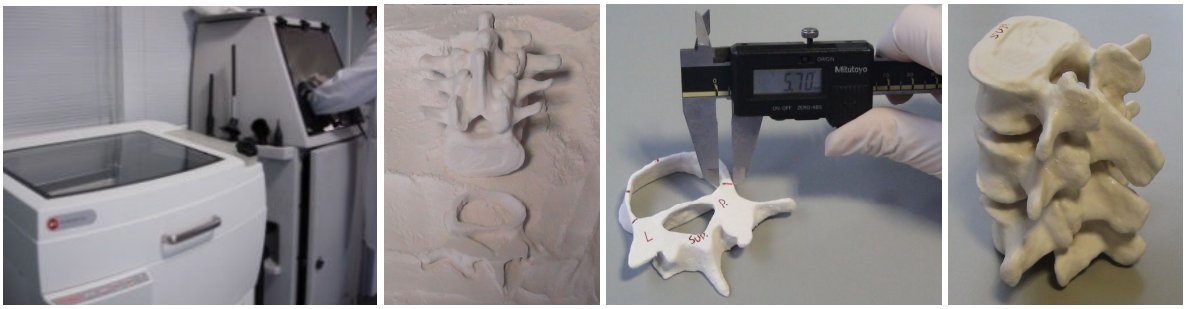


Fig. 2 - ZPrinter and RP experimental methodology used for measure lumbar vertebra segments L4-L2, F52.

The distribution of participants according to the age range and BMD score is presented in Table 1, with the identification of the pathology in lumbar vertebral L4. The values of cortical thickness in L4 from F52 are shown in Table 2.

Table 1 - BMD score in lumbar vertebra L4.

	Women's age (years) n (%)		
	50-59	60-69	>70
Normal	2 (40.0)	1 (11.0)	1 (50.0)
Osteopenic	2 (40.0)	5 (56.0)	0 (0.0)
Osteoporotic	1 (20.0)	3 (33.0)	1 (50.0)

Table 2 - Cortical thickness with RP and iQ-VIEW.

Position in L4:	1	2	3	4	5
RP [cm]	0.4	0.2	0.2	0.4	0.5
iQ-VIEW [cm]	0.3	0.2	0.2	0.4	0.4

The use of CT and RP experimental methodologies gave results quite similar regarding the cortical thickness. Further analysis will provide this information for all patients, according to the age range and the previous diagnosis of osteopenia or osteoporosis. The use of this information could be useful for complementary diagnostic and clinical treatment planning.

REFERENCES

[1]-Beaupied H., Lespessailles E., Benhamou CL., Evaluation of macrostructural bone biomechanics. Joint Bone Spine, 2007, 74, p. 233-239.

[2]-Epstein S., Is Cortical Bone Hip? What determines Cortical Bone Properties? Bone, 2006; 4, S3-S8.

[3]-Cavalcanti MGP., Ruprecht A., Vannier MW., 3D-CT vascular setting protocol using computer graphics for the evaluation of maxillofacial lesions. Pesqui. Odontol. Bras., 2001, 15(3), p. 229-236.

[4]-McGurk M, Potamianos P, Amis AA, Goodger NM, Rapid prototyping techniques for anatomical modelling in medicine. Ann R Coll Surg Engl, 1997, 79, p. 169-174.

PAPER REF: 2824

FEM ANALYSIS OF A FACE VENTED MASK INTERFACE BASED ON ONE IN-VITRO MODEL

Luana Souto[1], PedroTalaia[2(*)], António Ramos[3], Pedro Martins[4], Nuno Silva[5], Marta Drummond[6], Renato Natal Jorge[7]

[2,3,4,7]IDMEC, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
[2,3]Biomechanics Research Group, Dep. of Mechanical Eng., Universidade de Aveiro, Aveiro, Portugal
[1,7]Linde Homecare, Maia, Portugal
[6]Serviço de Pneumologia do Hospital São João, Fac. de Medicina da UP, Universidade do Porto, Porto; Portugal
[(*)]*Email:* ptalaia@ua.pt

ABSTRACT

The use of vented face masks is a common method in persons with respiratory failure. The interface between the mask and the face is associated with failure caused by several factors, as the appearance of cutaneous wounds or ulcers, or air leak by defective mask sealing in cushion-skin contact. The goal of this work is to prepare and validate a methodology based on FEM to evaluate in a virtual environment the interface between the vented mask cushion and the skin, taking as reverence the same system developed in-vitro. The in-vitro model was virtualized and meshed. Characteristics of materials and interfaces have been defined according to the literature and in-house experiments. The results for a particular pair of dummy head with the one correspondent vented mask are presented.

INTRODUCTION

Noninvasive ventilation (NV) using pressure applied to the airways of patients through the interfaces is considered the primary treatment for respiratory failure [1]. Patients with respiratory failure represent a serious health problem with social and occupational impact [2]. It is estimated a prevalence of 27,118 patients on home mechanical ventilated patients in Europe [3], but such data was for the year of 2001 and probably with the growing use of NV these values should be underestimated. However, it is found on the NV a level of failure around 40-60%, which is usually related to adverse events in the use of the interface. So it is become important to choose and use an interface in the most appropriate way for each patient and specific situation [1, 3].

METHODS AND CONCLUSIONS

After the silicon characterization [4], the model was implemented and a set of cases have been solved. The Fig. 1.a presents a detail of the initial model with mesh. The cushion is composed by brick elements, and the material law according to the Ogden's Law. Fig. 1.b - Fig 1.d shows respectively the equivalent applied force on the mask, contact pressure and cushion strain. The used protocol proved being feasible, being able to be applied into other pairs of head-mask.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by Ministério da Ciência, Tecnologia e Ensino Superior, FCT, Portugal, under grants SFRH/BI/33924/2009. The authors gratefully acknowledge the company Linde So Gas, Linde Homecare, for the supply of the vented face mask.

