Analysis of stresses in drilled composite materials

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1. INTRODUCTION

In medicine there are many surgical procedures that involve the bone tissue, often entail cutting, drilling or screwing operations of the bone. The success of these surgeries depends on many factors and the bone damage degree generated during the drilling. The cutting effort achieved during the drilling process is one of the problems and is directly related with the drilling parameters [1]. It is essential to understand and to improve the cutting conditions to minimize the bone damage.

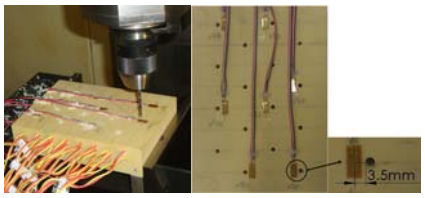
1.1. Objectives

- Main goal was to analysis the stresses during the drilling of composite materials, through two different methods and different parameters of drilling.
- In the experimental method were used strain gauges to obtain the stresses in the surface of the three composite blocks with similar density of cortical human bone.
- In the numerical model, 3D dynamic model was built to simulate the drill process.

2. EXPERIMENTAL METHOD

- In the experimental methodology were used three composite blocks from Sawbones with similar density to the cortical bone.
- During the experimental tests 18 holes with instrumented strain gauges (6 holes in each composite block) were produced.
- A conventional drill bit with Ø4mm, 30mm of depth and a point angle of 118º were used in all holes. The distances between the edges of the holes and the strain gauges were measured.
- Different feed-rates were used for each composite block, in order to evaluate the influence on the drilling process using the other parameters as a constant.

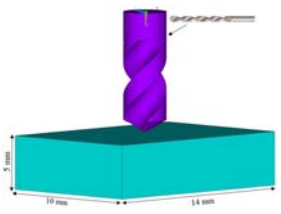
Parameters	
Drill diameter	4 [mm]
Drill length	30 [mm]
Drill speed(ω)	800 [rpm]
Feed-rate (V_f)	25, 50, 75 [mm/min]



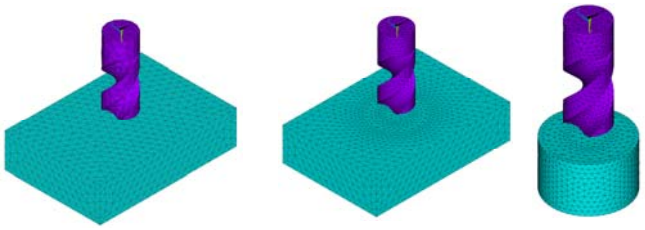
3. NUMERICAL MODEL

- For numerical method, the LS-DYNA from Ansys program was used to built a 3D dynamic model to simulate the drilling process.
- The model of drilling consists in the cortical bone and a drill bit, with all variables involved in the drilling process.
- Different mechanical properties of the materials were considered [2]:
  - **Drill bit**: rigid body with high elastic stiffness;
  - **Cortical bone**: elastic-plastic material, depending on the strain rate and the failure criterion of the material.

Properties	Drill bit	Cortical bone
Density (kg/m³)	7850	800
Young's modulus (GPa)	200	16.7
Poisson's ratio	0.3	0.3
Yield stress (MPa)	—	27
Tangent modulus (MPa)	—	2083.3
Hardening parameter	—	0
Cowper-Symonds model:		
C	—	0.13
P	—	0.0001
Failure plastic strain	—	0.0021



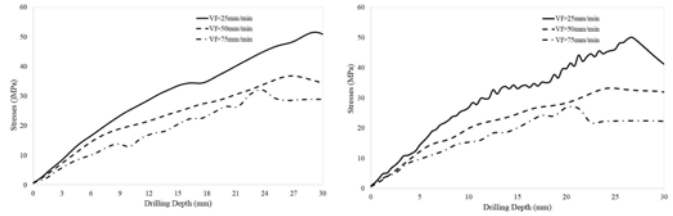
- The numerical model was meshed using *SOLID164* elements. Several mesh convergence study was carried out to obtain a more suitable model.
- The composite block was kept fixed in all vertical faces, while the drill bit was constrained to rotate-about its own longitudinal axis.



