Université de Bretagne Occidentale | Faculté des Sciences & Techniques

JOB OFFER – PhD Doctorate Thesis

Topic	**3DSTENT**	
	Vascular stent design instrumented by 3D printing and optimized by mechanical-biological simulation	
Thesis supervisor	Julien Ville, Full Professor, UBO, IRDL Christian Brosseau, Full Professor, UBO, Lab-STICC	
Co-supervisor	Azar Maalouf, Research Engineer, UBO, Lab-STICC	
Collaborative environment	Collaboration between UMR CNRS 6027 IRDL and UMR CNRS 6285 Lab-STICC International collaboration with Meknès University (Morocco)	
Keywords	Stent, 3D printing, instrumentation, multiphysics finite elements simulation, digital twin, metamaterial, surface treatment	

Abstract

The cardiovascular stent is considered in the treatment of coronary artery disease, a pathology of the coronary arteries that impacts 25% of the population. The objective of this thesis is to design and manufacture tubular or atypical stents such as bifurcations from mechanical metamaterials with potential applications in sensors. These stents will be based on biocompatible polymer materials on which surface treatments are considered for their functionalization. The issues are based on the compromise between biocompatibility, conformability, fatigue and stent connectivity. The innovation concerns the 3D printability of mechanical metamaterials, the design and manufacture of smart stents and finally the development of a digital twin to increase patient autonomy.

Project issues

Coronary artery disease is caused by the accumulation of atheroma plaques on the inner walls, the consequence of which is a narrowing of the diameter of the arteries thus restricting blood circulation. Atheroma begins with a simple deposition of fat such as a lipid streak, linear and without consequence for the flow; over time, this streak can grow, load in lipids, fibrinogen, platelets and other blood cells as well as calcium to form atheroma plaque.
From an epidemiological point of view, atheroma is a public health problem causing the majority of cardiovascular diseases and whose frequency concerns 25% of the French population but, in detail, 48% of individuals aged 50 to 60 years and 78% beyond 60 years.
With the exception of atherectomy, the treatments do not impact the atheroma plaque but try to compensate for the consequences of an obstruction of a blood vessel by it. In case of obstruction or significant arterial narrowing by atheroma, one of the gestures that can be suggested, is angioplasty. It depends on the condition of the affected artery and the general state. This technique aims at introducing a balloon into the artery, inflated at the level of the atheroma plaque, and to position a «stent». It is a metal and mesh stent, tubular in shape, helping to ensure a sufficient inner diameter to the artery. The stent, combined with the patient's antiplatelet medication, reduces any risk of recurrence of stenosis. The transition from the use of stainless steel materials

to polymer materials for the development of stents presents considerable challenges. It is the context in which the objectives of this thesis fall.

First, the subject consists in the research and selection of polymers in order to shape innovative mechanical metamaterials for tubular transmission. These metamaterials, with potential applications in sensors, actuators and energy recovery, are shaped using stereolithography 3D printing.
The study of the impact of the geometry of the cells (unit size, leg length and thickness) but also the characteristics of the section, the number of longitudinal and circumferential cells as well as the assembly of the unit cells on the mechanical performances (Poisson coefficient, Young's Modulus, torsional capacity of the structure) is suggested. This study is coupled with the prediction of 3D printability criteria of the polymer, using the investigation of the relationships between rheology (in the liquid state of the polymer), surface state and mechanical performance (in the solid state of printed geometries). It aims at better understanding the conformability capabilities of stents, which in itself, is a first innovative character of the subject.
At the same time, one of the problems is then a multiphysics simulation of blood flow within stents. Beyond the rheological and mechanical characterizations mentioned above, the suggested approach requires knowledge of fluidic or microfluidic, on the one hand, but also in hemo-rheology, biology and vascular medicine, on the other hand. Indeed, after the angioplasty, the wall of the stent will gradually be colonized by the cells of the arterial wall. The biocompatibility of the stent with the endothelial cells must make it possible to control the phenomenon of colonization of the stent wall without it being excessive to lead to the creation of a new narrowing called restenosis. From this point of view, it appears necessary to take into account the design of an active stent i.e. covered with an antiproliferative drug substance that aims to reduce the risk of stenosis but delays endothelialization, a phenomenon source of thrombosis, responsible for increased heart attack mortality for active coronary stents.