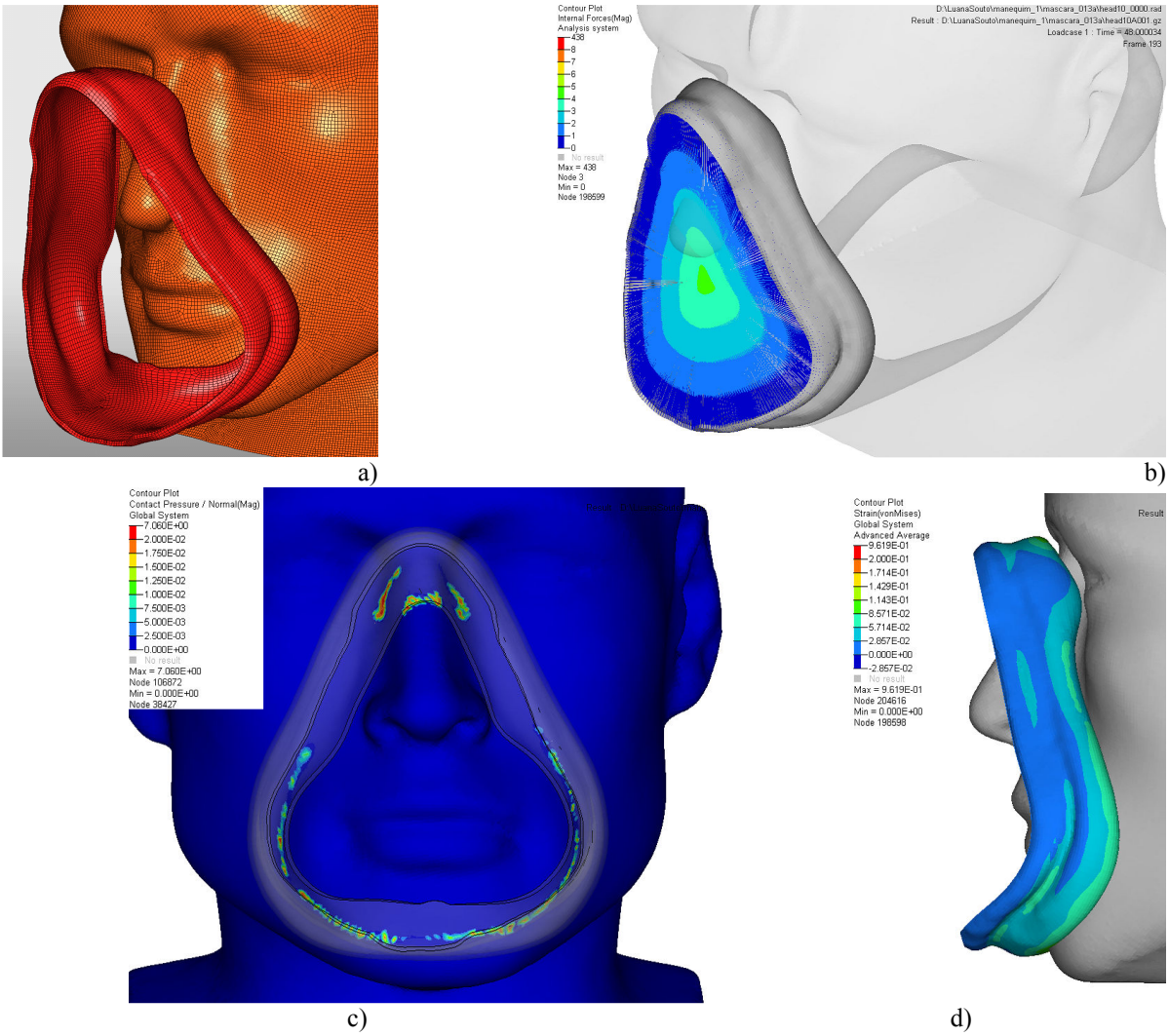


Fig.1 - Vented mask interface evaluation between cushion and skin for relaxed situation without air pressure, rigid skin, and contact with friction: a) FEM mesh detail; b) equivalent applied force on the force; c) contact force on skin; d) strain on cushion.

REFERENCES

[1]-Keenan, S.P., et al., Effect of noninvasive positive pressure ventilation on mortality in patients admitted with acute respiratory failure: a meta-analysis. Crit Care Med, 1997. 25(10): p. 1685-92.

[2]-Navalesi, P., et al., Physiologic evaluation of noninvasive mechanical ventilation delivered with three types of masks in patients with chronic hypercapnic respiratory failure. Crit Care Med, 2000. 28(6): p. 1785-90.

[3]-Lloyd-Owen, S.J., et al., Clinical value and cost of a respiratory sleep-related breathing disorders screening service for snorers referred to a District General Hospital ENT department. Respir Med, 1999. 93(7): p. 454-60.

[4]-Martins PALS, Natal Jorge RM, Ferreira AJM. A comparative study of several material models for prediction of hyperelastic properties: Application to Silicone-Rubber and Soft Tissues. Strain, 2006, 42, p. 135-147.

PAPER REF: 3060

MECHANICAL AND VASCULAR STIMULATION OF CELLS USING P-MINIMAL SURFACE DESIGNED SCAFFOLDS

Henrique A. Almeida(*), Paulo J. Bártolo

Centre for Rapid and Sustainable Product Development, Polytechnic Institute of Leiria, Portugal
(*)*Email:* henrique.almeida@ipleiria.pt

ABSTRACT

Scaffolds provide temporary mechanical and vascular support for tissue regeneration while shaping tri-dimensional in-growth tissues. Therefore scaffolds should be biocompatible, biodegradable with appropriate porosity, pore structure, pore distribution and optimal mechanical and vascular behaviour. The design of optimised scaffolds based on the fundamental knowledge of its microstructure is a relevant topic of research. This paper explores the use of Schwartz and Schoen primitives, a sub-class of Triple Periodic Minimal Surfaces. These geometric primitives enables the design of vary high surface-to-volume ratio structures with high porosity and mechanobiological stimulation.