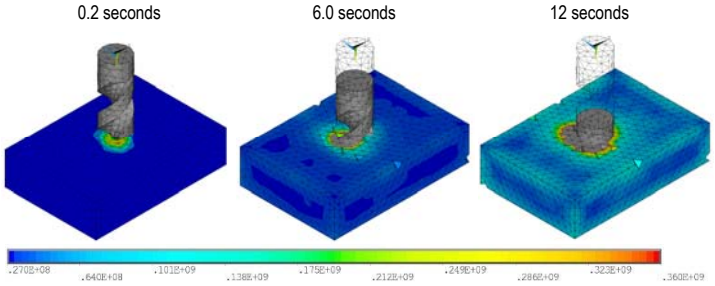
- Contact elements were used to simulate the contact between the drill bit and cortical bone, and defined by the Eroding contact algorithm available in LS-DYNA.
- The frictional contact between the drill-bit and cortical bone was modelled with a constant coefficient of friction of 0.3 [3].
- The simulations require 72hours on quad-core i7-4790k with 16GBRAM.

4. RESULTS AND DISCUSSION

- In the experimental method were obtained the strains during the drilling depth and calculated the normal stresses generated in the drilling process. The following figures show the evolution of stresses obtained in different holes performed with feed-rates equal to 25, 50 and 75mm/min, during the drill depth.



- In the numerical model were performed different numerical simulations with different feed-rates to compare the stresses results to the experimental results. The figure represents the levels of von Mises stresses in different stages of drilling until to complete the drilling of the cortical bone



- To compare the results in both methods were calculated the normal stresses obtained in each of the holes with strain gauge and the average of the values. The distance between the edge of the hole and the strain gauge was also considered.

Feed-rate (mm/min)	Experimental							Numerical
	H1	H2	H3	H4	H5	H6	Average	
V_f=25	14.87 (L=3.5mm)	14.32 (L=4.0mm)	13.77 (L=4.0mm)	11.57 (L=5.5mm)	11.52 (L=5.5mm)	11.09 (L=5.5mm)	12.86	12.88
V_f=50	17.90 (L=3.0mm)	16.98 (L=3.0mm)	12.25 (L=3.5mm)	10.70 (L=4,0mm)	8.51 (L=4,5mm)	7.86 (L=5.0mm)	12.37	11.85
V_f=75	11.03 (L=3.5mm)	9.07 (L=4.0mm)	8.80 (L=4.0mm)	8.40 (L=4.0mm)	7.48 (L=4.5mm)	7.42 (L=4.5mm)	8.70	8.68

H number of the hole, L distance between edge of the hole and strain gauge

- The results show that generated stresses in the bone increase with tool penetration.
- Through of the different feed-rates, it was found that the increase of feed-rate decreases the generated stresses in the bone.
- The levels of maximum stress were found in the near vicinity of the drilled area.
- Numerical and experimental model are in agreement.

5. CONCLUSIONS

- In this study two different methods were used to evaluate the stresses distribution in the cutting region and in vicinity areas, obtained for different drilling parameters.
- Using different feed-rates it was possible to verify a decrease of stresses and strains in composite materials when the feed-rate is higher. As foreseen, the normal stresses in the far hole regions were lower than near of the hole region.
- The 3D finite element model proved to be a great analysis tool to simulate the bone drilling dynamic process, useful to evaluate the performance of surgical tools alternatively to the hard theoretical work.

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[1] J. Soriano, et al. 2013. Machining Science and Technology: An International Journal 17:611-636.
[2] M.G. Fernandes, et al. 2015. 6th National Congress of Biomechanics, Rui B. Ruben et al. (Eds), pp231-232.
[3] Y.K. Tu, et al. 2013. Journal of Medical and Biological Engineering 33:269-274.

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Thursday	
8:30	**Registration**
9:30	**Open session** José Pedro Silva, IEEE Portugal Miguel Morgado, FCTUC, Portuguese Chapter IEEE-EMBS Renato Natal Jorge, INEGI, FEUP Jorge Belinha, INEGI, FEUP Pedro Martins, INEGI Marco Parente, FEUP Adelino Leite-Moreira, FMUP João Manuel R. S. Tavares, INEGI, FEUP
9:45	**Invited Lecture** "Alterações biomecânicas do joelho perante a rotura do ligamento cruzado anterior" José Carlos Pinto Noronha PhD, MD, Ortopedista Investigador da Universidade de Aveiro Diretor Clínico da Federação Portuguesa de Futebol
10:30	***Coffee break***

