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The Influence of Enhanced External Counterpulsation Intervention on the Biomechanical Stress Distribution of Advanced Plaque: A 3D FSI Study Based on *in vivo* Animal Experiment

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Abstract: Enhanced external counter pulsation (EECP) is an effective therapy to provide beneficial assistance for the failing heart by reducing cardiac afterload and increasing blood flow perfusion noninvasively. The technique of EECP involves the use of the EECP device to inflate and deflate a series of compression cuffs wrapped around the patient's calves, lower thighs, and upper thighs. As the result, the enhanced flow perfusion is derived from the device's propelling blood from veins of lower body to arteries of upper body and increases the blood supply for the important organs and brain.

In the ACCF/AHA Guideline and ESC Guideline on the management of stable ischemic heart disease and coronary artery disease, EECP has been given a Class IIb and Class IIa recommendation respectively. In the ASA Guideline on the early management of Acute Ischemic stroke, EECP has been given a Class IIa recommendation.

However, considering that EECP performance significantly elevates the acute blood pressure level as well as the perfusion level in systemic arterial tree and in diastolic, whether it will increase the risk of hypertension-related events such as atherosclerotic plaque rupture causes great concern in its clinical applications. But, the influence of EECP intervention on plaque progression remains elusive to this day and need to be assessed.

It is generally agreed that biomechanical stresses play important roles in advanced atherosclerotic plaque progression and rupture. We hypothesized that EECP may intervene the advanced plaque progression via induced the variation of mechanical stresses in plaques.

In this present paper, a pilot study containing animal experiment and numerical simulation was conducted to quantify the variations of biomechanical stresses of the plaque during EECP intervention. An experimentally induced hypercholesterolemic porcine model was developed and the basic hemodynamic measurements were performed in vivo before and during EECP intervention. Meanwhile, 3D multi-component idealized

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models with fluid-structure interactions (FSI) for carotid atherosclerotic plaques were introduced to solve the wall shear stress (WSS) and plaque structural stress (PWS) before and during intervention. Three cases of fibrous cap thickness (FC=600, 200 and 65μm) and three cases of material properties of the plaque components (normal, hard and soft) were involved in the current study.

Numerical results showed that the max WSS level at the throat of the plaque, the 3D critical plaque wall stress (3D CPWS) level at the fibrous cap and the global max plaque wall stress (GMPWS) level at the shoulder of the plaque were all significantly augmented during EECP. When FC=65 μm, EECP intervention augmented 118.1%±1.1% of the Max WSS level, 15.56%±1.68% of the 3D CPWS level and 14.78%±0.24% of the GMPWS level comparing to situations without EECP intervention.

Considering that blood flow shear stress and structural stress are indexes that are presently thought might contribute to advanced plaque progression and its final rupture, our pilot study thus suggests that EECP treatment may intervene the plaque progression by elevating the levels of these indexes. But whether EECP treatment will increase the risk of plaque rupture and should be taken into account in its patient selection need a further detailed study and follow-up observation.

Keywords: Enhanced external counter pulsation therapy, advanced plaque progression, wall shear stress, plaque wall stress, fluid-structure interaction.

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