INTRODUCTION

Tissue engineering represents a new, emerging interdisciplinary field involving combined efforts of biologists, engineers, material scientists and mathematicians towards the development of biological substitutes to restore, maintain, or improve tissue functions (Gibson, 2005). Most strategies in tissue engineering have focussed on using biomaterials as scaffolds to direct specific cell types to organise into three-dimensional structures and perform differentiated functions. The three most common strategies which have been adopted for the creation of new tissues are: Cell self-assembly, Acellular scaffold and Cell-seeded temporary scaffolds.

These scaffolds are often critical, both ex vivo as well as in vivo, as they serve some of the following purposes (Leong *et al*, 2003; Leong *et al*, 2008): allowing cell attachment, proliferation and differentiation, delivering and retaining cells and growth factor; enabling diffusion of cell nutrients and oxygen, as well an appropriate mechanical and biological environment for tissue regeneration in an organized way.

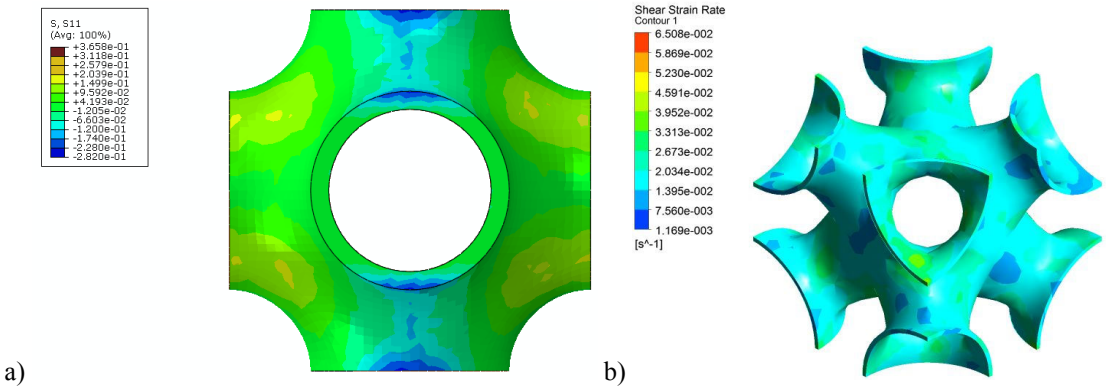
The mechanobiological requirements are: sufficient strength and stiffness to withstand stresses in the host tissue environment, adequate vascularization for the exchange of nutrients and oxygen and adequate surface finish to guarantee that a good biomechanical coupling is achieved between the scaffold and the cells.

The design of optimised scaffolds for tissue engineering is a relevant topic of research. Previous work, (Almeida *et al*, 2007a; Almeida *et al*, 2007b; Almeida and Bártolo, 2008a; Almeida and Bártolo, 2008b), developed a strategy to optimize both mechanical and vascular behaviour of both polymeric and ceramic scaffolds. The evaluation of scaffold's porosity and mechanical and vascular properties was performed for two types of Triple Periodic Minimal Surfaces. In this paper, triple periodic minimal surfaces are explored to design more biomimetic scaffolds considering their mechanical and vascular stimulation on the cells.

RESULTS AND CONCLUSIONS

Understanding the mechanical and vascular properties of highly porous scaffolds based on the knowledge of its microstructure is a problem of great interest in the design of scaffolds for tissue engineering applications. In this paper, porous scaffolds are designed and its mechanical and vascular behaviour simulated using Schwartz and Schoen P-minimal surfaces.

Numerical simulations on both P-minimal surfaces were performed considering two geometric variations: surface thickness and surface radius construction. The results demonstrate how the mechanical cell stimuli and the wall shear stress vary with the geometric variations of the P-minimal surfaces. The correct mechanical stimulation combined with adequate wall shear stress are parameters of extreme importance in scaffold design.



a) b)

Fig.1 - a) Mechanical and b) Vascular performance of P-minimal surface scaffolds.

ACKNOWLEDGMENTS

This research is sponsored by the Portuguese Foundation for Science and Technology through a PhD Grant (SFRH/BD/37604/2007).

REFERENCES

[1]-Almeida, H.A. and Bártolo, P.J., 2008a "Computer Simulation and Optimisation of Tissue Engineering Scaffolds: Mechanical and Vascular Behaviour", 9th Biennial ASME Conference on Engineering Systems Design and Analysis (ESDA2008), Technion Un., Haifa, Israel.

[2]-Almeida, H.A. and Bártolo, P.J., 2008b "Scaffolds Designed by Applying CAD/CAE Techniques", Polymers & Moulds Innovations (PMI2008), Un. College, Ghent, Belgium.

[3]-Almeida, H.A., et. al., 2007a "Design of Scaffolds Assisted by Computer", Modelling in Medicine and Biology VII, edited by C.A. Brebbia, Wit Press, pg. 157-166.

[4]-Almeida, H.A., et.al, 2007b "Mechanical Behaviour and Vascularisation Analysis of Tissue Engineering Scaffolds", Virtual and Rapid Manufacturing, edited by P.J. Bártolo et al, Taylor&Francis, pg. 73-80.

[5]-Gibson, L.J., 2005, "Biomechanics of cellular solids", J. of Biomechanics, 38(3):377-399.

[6]-Leong K.F., et. al., "Solid freeform fabrication of three-dimensional scaffolds for engineering replacement tissues and organs", Biomaterials, 24(13):2363-2378.

[7]-Leong, K.F., et.al., 2008. "Engineering functionally graded tissue engineering scaffolds", Journal of Mechanical Behaviour of Biomedical Materials, 1:140-152.