Thursday (Room: Auditório 1)	
11:00	**Oral presentations – Session I** Chairpersons: Miguel Morgado / Pedro Martins
	Interaction studies of amyloid beta-peptide with the natural compound resveratrol Stephanie Andrade, Joana Loureiro, Manuel Coelho, Maria do Carmo Pereira *Extraction of zera fusion proteins in aqueous two-phase systems* Maria Jacinto, Marco Archinti, Pau Marzábal, Ana Azevedo, M. Aires-Barros *Assistance and rehabilitation of gait disorders using active lower limb orthoses* Joana Figueiredo, Cristina P. Santos, Juan C. Moreno *Optimizing the approxv1 algorithm for coping with diffraction effects in protein-based volumetric memories* Dragos Trinca, Sanguthevar Rajasekaran
12:00	***Lunch***

Thursday (Room: Auditório 1)	
14:30 15:15	**Invited Lecture** "Laser Microsurgery in the Contractile Ring" Ana Xavier de Carvalho Investigadora do Instituto de Biologia Molecular e Celular Universidade do Porto
15:30	**Oral presentations – Session II** Chairpersons: Joaquim Gabriel / Jorge Belinha *Amino acid derivatized monoliths for purification of a dna vaccine against influenza* D. Bicho, B.F. Santos, A. Sousa, F. Sousa, J.A. Queiroz, C.T. Tomaz *Modeling partitioning of proteins in aqueous two-phase system* Dragana de Barros, Sara Campos, A. Azevedo, A. Baptista, M.R. Aires-Barros *Medical thermal imaging procedure for havs assessment* Ricardo Vardasca, Joaquim Gabriel
16:30	***Coffee break***

Thursday (Room: Auditório 1)	
17:00 18:45	**Oral presentations – Session III** Chairpersons: João Tavares / Ricardo Vardasca
	Random decision forests for automatic brain tumor segmentation on multi-modal mri images Adriano Pinto, Sérgio Pereira, Hugo Dinis, Deolinda Rasteiro, Carlos A. Silva *Wireless multi-physiological signal monitor for clinical discharge and readmission criteria setting and ambulatory usage* T. Marçal, B. Antunes, A. Matos, D. Pires, J. Simões, R. Ferreira, C. Correia *A nucleoid segmentation method robust to varying nucleoid number* João Santinha, Nádia Gonçalves, André Mora, Andre Ribeiro, José Fonseca *Coupling blood flow and growing vasculature in 3D* Mauricio Soares, Rui Travasso, Alexandre Diehl *Prototype for determination of pre-transfusion tests based on image processing techniques* Ana Ferraz, Vítor Carvalho, José Machado *Anaesthesia induction in small mammal's using an instrumented anaesthetic chamber* Rui Correia, Ana Pereira, Joaquim Gabriel, Luis Antunes *Integration of sample processing using aqueous two-phase separation and immunoassays on a single chip for point-of-use food safety applications* R. Soares, P. Novo, A. Azevedo, P. Fernandes, V. Chu, M. Aires-Barros, J.P. Conde

Friday (Room: Auditório 1)	
8:45 9:15	**Invited Lecture** "LABIOMEP supporting the Biomechanics" Mário Vaz LABIOMEP, INEGI Faculdade de Engenharia, Universidade do Porto
9:30	**Thesis presentations – Session I** Chairpersons: João Tavares / Marco Parente
	State of the art and challenges in bioprinting technologies, contribution of the 3D bioprinting in Tissue Engineering João B. L. Fermeiro, Maria do Rosário A. Calado, Ilídio J. S. Correia *PLGA nanoparticles for calcitriol delivery* M.J. Ramalho, J.A. Loureiro, B. Gomes, M.F. Frasco, M.A. Coelho, M.C. Pereira *A spectrophotometry based blood typing* J. Fernandes, F.O. Soares *An in vitro approach to unravel the modulation of the hypothalamic system by blood-circulating factors* JP Martins, CJ Alves, E Neto, DM Moreira, M Xavier, D Sousa, I Alencastre, M Lamghari
10:30	***Coffee break***

