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An intravascular ultrasound anisotropic elasticity-palpography technique for *in vivo* coronary atherosclerotic plaque detection and characterization

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KEYWORDS Coronary diseases; atherosclerosis; vulnerable plaque; inverse problem; young's moduli

1. Introduction

Critical to the detection of vulnerable plaque (VPs) rupture is quantification of their anisotropic mechanical properties (Finet *et al.* 2004, Nayak *et al.* 2017). A number of biomechanical studies have identified peak cap stress amplitude as a major key predictor of vulnerability to rupture. Quantifying intraplaque stress distribution, in order to predict plaque rupture, has been a challenge. To overcome this obstacle, the local strain has been measured based on intravascular ultrasound (IVUS) sequences. If we know the anisotropic local mechanical properties of the atherosclerotic lesion, then the intraplaque stress can be directly quantified. Therefore, on the basis of IVUS strain images, Céspedes *et al.* (2000) proposed an isotropic elasticity-palpography technique (E-PT). His approach was later improved by our group (Deleaval *et al. 2013*) to account for the non-concentric anatomic shape of the VPs. Even though these studies highlighted original, potential and promising 'homogenized' approaches for improving the evaluation of VP rupture, they did not overcome a main limitation related to the anisotropic mechanical behavior of the arterial wall and the atherosclerotic lesion media.

2. Material and Methods

2.1. Anisotropic elasticity index

The present biomechanical study was designed to extend the theoretical framework of the improved isotropic E-PT (Deleaval *et al. 2013*) by considering the anisotropic mechanical properties of the arterial wall and lesion constituents. Based on the continuum mechanics theory prescribing the strain field, an anisotropic index (AI) was defined.

This extended anisotropic E-PT was successfully applied to several coronary lesions of patients imaged *in vivo* with IVUS at the Cardiologic Hospital Louis Pradel of Lyon. The robustness and performance of the new anisotropic elasticity-palpography index were also investigated with respect to noise, which may affect the prediction of plaque vulnerability.

3. Results

To test the numerical performance of the proposed anisotropic E-PT algorithm, a finite element (FE) method was used to generate our input set of intraplaque displacement and radial strain fields.

We used VP geometries of patients imaged *in vivo* with an IVUS system operating at 40 MHz, since realistic human VP geometries were needed to perform the FE simulations. The resulting FE displacement and radial strain fields computed in the cross-sectional plane of the pathological artery and the associated internal and external contours of the coronary were the only inputs of our inverse model.

The performance of the anisotropic E-PT to detect and characterize a vulnerable plaque is showed on Figure 1.

4. Conclusion and clinical implication

The new anisotropic E-PT was successfully applied to several patients' coronary lesions. Our preliminary results

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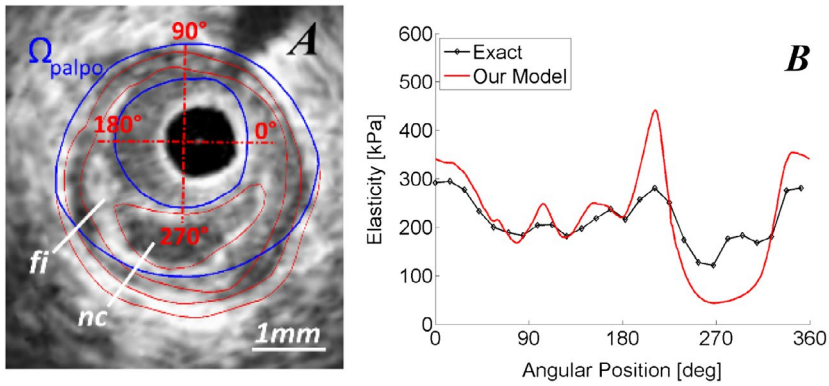

Figure 1 A) IVUS image showing the palpography domain (*blue contours*). B) Comparisons between the exact palpogram of the anisotropic elasticity index AI (*black curve*), and the one obtained with our extended anisotropic E-PT (*red curve*). 'fi': fibrous region; 'nc': necrotic core.

showed that this original technique is sufficient to detect and identify VPs.

Stabilization of vulnerable plaque remains a significant clinical problem (Abela *et al.* 2011). Studies conducted to analyze the structural variation in the fibrous cap and necrotic core with specific drug treatments (e.g., all statins, angiotensin converting enzyme inhibitors, etc...) revealed an enhancement in plaque stability (Nozue *et al.* 2012). Our group showed (Finet *et al.* 2004) that a very slight increase in the mechanical properties of plaque constituents, namely the hardening of the lipidic necrotic core, can tilt a VP from instability to stability. Therefore, the proposed improved anisotropic elasticity-palpography imaging technique is promising since it provides a non-invasive approach to analyze *in vivo* the evolution of the anisotropic mechanical properties of atherosclerotic plaques during drug therapies.

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