PAPER REF: 3061

INFLUENCE OF FLUID VELOCITY IN BIOREACTORS ON SCAFFOLDS UNDER DEGRADATION

Susana R. Almeida, Henrique A. Almeida(*), Paulo J. Bártolo

Centre for Rapid and Sustainable Product Development, Polytechnic Institute of Leiria, Portugal
(*)*Email:* henrique.almeida@ipleiria.pt

ABSTRACT

The regeneration of tissues or organs of the body is the key strategy to overcome the lack of tissue or organ shortage in the near future. Tissue engineering is a fast growing division of medicine that has now been introduced in clinical exercise and that certainly will replace other therapies in routine clinical practice. The interests in biodegradable polymeric biomaterials for biomedical engineering use have increased dramatically during the past decade. This paper aims to provide an evaluation of the variation of the fluid velocity in bioreactors for *in vitro* regeneration of scaffolds undergoing degradation.

INTRODUCTION

Tissue engineering represents a new, emerging interdisciplinary field involving combined efforts of biologists, engineers, material scientists and mathematicians towards the development of biological substitutes to restore, maintain, or improve tissue functions (Gibson, 2005).

Tissue engineering entails harvesting donor tissue that is then dissociated into individual cells. Donor cells may be adult or embryonic. If they are adult cells, they may be differentiated cells or stem cells. These cells may be directly implanted, or encouraged to proliferate in an organized manner in tissue culture (referred to as ex vivo). The organization of cultured cells can be guided by growing them on a 3D substrate known as a scaffold. The cell-seeded scaffold may then be placed in a bioreactor enhancing the cell proliferation and differentiation before implantation in the patient (Park & Lakes, 2007).

To reconstruct a new three dimensional tissue by tissue engineering techniques, a triad of components are needed: (1) cells, (2) scaffolds, and (3) bioactive molecules. Of these three components within a scaffold play a critical role in the reorganisation of neo tissues and organs. These scaffolds are often critical, both ex vivo as well as in vivo, as they serve some of the following purposes: allowing cell attachment, proliferation and differentiation, delivering and retaining cells and growth factor; enabling diffusion of cell nutrients and oxygen, as well an appropriate mechanical and biological environment for tissue regeneration in an organised way.

During this process, scaffolds tend to degrade while the tissue regeneration occurs due to enzymatic and hydrolytic degradation. This paper presents a vascular performance prediction scheme based on the fluid velocity and the degradation process of the biopolymer scaffold placed within a bioreactor.

RESULTS AND CONCLUSIONS

One of the mathematical degradation models defined by Chen et al. (2011) is based on the stochastic hydrolysis model. In hydrolysis reaction water molecules attack the chain bonds,

leading to a decrease in the average molecular weight of polymer matrix. As validated by experimental studies, polymer degradation often follows pseudo first-order kinetics (Gopferich, 1997), given by:

$$M_a^t = M_a^0 e^{-\lambda t} \tag{1}$$

where M_a^0 and M_a^t are the initial $(t = 0)$, time-dependent average molecular weights, respectively. k is defined as the degradation rate constant, which can be determined from experimental data by a linear regression (Tracy et al., 1999).

Once the scaffold models were modified due to the degradation factor, they were then positioned at the geometric centre of a bioreactor chamber. The Culture Media data is: Density of 1030 kg/m3 and Dynamic Viscosity 0.0025 Pa s. The Boundary Conditions are: Inlet and Outlet velocity 0.5895 m/s with a laminar fluid flow.

From the vascularisation simulations, it is possible to evaluate the variation of the wall shear stress on the scaffolds due to the degradation. Figure 1 illustrates the wall shear stress contour on the scaffold during the degradation process. From the vascularisation simulations, it is possible to conclude that as the scaffold degrades, and as the fluid velocity increases, the wall shear stress tends to increase.

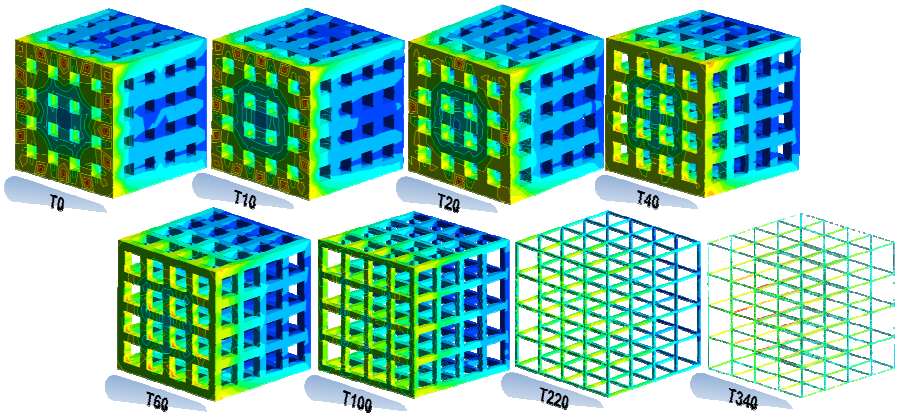


Fig.1 - Wall Shear Stress regarding the degradation variation of the scaffolds.

REFERENCES

[1]-Gibson, L.J., 2005, "Biomechanics of cellular solids", Journal of Biomechanics, 38(3):377-399.

[2]-Park, J. and Lakes, R.S., 2007, Biomaterials: An Introduction, Springer, chapter 16.

[3]-Chen, Y., Zhou, S. and Li, Q., 2011, "Mathematical modeling of degradation for bulk-erosive polymers: Applications in tissue engineering scaffolds and drug delivery systems", Acta Biomaterialia, 7:1140-1149.

[4]-Gopferich, A., 1997, "Polymer bulk erosion", Macromolecules, 30(9):2598-604.

[5]-Tracy, M.A., Ward, K.L., Firouzabadian, L., Wang, Y., Dong, N., Qian, R. and Zhang, Y., 1999, "Factors affecting the degradation rate of poly(lactide-co-glycolide) microspheres in vivo and in vitro", Biomaterials, 20(11):1057-62.