Friday (Room: Auditório 1)	
	Thesis presentations – Session II Chairpersons: Graça Minas / Pedro Martins
11:00	*Optimization and Validation of [13N]-NH3 Production for Clinical Studies of Positron Emission Tomography in the Evaluation of Myocardial Perfusion* Cristina Serra *Simplified multibody model for dynamic loading analysis of the lumbar human spine* V. Sousa , J.C.P. Claro *A Medical Device for Support of the Ankle Pathologies Diagnosis* Rita Ferreira , Ana Leal , Filipe Silva , Paulo Flores , João Espregueira-Mendes *Geometric Sensitivity Analysis of a Lumbar Motion Segment FE Model* I. Silva , A. Castro , J.C.P. Claro *Spatial monitoring of temperature estimation during ultrasound heating therapy* H. Simões Duarte , André Santos , M. Graça Ruano *Computer-Aided Bone Fracture identification based on ultrasound images* Luis Nascimento , M. Graça Ruano
12:30	***Lunch***

Friday (Room: Auditório 1)	
14:15 14:45	**Special session IEEE** Student Chapters da IEEE-EMBS João Apura, EMBS Student Chapter do IEEE-IST
15:00	**Poster presentations – Session I** Chairpersons: Graça Minas / Rui Bernardes *Analysis of multiple sclerosis dti images using tbss* J. Oliveira, Ricardo Morais, Sónia Baptista, João Pereira, Miguel Castelo-Branco *Software for human gait analysis and classification* A. Vieira, H. Sobral, J. Ferreira, P. Ferreira, S. Cruz, M. Crisóstomo, A. Coimbra *Human gait analysis using instrumented shoes* H. Sobral, A. Vieira, J. Ferreira, P. Ferreira, S. Cruz, M. Crisóstomo, A. Coimbra *Preparation and characterization of amylose-pyrazinamide inclusion complexes* A.C. Ribeiro, L.P. Fonseca, R.M.D. Soares, N.P. da Silveira, G.L. Peres *Characterization of silicon photodiodes for diffuse reflectance signal extraction* S. Pimenta, J.P. Carmo, R.G. Correia, E.M.S. Castanheira, G. Minas *Optimization of miniemulsion process using different solvents* Ana C.D. Pfluck, Dragana P.C. de Barros, Luis P. Fonseca *Patterned cnt-pdms nanocomposites for flexible pressure sensors* P.J. Sousa, L.R. Silva, L.M. Goncalves, G. Minas *Electrospun mats of biodegradable chitosan-based polyurethane urea* Tânia Vieira, João Paulo Borges, Célia Henriques *PDMS biofunctionalization study for the development of a microfluidic device: application to salivary cortisol* V.C. Pinto, M. Correia-Neves, G. Minas *Optimization of sitting posture classification based on user identification* B. Ribeiro, L. Martins, H. Pereira, R. Almeida, C. Quaresma, A. Ferreira, P. Vieira *Long neuroprobes based on silicon dicing and iridium oxide for electrical stimulation/recording* M.J. Oliveira, S.B. Gonçalves, A.C. Peixoto, A.F. Silva, J.H. Correia *Analysis of stresses in drilled composite materials* Maria Fernandes, Renato Natal, Elza Fonseca *Effect of sulfamethoxazole on postsynaptic zinc signals from hippocampal ca3 area* C.M. Matias, V.N. Corceiro, F.C. Bastos, S.A. Lopes, P.J.B. Mendes, F. Sampaio dos Aidos, J.C. Dionísio, R.M. Quinta-Ferreira, M. Emília Quinta-Ferreira
16:05	**Poster discussion**
16:30	***Coffee break***

