



**Politecnico
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Doctoral Dissertation
Doctoral Program in Bioengineering and
medical and surgical sciences (37th Cycle)

From Flow to Failure: The Interplay Between Haemodynamics and Coronary Plaque Stability

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Summary

The identification of coronary lesions at a higher risk of destabilization remains one of the foremost challenges in contemporary cardiovascular research. The intricate interplay between vessel structure and circulating blood has emerged as a critical factor influencing the evolution and destabilization of atherosclerotic plaques. Understanding and quantifying these interactions are essential for advancing diagnostic precision and improving therapeutic strategies.

In this research, we employed cutting-edge computational fluid dynamics (CFD) methodologies to simulate the complex physical phenomena occurring at the blood-endothelium interface. Shear forces, which are central to the pathophysiological processes governing plaque vulnerability, cannot be directly measured *in vivo*. By leveraging CFD, we developed advanced tools to study and quantify these forces, identifying anatomic-functional predictors of plaque destabilization that can be translated into clinical practice.

Three-dimensional coronary models were reconstructed from standard angiographic projections using dedicated software, and CFD simulations were performed, incorporating vessel-specific boundary conditions tailored to patient anatomy. Traditional descriptors, such as time-averaged wall shear stress (TAWSS), were complemented by innovative metrics introduced and tested for the first time in human studies. Among these, the Topological Shear Variation Index (TSVI) quantified the expansion-contraction action of pulsatile shear forces on the endothelium and proved to be superior predictors of future myocardial infarctions (MI) within a five-year timeframe, outperforming conventional markers like percentage area stenosis and translesional pressure gradients.

These methodologies were further extended to investigate the pathophysiology of spontaneous coronary artery dissection (SCAD), an enigmatic condition. By analysing vessel geometry and local hemodynamic patterns, we identified distinct hemodynamic

and structural signatures associated with dissection origins, shedding light on the complex mechanisms behind SCAD.

This comprehensive approach bridges bioengineering and clinical cardiology, offering novel insights into coronary artery disease. By enhancing the predictive capabilities of diagnostic tools and identifying high-risk lesions with greater precision, this research represents a significant step toward pre-emptive clinical interventions, ultimately aiming to improve patient outcomes.