PAPER REF: 3146

AN ANIMAL MODEL IN SHEEP FOR TESTING THE RAPID MANUFATURING SYSTEM OF ORTHOPEDIC PROSTHESES

José Potes[1(*)], Carlos Relvas[2], Joana Reis[3], Fenando Fonseca[4], José Simões[5], António Torres Marques[6]

[1, 3]Department of Veterinary Medicine, Institute of Agrarian and Enviromental Mediterranean Sciences Institute, University of Évora, Portugal

[2, 5]Department of Mechanical Engineering, University of Aveiro, Aveiro, Portugal

[4]Faculty of Health Sciences of Beira Interior, Portugal

[6]Department of Mechanical Engineering, Faculty of Engineering of Porto University, Campus FEUP, Porto, Portugal

[(*)]*Email:* jacpotes@uevora.pt

ABSTRACT

This presentation aimed the development of a methodology of rapid manufacture of orthopaedic implants simultaneously with surgical time, considering two potential applications in the fields of orthopaedics: the manufacture of anatomically adapted implants and implants for bone loss replacement. This work innovation consists on the harvesting of the *in situ* geometry of the implant by direct capture of the shape. After sterilization process, the implant was able to be placed on the patient. The system has been tested using the sheep as an animal model for in vivo hip arthroplasty. The time increase of surgery was 80 minutes, being 40 the time of implant manufacturing. The system developed has been tested and the goals defined of the study achieved, enabling the rapid manufacture of an implant in a stretch of time compatible with the surgery time.

INTRODUCTION

There are several reasons to recommend the use of anatomic adapted implant or usually designed as customised. The use of an implant, which was concept and built, as the patient anatomy, must be able to offer the function of the musculoskelectal in a near physiological way, allowing a larger longevity and an efficient transfer of resulting load of a better adjustment to patient bone. The use of the sheep for orthopaedic research continues to increase. This is due to the similarities with humans in weight, bone and joint structure and bone regeneration. The animal is prepared, surgery accessed as routinely used in our facilities and described elsewhere (Costa Reis *et al* 2004, Potes *et al* 2008).

The approach to the geometric implant was obtained *in situ* during the surgery time, using direct capture of the fitting structure, through a guide model, which uses an elastomeric material (polyvenylsiloxane) and allows fine detail and great accuracy of the geometry, as an impressed material. After scanning the elastomeric specimen, the implant is obtained by machining, using a CNC milling machine programmed with a dedicated CAD/CAM system. This geometric shape is used in a 3D laser machine to get a digital model of the implant. This virtual 3D model is transferred to a CAM system to gear the command program to a CNC machine, where the implant is built on an over-dimensioned pre-implant.

After sterilization the implant is ready to be fitted.

RESULTS AND CONCLUSIONS

This study shows that the time necessary for the shape harvesting process *in situ,* of the femoral canal and the manufacture of customized implant simultaneously with the surgical time, have revealed adjusted and compatible with the time under anaesthesia. In the performed study one must emphasise that the total time related with the manufacture of the implant did not exceed 40 minutes and must be added to another 40 minutes for the sterilization, prior to their implantation. This concept of rapid of anatomically adapted implants can be used also in other pathological situations such as the repair of bone defects or anatomical correction of bone structures.

REFERENCES

[1]-Costa Reis J, Potes J, Fialho L, Capela e Silva F, Cabrita AS, Marques AT, Simões JA. Estudo Animal de Proteses de Anca em Compósito PEEK-Carbono, Revista Portuguesa de Ortopedia e Trauma. 2004, 12: p. 109-124.

[2]-Potes J, Costa Reis J, Capela e Silva F, Relvas C, Cabrita AS, Simões JA. The Sheep as an Animal Model in the Orthopaedic Research. Experimental Pathology and Health Sciences. 2008, 2(1): p. 29-32.

[3]-Relvas C, Costa Reis J, Potes J, Fonseca F, Simões JA. Rapid Manufacturing System of Orthopedics Implants. Revista Brasileira de Ortopedia. 2009, 44(3): p. 260-265.

PAPER REF: 3186

FABRICATION OF MILI-SCALE CHANNELS FOR HEMODYNAMIC STUDIES

E.D. Costa(*), J. Carneiro, M.S.N. Oliveira, J.B.L.M. Campos, J.M. Miranda
Transport Phenomena Research Center (CEFT), University of Porto, Porto, Portugal
(*)*Email:* erdoutel@fe.up.pt

ABSTRACT

An anatomical model representing a mili-scale bifurcation of an artery was constructed. A sequential method was developed to obtain a transparent PDMS model from a mold produced by rapid prototyping. The final objective is to manufacture transparent models that allow optical access to measure the velocity profiles of the flow of blood analogues by micro-particle image velocimetry (μPIV).

INTRODUCTION

From clinical practice, it is known that specific sites in human circulatory system are particularly sensitive to the development of cardiovascular diseases, such as atherosclerosis, stenosis and cerebral aneurisms (Akram, 2000). Local hemodynamic is believed to play an important role in the development of these lesions and so its knowledge is of great importance (Kristopher, 2005). Several researchers have been working on patient specific in vitro techniques that allow the experimental study of blood circulation in realistic configurations (Burgmann, 2009). This approach requires the construction of a model of the blood vessel under study. The models of complex geometries can be constructed by direct rapid prototyping from a 3D computational representation of the blood vessel or by casting in a mold produced by rapid prototyping.