Friday (Room: Auditório 2)	
15:00	**Poster presentations – Session II** Chairpersons: Cecília Calado / Jorge Belinha
	Modeling and elastic simulation of auxetic magnesium stents V.H. Carneiro, H. Puga *A light-guide optimization for proof-of-principle of a megavoltage orthogonal ray imaging prototype* Hugo Simões, Paulo Crespo *Towards a rfid microsystem for surgical instrument detection using millimetre waves* Manuel Zamith, Paulo Mendes *Population-based dosimetry in nuclear medicine and pet: development of portuguese female and male anthropomorphic models* Ana Teresa Nunes, Miguel Patricio, Francisco Alves *Comparison between the initial creep response of porcine and human lumbar intervertebral discs* A.R.G Araújo, N. Peixinho, A.C.M. Pinho, J.C.P. Claro *Shielding the magnetic field from a transcranial stimulator using aluminium and iron: simulation and experimental results* N.S. Santos, S.C.P. Sousa, P. Crespo, P.C. Miranda, R. Salvador, J. Silvestre *Zinc changes evoked by phenolic compounds and effect on tea-ltp at hippocampal mossy fiber synapses* F.C. Bastos, S.A. Lopes, V.N. Corceiro, C.M. Matias, P.J.B. Mendes, F.D.S. Sampaio dos Aidos, J.C. Dionísio, R.M. Quinta-Ferreira, M.E. Quinta-Ferreira *Development of a high-throughput monitoring technique of bacteria photodynamic inactivation* Bernardo Cunha, Pedro N. Sampaio, Cecília R.C. Calado *Comparative analysis of near-infrared (NIR) and mid-infrared (MIR) spectroscopy to monitor recombinant cyprosin production* Pedro N. Sampaio, Cecília R.C. Calado *Optimization of investment casting of ti6al4v hip prostheses by numerical and experimental methods* Nannan Song, Shenghua Wu, Rui Neto, Margarida Machado *Correlation study between blood pressure and pulse transit time* Tânia Pereira, Rui Sanches, Pedro Reis, José Pêgo, Ricardo Simões *Implementation of a multivibrational medical device to assist the removal of teeth and roots* Sara Setas, Eurico Seabra, Luís F. Silva, Cátia Pombo, Gabriel Joaquim *Active pedal exerciser for leg rehabilitation* F. Garcia, J. Ferreira, P. Ferreira, S. Cruz, M. Crisóstomo , A.P. Coimbra
16:05	**Poster discussion**
16:30	***Coffee break***

Friday (Room: Auditório 1)	
17:00 18:30	**Oral presentations – Session IV** Chairpersons: Filomena Soares / Isabel Rocha
	A serious game for rehabilitation of neurological disabilities: premilinary study Tiago Martins, Vitor Carvalho, Filomena Soares *Mechatronic system for assistance on bath of bedridden elderly people* K. Bezerra, J. Machado, V. Carvalho, F. Soares, B. Silva, D. Matos *Screening of L-histidine based ligands to purify the supercoiled plasmid dna isoform* Lúcia Amorim, Fani Sousa, João Queiroz, Carla Cruz, Ângela Sousa *An ultra-high resolution preclinical positron emission tomography scanner* P. Martins, A. Blanco, P. Crespo, M. Marques, R. Marques, P. Gordo, M. Kajetanowicz, G. Korcyl, L. Lopes, J. Michel, M. Palka, M. Traxler, A. Abrunhosa, M. Couceiro, P. Fonte *Application of modified hilbert-huang transform to autonomic evaluation in metabolic syndrome* N. Goncalves-Rosa, C. Tavares, V. Geraldes, C. Nunes-da-Silva, I. Rocha *Wavelet analysis of hrv during microgravity simulation* Rui Garcês, Mafalda Carvalho, Cristiano Tavares, T. Russomano, Isabel Rocha *Maxwell's equations based 3d model of light scattering in the retina* Miriam Santos, Adérito Araújo, Sílvia Barbeiro, Francisco Caramelo, António Correia, Maria Isabel Marques, Miguel Morgado, Luís Pinto, Pedro Serranho, Rui Bernardes *PDMS encasing system for integrated lab-on-chip Ag/AgCl reference electrodes* T.S. Monteiro, L.M. Gonçalves, G. Minas, S.C. Freitas