In a second step, the advances of additive manufacturing must be taken into account for the design and manufacture of stents with complex, fragile or atypical geometries such as bifurcations, which reinforces the innovative character of the study. Indeed, recent advances have provided unprecedented opportunities to revolutionize traditional vascular stents. To do this, a state of the art of biomaterials and additive manufacturing technologies must be carried out in order to critically assess the limits and challenges to be overcome to accelerate the clinical adoption of stents with mechanical and biological improved features. On this last point, an instrumental component is thus envisaged. This involves, with the advent of 5G and future trends for millimeter wave and higher frequency communication systems, designing and manufacturing a stent that is both smart and connected. Nowadays, providing a stent with an antenna and a hundred sensors can detect the different types of cells characteristic of restenosis, thrombosis and healing. Thanks to its antenna, the stent is able to communicate this data to the doctor, thus providing real-time information on the state of the blood vessel in order to adapt the treatment and anticipate possible complications.
In the framework of this thesis, consistent with the initially suggested polymer selection, one of the alternatives consists in the design and manufacture of polymer-based stents with a focus on surface treatment and deposition (especially with a biocompatible metal like titanium) investigations. This last study will pave the way for a functionalization of the stent with sensors for example. In addition, the development of a digital twin must reflect the level of activity of its physical twin. In itself, the challenge is multiple: it is to guarantee the compromise between biocompatibility (risk assessment of stenosis vs thrombosis), conformability (modulation of mechanical properties in relation to geometry), fatigue (understanding of the life cycle) and connectivity (electronic conduction). It is also, in a spirit of personalized medicine, to give the patient a proven gain in autonomy.

Université de Bretagne Occidentale
IRDL - UMR CNRS 6027 & Lab-STICC UMR CNRS 6285
Faculté des Sciences et Techniques
6 Avenue Victor le Gorgeu
CS 93837
29238 Brest
Tél. +33 (0)2 98 01 66 64

In summary, the challenges associated with this multidisciplinary problem are of two kinds: i) obtain the optimized manufacturing conditions of a morphologically complex object (typically, a «wire mesh» cylinder of centimeter in length and millimeter in diameter) using a biocompatible resin and having stable and optimized mechanical properties, and ii) define the conditions for integrating this object into an arterial environment without compromising the endothelial wall of the artery. For this, the geometry of the aorta can be characterized by MRI techniques that provide information on the compression and dilation of the aorta during pulsations. By combining these data with pressure measurements, the parameters that control the mechanical behavior of the wall, and in particular the elasticity, can be refined to have a precise idea of the patient's aorta and its behavior. Recently, the techniques of mechanical-biological simulation by finite elements allow to 3D model the effect of a prosthesis placed by surgery. These computational methods should improve our understanding of the problems related to vascular stent optimization.

Requirements

From a general point of view, the subject's approach is both experimental (3D printing by stereolithography, study of surface treatments without functionalization at first, then structural, rheological, mechanical and electromagnetic characterizations), but also requires assertive skills in multiphysics modeling (mechanics, electronics, biology). An interest in surface treatment techniques and, to a lesser extent, process engineering (adaptation of the stereolithography process) would be appreciated. More generally, the expected skills are those of a holder of a Master in Physics Engineering or Materials or Mechanics. The innovative character is threefold and is based, on i) 3D printability of mechanical metamaterials, ii) design and manufacture of smart stents, tubular and bifurcated geometries, and iii) development of a digital twin to increase patient autonomy.

Resources presentation

Materials elaboration, shaping and characterization as well as modeling equipments are available in two research units on the site of the Faculty of Sciences (Brest) : IRDL UMR CNRS 6027 and Lab-STICC UMR CNRS 6285. Supervision is provided by two Full Professors, one within each unit, as well as a Research Engineer. According to the progress of the work, it is envisaged to extend the initial consortium, within the University of Western Brittany, to the University Hospital Center and possibly to a biologist in order to address biocompatibility and biodegradability, a physicist for surface treatment technology, an angiologist and a cardiologist for medical locks and solutions.

Contacts

Thesis supervisor :

Julien VILLE, Full Professor
Institut de Recherche Dupuy de Lôme – UMR CNRS 6027
Faculté des Sciences et Techniques
6 Avenue Victor le Gorgeu
Université de Bretagne Occidentale, Brest, France
julien.ville@univ-brest.fr

Faculté des Sciences & Techniques

Thesis co-supervisors :

Christian BROSSEAU, Full Professor
Lab-STICC – UMR CNRS 6285
Faculté des Sciences et Techniques
6 Avenue Victor le Gorgeu
Université de Bretagne Occidentale, Brest, France
christian.brosseau@univ-brest.fr

Azar MAALOUF, Research Engineer
Lab-STICC – UMR CNRS 6285
Faculté des Sciences et Techniques
6 Avenue Victor le Gorgeu
Université de Bretagne Occidentale, Brest, France
azar.maalouf@univ-brest.fr

How to apply ?

Send CV and cover letter to Julien VILLE, Christian BROSSEAU and Azar MAALOUF before may, 15th, 2024.