RESULTS AND CONCLUSIONS

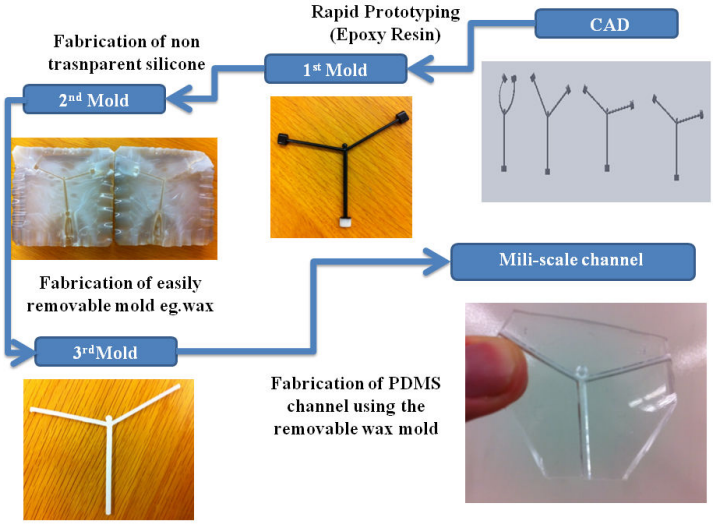


Fig. 1 - Fabrication method

In this work a four-step method was developed to create and replicate simplified models of arteries as shown in Fig. 1. Starting from the geometry previously created in CAD, a first mold made of an epoxy-resin was constructed by rapid prototyping using stereolithography. A negative version of the mold was then fabricated in non-transparent silicone. The next step was to use the silicone mold to cast a third mold using materials that can be easily removable from the final channel. This last mold is destroyed during the final step of fabrication, but we are able to use the second mold repeatedly to replicate anatomical models maintaining nearly the same characteristics. The final transparent channel is fabricated in polydimethylsiloxane (PDMS) and can be used in the hemodynamic studies using optical techniques.

Since the PIV technique requires an optical access, the refractive index of the PDMS was measured and a blood analogue solution that matches this refractive index was prepared (Fig. 2). The PDMS model was observed by microscopy (cf. Fig. 3) to verify the dimensions of the channels and the cross-section of the channels were compared to the original CAD-drawing (green lines in Fig. 3).

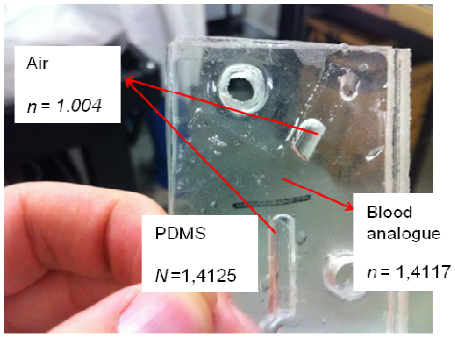


Fig.2 - Refractive index matching of blood analogue and PDMS.

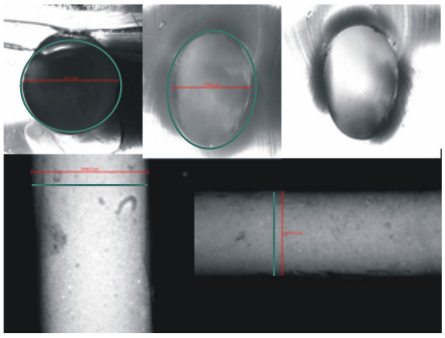


Fig.3 - Visualization of the mili-channels by microscopy.

This study shows that refractive index of the PDMS and the refractive index of a blood analogue can be matched and the dimensions of the channels are similar to the ones of the CAD model. Work is under way to visualize the flow of blood analogues by fluorescence microscopy and µPIV techniques.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Francisco Galindo-Rosales and Laura Campo-Deaño for the help with the CAD models and the funding by Fundação para a Ciência e a Tecnologia, FCT, Portugal and FEDER under projects PTDC/EME-MFE/102974/2008 and PTDC/EME-MFE/099109/2008.

REFERENCES

[1]-Akram M. Shaaban and André J. Duerinckx, 2000. Wall Shear Stress and Early Atherosclerosis: A Review. AJR 174, 1657-1665.

[2]-Kristopher S Cunningham and Avrum I Gotlieb, 2005. The role of shear stress in the pathogenesis of atherosclerosis. Laboratory Investigation 85, 9-23.

[3]-S. Burgmann, et. al., 2009. A refractive index-matched facility for fluid-structure interaction studies of pulsatile and oscillating flow in elastic vessels of adjustable compliance. Experiments in fluids 47, 865-881.

PAPER REF: 2781

RAPID PROTOTYPE USED TO PERSONALIZE PVA MENISCUS

Célio H. Wataya[1(*)], André L.M. Jardini[2], Gustavo Paschoal[3], Vanessa P. Bavaresco[4], Cecília A.C. Zavaglia[4]

[1]Federal Institute of Pará - Brasil. ,
[2]National Institute of C&T (INCT-BIOFABRIS)
[3]Tecnology of Information Center "Renato Archer", Campinas - São Paulo, Brasil.
[4]State University of Campinas, Campinas -São Paulo,Brasil. ,
[(*)]cwataya45@fem.unicamp.br

ABSTRACT

This paper presents the study of obtaining artificial meniscus using polyvinyl alcohol hydrogel (PVA), a biocompatible polymer, non-absorbable with good mechanical properties and swelling capacity, which favors its role to replace the injured meniscus. In addition, viscoelastic characteristics similar to human soft tissue can be provided in the production process of the gel by adjusting the water content. There are many studies on the various biomechanical characteristics of the human meniscus. The methodology has the following sequence: prepared a 20% PVA solution and placed in cast polymethylmethacrylate and plaster, previously shaped by rapid prototyping, which was used for both images of a scanner and software to capture the image of the meniscus, this image allowed the conformation of the mold.

INTRODUCTION

In order to create something accessible and relatively low market value in relation to recovery of the meniscus, this study sought to develop an artificial meniscus, through the polyvinyl alcohol (PVA), a relatively inexpensive polymer, which is produced in larger amounts in the world because it's relatively easy to obtain and a huge range of applications both in the industrial, commercial as in medicine, Rosiak et al, 1995 and rapid prototyping (RP). Rapid prototyping, also known by the names freeform fabrication (SFF), additive manufacturing, and automated manufacturing, among others, is a set of technologies used to produce highly detailed three-dimensional physical objects, drawings based on a three-dimensional CAD (Computer Aided Manufacturing). These methods are similar to ones that add and link layers of materials in order to obtain physical objects and highly complex geometries. PR binds and connects liquids, dust and leaves, in order to form parts, manufacture of plastic objects, wood, ceramics and metals. Pham, 2001 and Chua, 2003.