Friday (Room: Auditório 2)	
17:00 19:15	**Oral presentations – Session V** Chairpersons: Margarida Machado / Rui Bernardes
	Molecular fingerprint of human gastric cell line infected by helicobacter pylori Filipa Rosa, Kevin Sales, Pedro Sampaio, Marta Lopes, Cecília R.C. Calado *On producing customised soft-tissue prostheses using digital tools and silicone casting techniques* Mafalda Couto, Margarida Machado, Rui Neto *Hand therapist: a rehabilitation approach based on wearable technology and video gaming* Rastislav Lipovský, Hugo Alexandre Ferreira *Upgrading wheat straw to homo and co-polyhydroxyalkanoates* M. Teresa Cesário, Rodrigo Raposo, M. Catarina M. D de Almeida, Bruno S. Ferreira, Frederik van Keulen, M. Manuela R. da Fonseca *A discontinuous galerkin scheme for solving 2d wave propagations in anisotropic materials* Aderito Araujo, Silvia Barbeiro, Maryam Khaksar Ghalati *Effect of transient magnetic stimulation on zinc signals associated with synaptic plasticity in hippocampal CA3 area* Antónia Maura A. Ferreira, Fátima C. Bastos, Nuno Saraiva Santos, Sónia C.P. Sousa, Paulo Crespo, Paulo J.B. Mendes, M. Emília Quinta-Ferreira *Image-derived input function for brain pet quantification* André Gorgulho, Miguel Patrício *Performance assessment of wireless power transfer links for implantable microssystems* Hugo Dinis, Paulo Mendes *Protein engineering of therapeutic growth factor for control release* Jun-Hyeog Jang

Saturday (Room: Auditório 1)	
8:45 9:15	**Special session IEEE** Introduction of IEEE José Pedro Silva, IEEE Portuguese Section
9:30	**Thesis presentations – Session III** Chairpersons: Renato Natal / Miguel Morgado
	Robotic Locomotion combining Central Pattern Generators and Reflexes Cesar Ferreira *Optimization of a Multibody System of the Human Lombar Spine* S. Sousa, J.C.P. Claro *3D liver segmentation in computed tomography and positron emission tomography exams through active surfaces* Diana Mendes
10:30	***Coffee break***

Saturday (Room: Auditório 1)	
11:00	**Oral presentations – Session VI** Chairpersons: Graça Minas / Jorge Belinha
	Chitosan microparticles as a binding system against helicobacter pylori Patrícia Henriques, Paula Sampaio, Maria Lázaro, André Maia, António Gouveia, José Manuel Lopes, Ana Magalhães, Celso Reis, M. Cristina L. Martins, Paulo Costa, Inês C Gonçalves *MISIMBA' – a simulator of synthetic time-lapsed microscopy images of bacterial cells* Leonardo Martins, Andre Ribeiro, José Fonseca *A web-based framework using a Model-View-Controller architecture for Human motion analysis* Joana Rosa, Hugo Silva, Ricardo Matias *Mechanical resonance in human chromosomes* Tiago Branco, Miguel Patrício, Francisco Caramelo, Maria Filomena Botelho *Gamma distribution model in breast cancer diffusion-weighted imaging* Filipa Borlinhas, Luísa Nogueira, Sofia Brandão, Rita G. Nunes, Joana Loureiro, Isabel Ramos, Hugo A. Ferreira *Diffusion kurtosis imaging: monte carlo simulation of diffusion processes using crowdprocess* David Naves Sousa, Hugo Alexandre Ferreira *Human brain tractography: a dti vs dki comparison analysis* Ricardo Loução, Rita G. Nunes, Rafael Neto-Henriques, Marta Correia, Hugo Ferreira
13:00	**Close session**

Saturday (Room: Auditório 2)	
11:00	**Oral presentations – Session VII** Chairpersons: Isabel Rocha / Elza Fonseca
	Development of a tool for automatic classification of intratumoral heterogeneity of lung cancers based on pet/ct intensity values Carlos Pereira, Célia Gomes, Francisco Caramelo *Diffusional kurtosis imaging using a fast heuristic constrained linear least squares algorithm: a plugin for OsiriX* Nuno Mesquita, João Santinha, José Fonseca *Metabolic.Care: development and characterization of a new thermographic platform for diabetic foot detection* Helena Catarina Pereira, Pedro do Mar, Carlos Correia *Fluorescence lifetime microscope for corneal metabolic imaging* Susana F. Silva, Ana Batista, José Paulo Domingues, Maria João Quadrado, Miguel Morgado *3D gait analysis in rheumatoid arthritis postmenopausal women with and without falls history* Pedro Aleixo, João M.C.S. Abrantes *Footedness influence on Stability measures* Tiago Atalaia, João M.C.S. Abrantes *Reliability of a wearable system to evaluate ambulatory autonomic activity* Cristiano Tavares, Vera Geraldes, Stephane Bastier, Anne Pavy Le-Traon, Isabel Rocha
13:00	**Close session**