In Vitro Validation of a 4D Ultrasound Strain Imaging Approach for the Identification of Patient Specific Anisotropic Elastic Material Properties of Abdominal Aortic Aneurysm

Achim Hegner*†[1,2], Andreas Wittek[1], Wojciech Derwich[3], Kyriakos Oikonomou[3], Armin Huß[1], Antonio J. Gámez[2], and Christopher Blase‡[1]

[1]Frankfurt University of Applied Sciences – Germany
[2]Universidad de Cádiz = University of Cádiz – Spain
[3]Frankfurt University Hospital – Germany

Abstract

Introduction:
Biomechanical computational models should be largely patient-specific to provide deeper insight into the pathophysiology of abdominal aortic aneurysms (AAA) and to be relevant for future clinical diagnostics. The identification of individual material properties is of central importance, but they are usually unknown and difficult to determine in vivo. Time resolved 3D ultrasound combined with speckle tracking (4D-US) is a non-invasive imaging technique that provides full-field information of heterogeneous aortic wall strain distributions in vivo. These strains are cyclic strains with respect to diastole. We here present a substantial new development of an in vivo 4D-US strain imaging approach that was presented previously by our group. It identifies the parameters of a nonlinear and anisotropic material equation, while using only information that can be collected in vivo. For this approach we perform an in vitro validation using an intact tubular section of a porcine aorta in an inflation-extension experiment.

Material and Methods:
A porcine aorta from the thoracoabdominal region was obtained from a local organic butcher, cleaned of attached tissue, and marked for global deformation measurements. The specimen was immersed in 0.9% (w/v) NaCl solution at 37○C and tested with a custom inflation-extension device. Both ends were clamped in holders, while cyclic length and pressure changes were applied at a frequency of 0.84 Hz. Saline was pumped through the fixed lower holder connected to a pump cylinder, while a linear motor adjusted the upper holder to simulate physiological length changes. Motors synchronized using a trigger signal simulated a pulse cycle. Axial force and transmural pressure were recorded at 50 Hz. Deformations were captured with two orthogonally mounted CMOS cameras and the 4D-US device in parallel. On the one hand, specimen deformations were determined from camera images and stress-stretch curves were calculated from wall thickness and recorded force/pressure values. The

*Speaker
†Corresponding author: hegner@fb2.fra-uas.de
‡Corresponding author: cblase@fb2.fra-uas.de

parameters for the anisotropic Holzapfel-Gasser-Ogden (HGO) material equation were identified by fitting to calculated stress-stretch curves.
On the other hand, from the 4D-US images a finite element analysis model was created. Since only diastole and systole can be used as load cases in vivo, only experimentally measured values from these two states were used for parameter identification. Boundary conditions from the experiment were applied to the model: lower end was fixed, upper end could move only in axial direction, transmural pressure was applied to the inner surfaces, and sensor force was applied to the upper end. Our newly developed in vivo 4D-US strain imaging approach uses an evolutionary self-adaptive Differential Evolution (JADE) algorithm as optimization strategy. It iteratively calculates the material-dependent load-free geometry and, based on this, the diastolic and systolic geometries using diastolic and systolic force/pressure values. Cyclic strains are then calculated with respect to diastole. Parameters are identified by minimising an error function that compares cyclic measured strains using 4D-US and the calculated cyclic model strains.
Results:
Identified material behaviour from mechanical data and 4D-US showed very good agreement. Comparison of stress-stretch curves calculated using the identified parameters show coefficients of determination in the range $R^2 = 0.952 - 0.990$.

Conclusion:
We successfully performed an in vitro validation of a new developed 4D-US strain imaging approach for the identification of patient-specific parameters of an anisotropic material equation using only information that can be collected in vivo. Also, performance could be increased by factor seven.