RESULTS AND CONCLUSIONS

Making the mold: The mold was prepared through the use of a self-positioning scanner manual EXAscan of Creaform, which generated images to the system of prostheses Evolution of Search produduziu that this model, the software Magics. Through the mold produced 15.0 virtual mold which was made real.

Preparation, bottling and irradiation PVAl. To obtain the devices PVAl as substituents of the meniscus was used PVAl (Aldrich MW 89,000 to 98,000 g / mol, 99% hydrolyzed) in polymer concentration in solution of 20% (w / w). In a beaker were added to the polymer previously weighed and distilled water. The solution is heated to 95^0C until total

homogenization and upon reaching room temperature were dried. PVAl The solution was placed in mold meniscus, polymethylmethacrylate and plaster, after that, left to dry for 24 hours ventilation for the evaporation of the solvent, Figure 1.

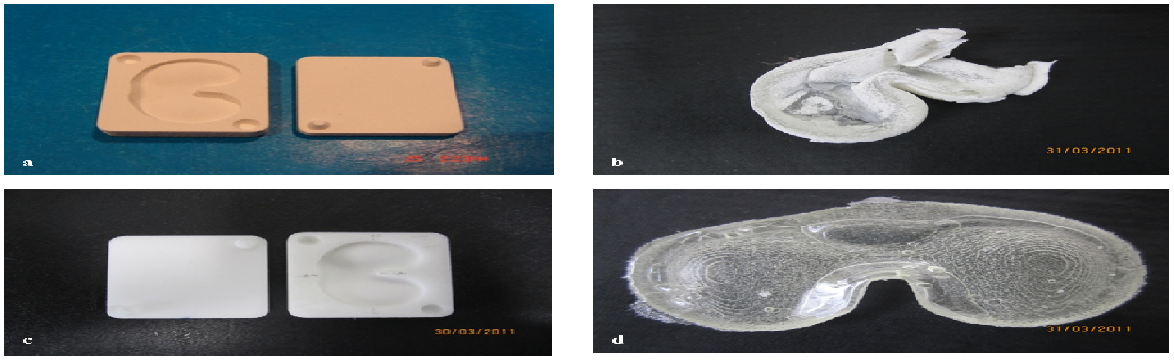


Figure 1 - PVAl placed in polymethylmethacrylate and plaster mold and dry.

After drying, the piece of meniscus was subjected to a chemical treatment of acetalization. After that stored in distilled water under refrigeration until they are subjected to irradiation. Mondino, 1999; Yoshii, 1995. It took a piece of meniscus at the Institute of Energy and Nuclear Research (IPEN), National Nuclear Energy Commission (CNEN) using ionizing radiation of electron beam (electron beam - EB) issued by Dynarnitron electron accelerator (E = 1.5 MeV) of the Radiation Dynarnis, Inc. The pattern obtained polyamide had its rough surface which gave the appearance of a translucent surface which is not ideal, however, the surface can be improved by changing the material of construction of the mold, the mold has plaster, gypsum particles were impregnated on the surface of PVAl, precluding their use. There was no rejection when introduced into mouse brain, or bleeding, formed a capsule around the material and also a layer of connective tissue around the material, demonstrating the adaptation of the material to the animal body.
CONCLUSIONS: The plaster mold is discarded for use in modeling the PVAl, the polyamide should have been perfected as to make its surface smooth or use other material that provides a smooth surface. The PVAl is biocompatible, since they do not cause any kind of rejection, but on the contrary, there was good acceptance and adaptation by the animal.

ACKNOWLEDGMENTS: The authors gratefully acknowledge the funding by Capes/Br.

REFERENCES

[1]-Bavaresco, Vanessa Petrilli, hard coating with hydrogel substrates for use as superflcie articulate, Campinas, Faculty of Mechanical Engineering, State University of Campinas, 2000. Thesis (MA).

[2]-Castiglia, M. M. et. Al (2001). " Comunicação de imagens digitais em Medicina". http://virtual.epm.br/material/tis/curmed/temas/med5/med5t21999/dicom/dicom2.htm

[3]-Chua, C. K.; Leong., K.F.; Lim, C.S., (2003). Rapid prototyping, principles and applications. Singapore, World Scientific Publishing Co. 420p, ISBN 981-238-117-1 CenPRA

[4]-Grenda, E. (2003). The wordwide guide to rapid prototyping. Home.att.net/~castleisland/ Jacobs, P.F. Hilton, Peter D. (2000). Rapid tooling - Technologies and industrial applications. Basel, Switzerland.

PAPER REF: 2826

USE OF REVERSE ENGINEERING TOOLS TO CREATE A TEST-BED FOR EVALUATION OF HOUSE MECHANICAL VENTILATION SYSTEMS

PedroTalaia[1(*)], António Ramos[2], Luana Souto[3], Pedro Martins[4], Carlos Relvas[5], José A. O. Simões[6], Nuno Silva[7], Marta Drummond[8], Renato Natal Jorge[9]

[1, 3, 4, 9]IDMEC, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
[1, 2, 5, 6]Biomechanics Research Group, Dep. of Mechanical Eng., Universidade de Aveiro, Aveiro, Portugal
[3, 7]Linde Homecare, Maia, Portugal
[8]Serviço de Pneumologia do Hospital São João, Fac. de Medicina da UP, Universidade do Porto, Porto; Portugal
[(*)]*Email:* ptalaia@ua.pt

ABSTRACT

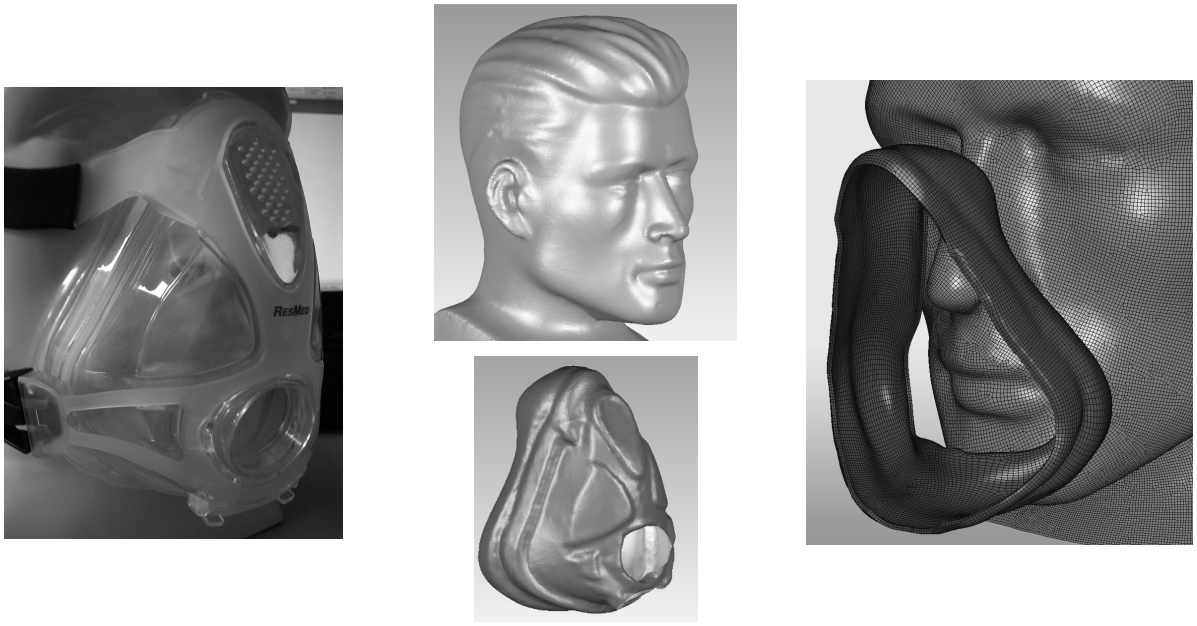
The use of vented face masks is a common method in persons with respiratory failure. The interface between the mask and the face is associated with failure caused by several factors, as the appearance of cutaneous wounds or ulcers, or air leak by defective mask sealing in cushion-skin contact. The goal of this work is to prepare a test-bed to evaluate the actual vented masks on the market, and to evaluate new concepts to be developed and proposed. A protocol to acquire the geometry of the mask and the face has been established by means of reverse-engineering, and the mechanical properties of mask materials that take a role in the interface have been characterized according with the literature. It is presented an example of a test-bed to evaluate in-vitro the ventilation mask interface and his correspondent version in CAD/CAE. The silicon proprieties as material of the ventilation mask cushion is also presented.

INTRODUCTION

Noninvasive ventilation (NV) using pressure applied to the airways of patients through the interfaces is considered the primary treatment for respiratory failure [1]. Patients with respiratory failure represent a serious health problem with social and occupational impact [2]. It is estimated a prevalence of 27,118 patients on home mechanical ventilated patients in Europe [3], but such data was for the year of 2001 and probably with the growing use of NV these values should be underestimated. However, it is found on the NV a level of failure around 40-60%, which is usually related to adverse events in the use of the interface. So it's become important to choose and use an interface in the most appropriate way for each patient and specific situation [1, 3].

METHODS AND RESULTS

The geometry of the set head dummy with vented mask (Fig. 1.a) has been acquired. The silicon rubber has been characterized has an Ogden material [4] and the respective parameter obtained. The vented mask and the head dummy have been digitalized in a 3D scanner (Fig. 1.b), the respective geometries converted and assembled. The several components on the assembled model have then been meshed (Fig. 1.c). The cushion was modelled with brick elements, and Ogden's law material. The skin was modelled as rigid shell elements. Two contacts have been defined with friction: self-contact on the cushion, and contact between cushion and skin.



a) b) c)

Fig.1 - Example of a test scenario: a) vented mask applied to a dummy head; b) geometry reconstruction of the parts; c) CAD/CAE model of the in-vitro scenario for FEM analysis

An in-vitro model was implemented, as a virtual model. The followed protocol points the applicability of such work-path for other face vented masks or dummy heads. Compatible protocol is in preparation for human or cadaveric faces, with the respective change in the skin, soft tissues and bone structure characterization.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by Ministério da Ciência, Tecnologia e Ensino Superior, FCT, Portugal, under grants SFRH/BI/33924/2009.

The authors gratefully acknowledge the company Linde So Gas, Linde Homecare, for the supply of the vented face mask.

REFERENCES

[1]-Keenan, S.P., et al., Effect of noninvasive positive pressure ventilation on mortality in patients admitted with acute respiratory failure: a meta-analysis. Crit Care Med, 1997. 25(10): p. 1685-92.

[2]-Navalesi, P., et al., Physiologic evaluation of noninvasive mechanical ventilation delivered with three types of masks in patients with chronic hypercapnic respiratory failure. Crit Care Med, 2000. 28(6): p. 1785-90.

[3]-Lloyd-Owen, S.J., et al., Clinical value and cost of a respiratory sleep-related breathing disorders screening service for snorers referred to a District General Hospital ENT department. Respir Med, 1999. 93(7): p. 454-60.

[4]-Martins PALS, Natal Jorge RM, Ferreira AJM. A comparative study of several material models for prediction of hyperelastic properties: Application to Silicone-Rubber and Soft Tissues. Strain, 2006, 42, p. 135-147.